

Generation of Coherence Singularity using Interferometric Technique

Haneen V N, Dinesh N Naik

Applied and Adaptive Optics Laboratory, Department of Physics, Indian Institute of Space Science and Technology,
Thiruvananthapuram, Kerala, 695547.

Coherence vortices have gained considerable attention, and their generation and characterization are still being extensively studied [1]. In this work, we propose a novel method for generating a coherence vortex by exploiting the analogy between the optical field and the coherence function, without modifying the source's intensity distribution or adding the vortex phase explicitly into the incoherent light as in the prior studies. Dinesh et al. have synthesized an optical vortex beam by coupling lateral shear with a linear phase difference between two out-of-phase Gaussian beams [2]. Similarly, we explore the out-of-phase interference of two coherence functions, laterally displaced along the y-axis and possessing opposite linear phase gradients along the x-axis. While interference between coherence functions has been discussed in earlier research [3,4], our approach uses this interference to introduce a topological feature in the coherence function.

Consider incoherent Gaussian fields that are shifted by $\pm x_0$ along x,

$$u_j(x, y; t) = e^{-\frac{(x - (-1)^j x_0)^2 + y^2}{2\omega_0^2}} e^{i\phi_{Rj}(x, y; t)}, j = 1, 2 \quad (1)$$

ϕ_R is the time-varying random phase. Fourier transform of $u_j(x, y; t)$ gives the far-field distribution $U_j(f_x, f_y; t)$. Correlating $U_j(f_x, f_y; t)$ with a sheared copy yields the far-field spatial coherence function, which exhibits a Gaussian profile with a linear phase along $\pm x$ direction. The out-of-phase superposition of two such coherence functions with a lateral separation of δ along y will yield the total coherence function in the far-field as,

$$\Gamma(\hat{f}_x, \hat{f}_y) = 2\pi\omega_0^2 e^{-(\pi\omega_0)^2(\hat{f}_x^2 + \hat{f}_y^2 + \hat{f}_y\Delta\alpha\delta + (\Delta\alpha\delta)^2/2)} \sinh((\pi\omega_0)^2(\hat{f}_y\Delta\alpha\delta + (\Delta\alpha\delta)^2/2) + i(2\pi x_0 \hat{f}_x)) \quad (2)$$

Where $\Delta\alpha$ is a measure of shear applied to the far-field to find the correlation and $\hat{f}_x = \Delta\alpha f_x$. Applying the small argument approximation for $\sinh$ reduces equation (2) into a form of $(A + iB)$, and when the rate of change of $\hat{f}_x$ equals to that of $\hat{f}_y$, it can produce a circularly symmetric vortex. Fig.1 shows the simulation results along with the plot of the analytically derived expression.

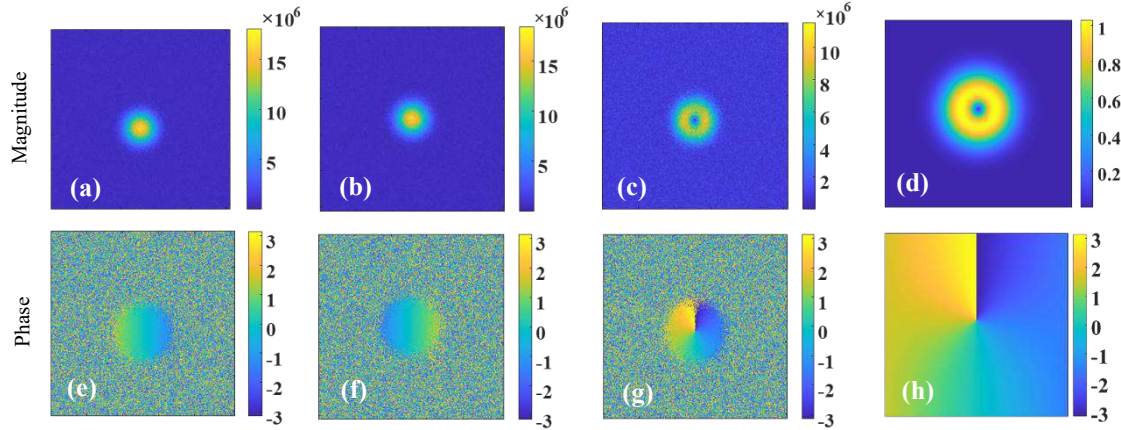


Fig.1: Magnitude (arbitrary units) and phase (rad) of individual coherence functions – (a), (b), (e), (f), superposition of coherence functions – (c), (g), mathematically derived equation (d), (h).

The resulting coherence vortex can be visualized as fringe contrast and fringe phase, using optical correlation by a Sagnac shearing interferometer.

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Dispersion-Engineered Spiral Photonic Crystal Fiber Structure for Nonlinear Applications

Khushboo*, Than Singh Saini

Department of Physics, National Institute of Technology Kurukshetra, Kurukshetra-136119, HR, India

*Email Address: 9466khushboo@gmail.com

Nonlinear optical effects in optical fibers, including four-wave mixing, supercontinuum generation (SCG), Raman scattering, the Kerr effect, and Self-phase modulation, have garnered significant interest among researchers in this domain due to their significant applications. In the past few years, tellurites, chalcogenides, and fluoride-based photonic crystal fibers (PCFs) have been designed and developed for nonlinear applications. Materials with high nonlinear refractive indices, wider transmission windows, and lower absorption are more suitable for achieving wideband supercontinua [1]. Additionally, for generation of efficient and stable nonlinear effects in PCFs, the pump wavelength should be around the zero-dispersion wavelength (ZDW) of the designed PCFs. But commercially available sources are limited.

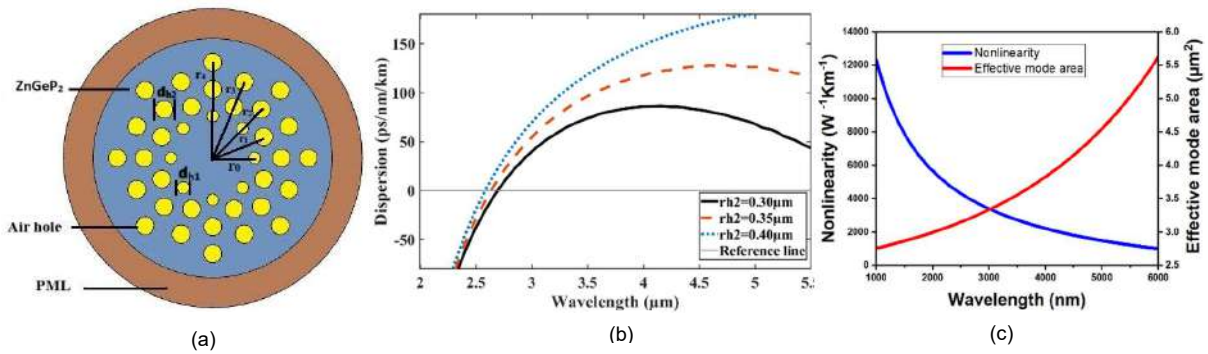


Fig.1. (a) Transverse cross-sectional view of designed PCF structure; (b) Spectral variation of chromatic dispersion at different parameters; (c) Spectral Variation of Nonlinearity and Effective mode area of fundamental mode.

In this work, we have designed a spiral PCF structure using chalcogenide-like material ZnGeP₂ which show ZDW at operating wavelength of commercially available sources (2.8 μm). ZnGeP₂ exhibits high nonlinear coefficient, and broad transparency window in the mid-IR, making it an ideal medium for extending SCG into the long-wave infrared region [2]. The transverse cross-sectional view of the designed spiral PCF structure is shown in Fig. 1(a). Eight spiral arms having five air holes in each arm are arranged in such a way that every n th air hole is at distance $r_n = (r_{n-1} + 0.9 d_{h1})$ from the centre [3]. The effective core diameter is calculated by $d_c = 2(r_0 - r_{h1})$. At $r_0 = 1.4$ μm distance from the centre, the diameter of 1st ring of air hole is d_{h1} , and other rings have diameter d_{h2} . The spectral variation of chromatic dispersion with optimized geometrical parameters $r_{h1} = 0.2$ μm with different r_{h2} is shown in Fig. 1(b).

At optimized geometrical parameters $r_{h1} = 0.2$ μm, $r_{h2} = 0.3$ μm, the designed structure of PCF offers ZDW at 2.7 μm with dispersion varying between -37.34 ps/nm/km and 46.04 ps/nm/km for the spectral range extending from ~2.5 μm to ~5 μm. The proposed PCF structure shows a high nonlinearity coefficient of 3721 W⁻¹ km⁻¹ and an effective mode area of 3.25 μm² at a pumping wavelength of 2.8 μm as shown in Fig.1 (c). This work highlights the potential of ZnGeP₂ spiral PCFs to expand its functionality towards future photonics and nonlinear devices. This design can be used for the generation of broadband mid-IR sources, Raman scattering, etc by pumping it with a commercially available fibre laser at 2.8 μm.

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Telecom-Band Bell-State transformation using waveplate logic in a Fiber-Integrated Source

Khushboo¹, Vivek Venkataraman^{1,2} and Joyee Ghosh¹

¹Quantum Photonics Lab, Department of Physics, Indian Institute of Technology Delhi, New Delhi, 110016, India

²Department of Electrical Engineering, Indian Institute of Technology Delhi, New Delhi, 110016, India

¹Email: joyee@physics.iitd.ac.in

²Email: vivekv@ee.iitd.ac.in

Quantum communication methods including superdense coding, quantum teleportation, and entanglement swapping^[1] use maximally entangled two-qubit Bell states. We show deterministic transformation of the $|\Phi^+\rangle$ state into all four Bell states using half-wave plates (HWPs). A Pauli-Z (phase-flip) gate is implemented with a HWP aligned at 0° , a Pauli-X (bit-flip) gate at 45° , and Pauli-Y operations using two HWPs. These waveplate-based transformations allow for on-demand creation of $|\Phi^-\rangle$, $|\Psi^+\rangle$, and $|\Psi^-\rangle$ states without altering the source^[2].

This study uses a completely fiber-integrated, broadband source at 1550 nm to generate and manipulate polarization-entangled Bell states. Through type-0 spontaneous parametric down-conversion (SPDC) in a zinc-diffused periodically poled lithium niobate (PPLN) ridge waveguide, the source generates the Bell state $|\Phi^+\rangle$. A continuous-wave 775 nm laser pumps a 4-cm PPLN waveguide in a Sagnac interferometer to generate vertically polarized (Fig. 1), polarization-entangled photon pairs. A C/L-band splitter separates signal (1520–1550 nm) and idler (1550–1580 nm) photons, allowing operation in the telecom band and real-world quantum network deployment^[3].

The performance criteria in Table 1 assess the entanglement quality and purity of the four Bell states. Two-photon interference raw visibilities (without subtracting background counts) always surpass 91% (without accidental subtraction), showing high polarization correlations. High fidelities, CHSH S parameters exceeding the classical limit, and concurrence values > 0.84 indicate high-purity entanglement in all states.

Bell state	Avg. Vis.(%)	S Value	Fidelity (F)	Concurrence
$ \Phi^+\rangle$	97.27%	2.71 ± 0.009	93.71%	0.93
$ \Phi^-\rangle$	95.41%	2.69 ± 0.009	90.93%	0.86
$ \Psi^+\rangle$	96.00%	2.68 ± 0.009	88.87%	0.84
$ \Psi^-\rangle$	91.55%	2.41 ± 0.010	89.79%	0.86

Table 1: Calculated average visibility, Bell-CHSH parameter S, fidelity F and concurrence.

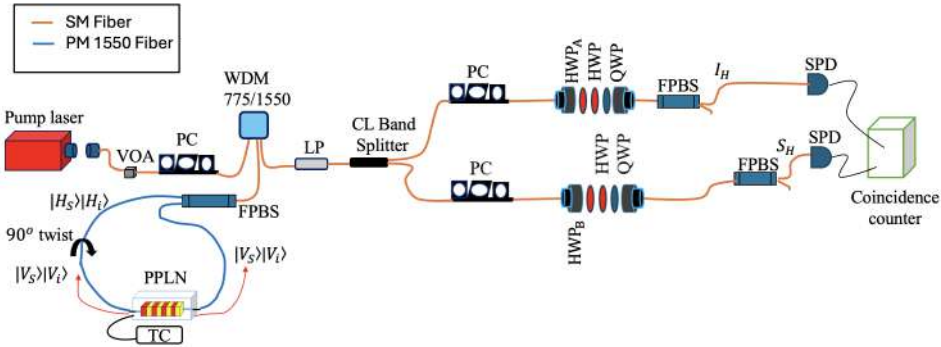


Figure 1: Experimental setup for the transformation of the entangled state $|\Phi^+\rangle$ into $|\Phi^-\rangle$ and $|\Psi^+\rangle$ by performing Pauli-Z and Pauli-X gate operations, respectively, using HWP_A only. An additional HWP_B along with HWP_A is used to transform the state $|\Phi^+\rangle$ into $|\Psi^-\rangle$. VOA: Variable Optical Attenuator, WDM: Wavelength division multiplexer, FPBS: Fiber polarizing beam splitter, LP: Long Pass filter, PC: Polarization controller, SPD: Single Photon Detector

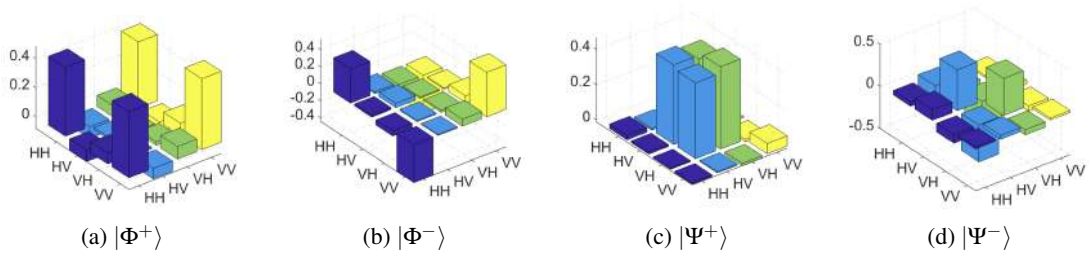


Figure 2: Density matrices calculated for entangled states: (a) $|\Psi^+\rangle$, (b) $|\Psi^-\rangle$, (c) $|\Phi^+\rangle$, and (d) $|\Phi^-\rangle$.

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Study of space-time dynamics of nanosecond laser induced copper plasma

Poulami Das*, Subhankar Nanda, Satyaranjan Satyajit, Amitava Adak

Indian Institute of Technology (Indian School of Mines), Dhanbad

*Email: 22DR0163@iitism.ac.in

Laser-Induced Plasma (LIP) has numerous applications in industry and research, including micromachining [1], thin-film deposition via pulsed laser [2], clean nanoparticle synthesis [3], and elemental analysis techniques such as Laser-Induced Breakdown Spectroscopy (LIBS) [4], among others. Since plasma properties critically influence the effectiveness of these applications, understanding plasma behaviour, especially for solids in a confining medium—is essential. In our study, we generated a transient plasma on a solid copper target using a high-energy pulsed Nd:YAG laser operating at 1064 nm, with a pulse duration (FWHM) of 7 ns and a fluence of 44 J/mm² in ambient air. The resulting micron-scale plasma was investigated using a novel pump–probe transmission technique. In this setup, a continuous-wave (CW) diode laser at 405 nm was used to probe the plasma in a transverse geometry. Figure 1(a) shows the time-resolved probe transmission signal at various lateral distances from the plasma centre. Time ‘zero’ corresponds to the peak of the laser pulse. As the probe position moves farther from the central plasma region, the onset of the perturbation in the probe signal exhibits a clear time delay, and parallelly the perturbed probe transmission is attenuated. This spatiotemporal variation of the transmission signal reflects the plasma's expansion dynamics. From this data, we analysed the early-time expansion behaviour of the plasma and estimated key parameters, including the velocity, as presented in Figure 1(b). Notably, the plasma was found to propagate at supersonic velocities across all probed distances.

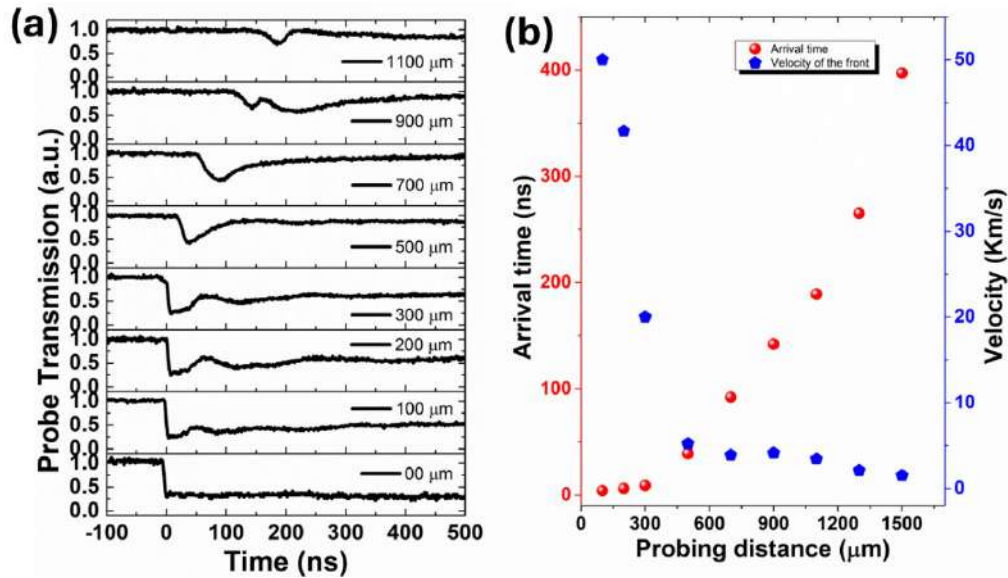


Fig. 1 (a) Probe transmission signal at different spatial position of the plasma. (b) The arrival time of the perturbation in the probe signal which indicate the plasma front and the corresponding velocity at each spatial position.

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Low Cost Secured Optical Communication Using Light Polarization

Vihan Verma

DPS-Bopal, Near Bopal Railway Crossing, Ahmedabad, Gujarat 380058, India

Secure, high-speed communication has become a critical requirement in modern wireless systems, especially in the context of emerging domains such as the Internet of Things (IoT), smart infrastructure, and extended-reality (XR) applications. Conventional short-range communication technologies such as radio frequency (RF) and infrared (IR) are prone to spectrum congestion, multipath interference, and increasing vulnerabilities at the physical layer. As a result, Visible Light Communication (VLC) is gaining attention as a complementary or alternative technology due to its high bandwidth and immunity to electromagnetic interference. Standards such as IEEE 802.15.7 and ITU-T G.9991 have established VLC protocols, enabling structured development and deployment.

Recent research has explored various approaches to enhance the security of VLC systems, including intelligent reflecting surfaces (IRS) [1], gold nanoparticle-assisted channels [2], mutual authentication [3], and physical-layer encryption using polarization states [4,5] or random wavefront modulation [5]. While these techniques demonstrate advanced capabilities, they often involve high implementation complexity, expensive photonic components, or computationally intensive post-processing—making them unsuitable for low-cost or educational deployments.

In this paper, I present a simple, low-cost, and hardware-implemented VLC system that utilizes light polarization as a means of encoding binary data that can be used to pass key from A to B. The system is composed of two terminals: a transmitter (Alice), which converts user-input decimal data into binary and modulates the signal using linear polarization states, and a receiver (Bob), which optically decodes the polarization pattern and reconstructs the original value. This setup achieves free-space optical communication without fibre or radio interfaces, and incorporates inherent physical-layer security through the selective detectability of polarized signals.

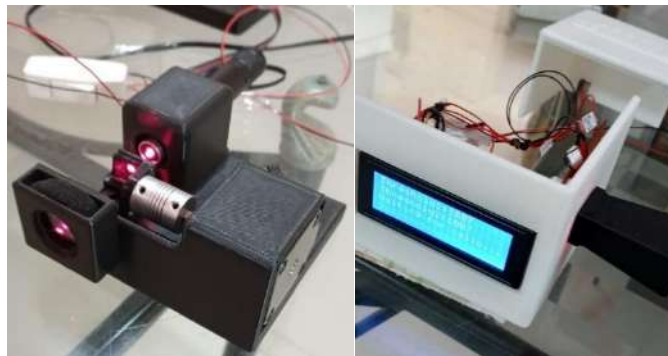


Fig. 1 3D Printed Prototypes of 'Alice' the Transmitter and 'Bob' the Receiver

Compared to prior work, this system emphasizes practicality and accessibility. It is built using affordable off-the-shelf components, 3D printed housing, requires no advanced optics or computation, and can be prototyped easily in academic settings. Experimental results demonstrate reliable transmission over 10 feet under indoor and outdoor lighting conditions, with high decoding accuracy and minimal alignment effort. It also incorporates an auto-calibration routine to normalize the effect of ambient light conditions. The simplicity of this architecture makes it ideal for demonstration, training, and as a prototype for further research in polarization multiplexing, multi-bit channel encoding, or low-power VLC for key transmission in IoT devices.

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HoloGeaR: Real-time Numerical Hologram Generation and Reconstruction

Akshay Kumar and Manish Kumar

Centre for Sensors, Instrumentation, and Cyber Physical System Engineering (SeNSE)
Indian Institute of Technology Delhi, Hauz Khas, New Delhi-110016, India

Digital holography (DH) is a powerful lensless imaging method that has changed everything from microscopy and metrology to medical diagnostics and 3D display. It can simultaneously obtain a sample's amplitude and phase information in a single shot [1], unlike photography, which only captures amplitude. This lets you do full wavefront reconstruction and quantitative analysis. Recent improvements in high-resolution sensors and computing power have made DH useful in real time, which makes it easier to analyze dynamic scenes. However, the complexity of optical setups and computational algorithms (involving FFT) often makes it difficult for more people to use and explore them interactively.

We have introduced an intuitive solution, HoloGeaR (**H**ologram **G**eneration and **R**econstruction), a new digital holography platform that works in real time and has an interactive graphical user interface (GUI) that is developed using a Python-based cross-platform GUI toolkit, PyQt. This application consolidates two essential holographic functions into a single user-friendly interface. The first one is "Hologram Generation," where users can create digital holograms from several source images at varying depths. This simulates optical interference between the object image and a reference wave. At the same time, the "Hologram Reconstruction" function is a powerful tool for reconstructing wavefronts from physically captured holograms or computer-generated holograms, using the Angular Spectrum Method (ASM) [2] for accurate wave propagation. Hologram reconstruction works in real time, even on a low-end device using only central processing unit (CPU).

An essential aspect of a real-time hologram reconstruction algorithm is calculating the Fourier transform as quickly as possible for wave propagation. We employed ASM for wave propagation, which consists of two Fourier transforms, offering superior accuracy and speed relative to alternative approaches. To enhance calculation speed, we incorporated pyFFTW (a Python library for fast FFT) [3] into our reconstruction algorithm, enabling real-time reconstruction even for large datasets.

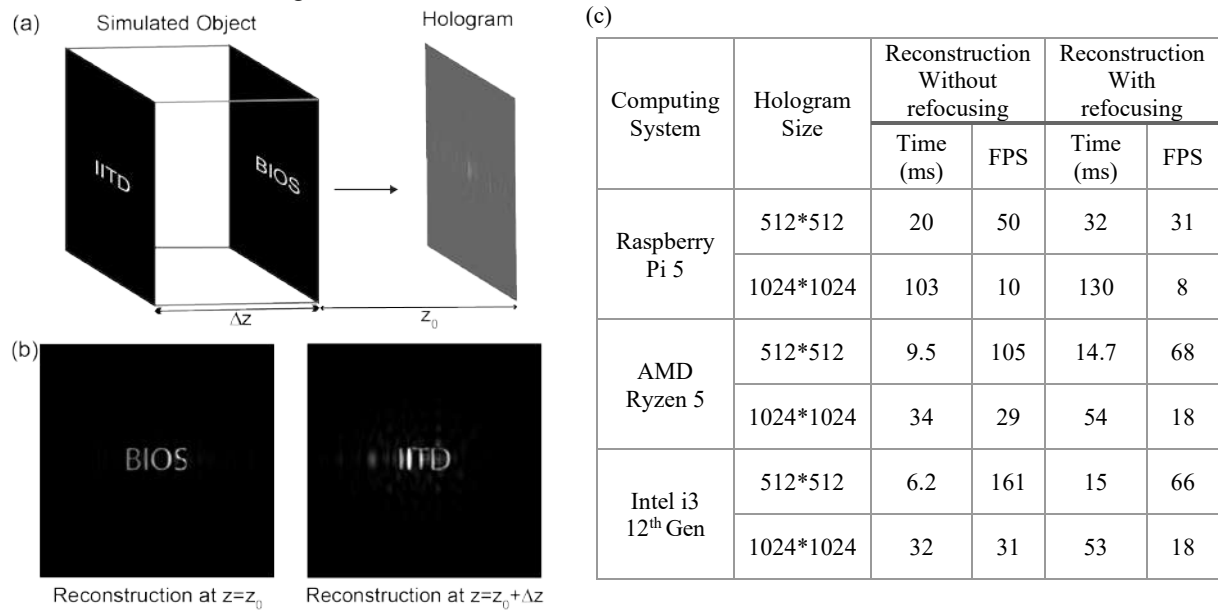


Fig. 1 (a) Simulated object with two images at a distance Δz apart and numerically calculated hologram of the simulated object at a propagated distance z_0 , (b) reconstruction of the hologram at distance z_0 and $z_0 + \Delta z$ corresponding to image distance in the simulated object from the hologram, (c) Table of reconstruction time taken and FPS while reconstructing a 1024*1024 px and 512*512 px hologram using different CPUs, with distance refocusing and without distance refocusing

Its ability to work in real time and its integrated workflow make it much easier to understand and use digital holography in real life. Researchers and teachers can use HoloGeaR as a valuable tool. This can also be implemented into a digital holographic microscope system to monitor biological samples in real-time. We acknowledge ANRF and IIT Delhi for funding this research.

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Towards atom interferometry using cold atoms

Hemant Yadav¹, Deepshikha Singh¹, Kripali Jain¹, Shivam Dhyani¹, Bodhaditya Santra¹

¹. Department of Physics, Indian Institute of Technology Delhi, New Delhi, 110016, India

Cold atom interferometry has emerged as a powerful quantum sensing technique for measuring inertial forces such as acceleration and rotation with unprecedented precision. At its core, the method exploits the wave-particle duality of ultracold atoms, using matter-wave interference to sense minute changes in phase that arise from motion in a gravitational or inertial field [1]. This makes atom interferometers attractive for applications in navigation, geophysics, and fundamental physics, where long-term stability and accuracy surpass those of conventional sensors. We have carried out experiments toward the development of a cold-atom-based interferometer for quantum sensing applications such as inertial navigation [2]. The setup is based on a homemade external cavity diode laser (ECDL) system, integrated with custom-designed control electronics [3]. Using laser cooling and trapping techniques, we have successfully prepared ultracold ensembles of ^{133}Cs atoms in a magneto-optical trap (MOT). We have characterized the trapped atoms in terms of number and temperature, confirming conditions suitable for coherent interferometric manipulation. From fluorescence imaging and time of flight method, we have characterized the MOT, obtaining atom numbers in the order of $\sim 10^6$. To further reduce the atomic temperature below the Doppler cooling limit, we implemented polarization gradient cooling (PGC). By carefully optimizing the detuning and intensity of the cooling beams after the MOT stage, we achieved sub-Doppler cooling of cesium atoms. This allowed us to reach temperatures as low as $\sim 11\text{ }\mu\text{K}$, significantly improving the phase space density of the atomic ensemble. These results confirm that the atoms are sufficiently cold and numerous to serve as an effective source for matter-wave interferometry.

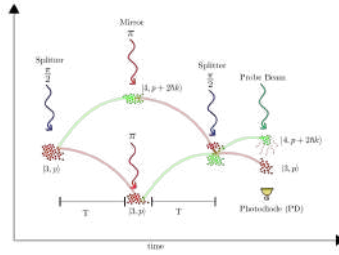


Fig. 1 Mach-Zehnder type cold atom interferometer using Raman transitions. Atomic wave packets are split, redirected, and recombined by $\pi/2$ - π - $\pi/2$ light pulses, and the output populations are measured with a probe beam using photodiode and camera to extract the inertial phase shift.

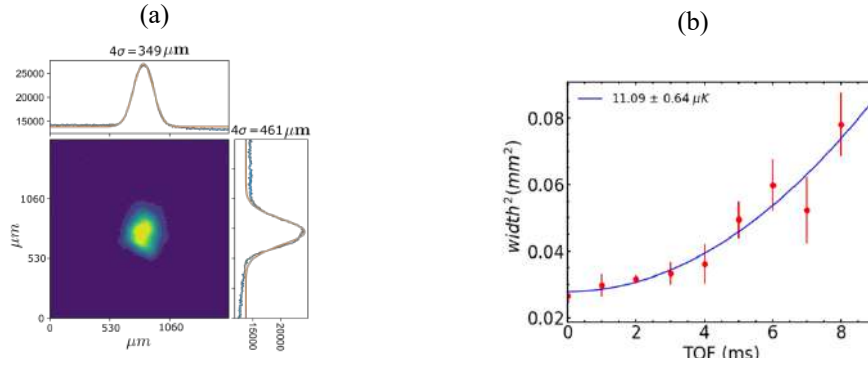


Fig. 2 (a) The fluorescence image of the MOT of ^{133}Cs atoms captured with a CCD camera. (b) The polarization gradient cooling resulted in obtaining ultra low temperature of $\sim 11\text{ }\mu\text{K}$.

This work demonstrates the feasibility of precision inertial sensing using ultracold cesium atoms and establishes a robust platform for future advancements toward compact, portable, and high-sensitivity atom interferometers.

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Attosecond Pulse Generation from Weyl Semimetals

Prachi Venkat¹, Amar Bharti² and Gopal Dixit¹

1. *Department of Physics, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India*
2. *Collective Dynamics and Quantum Transport Unit, OIST Graduate University, Onna 904 0495, Japan*

The generation of attosecond pulses from higher-order harmonics is an essential milestone toward enabling time-resolved spectroscopy of electronic processes in matter on the attosecond timescale. The avenue for high-harmonic generation from solids has proliferated since its discovery a decade ago.

However, isolated attosecond pulse generation from solids remains scarce. We report Weyl semimetals for efficient attosecond pulse generation in extreme ultraviolet region. The generation of isolated attosecond pulses from Weyl semimetals is achieved using two-color laser pulses, which generate a broad higher-harmonic plateau ranging from 4 to 12 eV. Attosecond pulses with comparable durations - spanning approximately 490 to 625 as - are generated in both collinear and orthogonal configurations of the two-color fields.

The strength and duration of the attosecond pulses can be optimized by tailoring the polarization direction and relative strength of two-color field. Owing to the relatively high electron density and intrinsic periodicity of solids compared to gases, attosecond pulses from solid HHG hold immense potential for enabling attosecond pump - attosecond probe experiments on compact, table-top platforms. Our findings open a new avenue for advancing attosecond spectroscopy and exploring ultrafast electron dynamics in matter.

Experimental Implementation of Measurement Device Independent Quantum Key Distribution: Comparison between Single Photon Avalanche and Superconducting Nanowire Single Photon Detectors

Gokul Agasthilingam¹, Harinee Natarajan¹, Varun Raghunathan¹

¹. Department of Electrical Communication Engineering, Indian Institute of Science, Bengaluru, varunr@iisc.ac.in

Background & Motivation:

Measurement device independent Quantum Key Distribution (MDI-QKD) removes detector side-channels by performing Bell-state measurements at a central untrusted measurement node, but overall key throughput remains limited by the requirement of coincidence measurements [1,2]. Improvements in detection efficiency, dark-count rate, after-pulsing probabilities, and timing jitter can yield significant improvements in secret-key rate (SKR) performance and maximum secure communication distance, offering viable solutions of long-distance MDI-QKD. Given the practical trade-offs between single photon avalanche detectors (SPADs) and superconducting nanowire single photon detectors (SNSPDs) [3], a rigorous experimental comparison is necessary. Here, we hold all system parameters fixed and swap only the detection modules to quantify its impact on SKR, quantum bit error rate (QBER), and achievable link length when implementing the MDI-QKD protocol.

Methods:

We implement a fiber-based MDI-QKD link with Alice and Bob sending weak-coherent time-bin qubits at 1550 nm. Each transmitter uses a narrow-linewidth DFB laser with optical pulse randomly modulated in time bins for generating Z-basis states and relative phase for X-basis states. The transmitted states arriving at the central measurement node (Charlie) are overlapped precisely in time and polarization to ensure optimal two-photon interference visibility. At the detection end, we exchange between the SPADs (IDQuantique IDQubes, gated, 25% detector efficiency, 10 μ s deadtime, maximum dark count rate < 2 kHz) and SNSPDs (IDQuantique ID281, 85% efficiency, < 30 ns recovery time, maximum dark count rate < 100 Hz). We use a three-intensity decoy-state protocol [4] with mean photon numbers {0.20, 0.12, 0} (for signal, weak, vacuum) to bound the single-photon yield and phase error, estimating an SKR secure against photon-number-splitting (PNS) attacks.

Results

Swapping only the single-photon detectors keeping result of the system settings identical results in SNSPDs delivered three orders of magnitude higher SKR, especially at 50km, replacing the SPAD with SNSPD increases the secret-key rate by approximately 750-times, while the Z-basis QBER reduces by 4-6 times due to reduces dark count rate and after-pulsing of SNSPDs. The X-basis QBER remain nearly comparable (34% for SPAD vs 33% for SNSPD). At 200 km, the SPAD results in no useful SKR, while the SNSPD link still achieves a positive SKR despite higher QBER (Z = 30%, X = 34%).

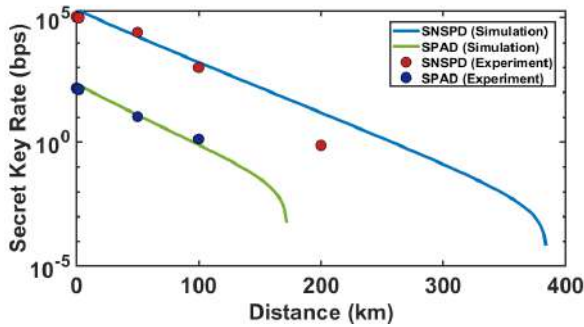


Fig. 1 SKR vs. fiber distance for MDI-QKD with SNSPD and SPAD receivers. Solid curves and filled markers represent simulated (SPADs - green; SNSPDs - blue) and experimental data (SPADs - violet; SNSPDs - red) respectively.

Table. 1 Summary of experimental SKR (bps) and QBER as a function of distance between Alice and Bob for SPAD and SNSPD used in MDI-QKD link.

Distance (km)	SPADs (bps)		SNSPDs (bps)	
	SKR	QBER(%)	SKR	QBER(%)
0	147.79	3.72 (Z) 28.98 (X)	1.12×10^5	0.92 (Z) 31.32 (X)
2	133.60	3.63 (Z) 34.15 (X)	1.03×10^5	0.58 (Z) 30.75 (X)
50	10.68	2.75 (Z) 34.06 (X)	2.62×10^4	0.74 (Z) 32.84 (X)
100	1.32	3.41 (Z) 35.13 (X)	994.12	0.83 (Z) 36.54 (X)
200	NA	-- (Z) -- (X)	0.74	30.33 (Z) 34.28 (X)

Under similar conditions, detector technology is one of the principal determinants of practical MDI-QKD performance. Replacing SPADs with SNSPDs delivers substantially higher SKR and extend the secure reach to up to 200 km, and lowers Z-basis errors without altering sources, decoy settings, or post-processing. Future work will extend these matched detector tests to higher clock rates and field-deployed fibers, optimizing coupling and timing to further expand the MDI-QKD rate-distance envelope.

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3D-Coded Aperture Imaging with Helico-Conical Beams

Harsh Vardhan^{1*}, Shivasubramanian Gopinath², Vipin Tiwari², Aswathi K Sivarajan¹, Sakshi Choudhary¹, Salla Gangi Reddy¹, Vijayakumar Anand^{2,3}, Ravi Kumar¹

¹Department of Physics, SRM University-AP, Andhra Pradesh - 522502, India

²Institute of Physics, University of Tartu, W. Ostwaldi 1, 50411 Tartu, Estonia

³Optical Sciences Center, Swinburne University of Technology, Melbourne 3122, Australia

Corresponding author: harshvardhan_r@srmap.edu.in

Abstract

Imaging involves recording and reproducing images either through direct optical methods or indirect approaches like coded aperture imaging (CAI), where computational techniques reconstruct the image after optical capture [1, 2]. The invention of interferenceless coded aperture correlation holography (I-COACH) in 2017 significantly advanced CAI by enabling three-dimensional imaging without the need for two-beam interference [3]. In this work, we propose and experimentally demonstrate an I-COACH system using a Helico-Conical Vortex (HCV) mask. The HCV mask carries orbital angular momentum and features a phase profile dependent on both azimuthal and radial coordinates, resulting from the combination of helical and conical phase functions and producing a spiral intensity distribution at the focal plane [4]. We evaluate I-COACH performance with the HCV mask in comparison to other coded masks (CMs), such as diffractive axicon and spiral lens. Image reconstruction quality is assessed using four algorithms: non-linear reconstruction (NLR), Lucy-Richardson algorithm (LRA), Lucy-Richardson-Rosen algorithm (LRRRA), and non-linear LRA (NL-LRA). A quantitative evaluation is performed using key metrics including entropy, root mean squared error (RMSE), structural similarity index (SSIM), and peak signal-to-noise ratio (PSNR). Figure 1(a) depicts the experimental setup used to demonstrate 3D imaging by capturing the point spread function (PSF) and object hologram (OH) separately in two different planes, at $z_s = 5$ cm and $z_s = 5.2$ cm. Figure 1(b) shows experimental results for two objects ("2" and "1") positioned in different planes. Column 1 presents the phase-only CMs, columns 2 and 3 display the recorded PSF and OH for the HCV beam, axicon, Spiral lens, and columns 4–7 show reconstructions from the four mentioned algorithms. The direct images of both objects are provided at the bottom of Fig. 1(b). The results confirm the effectiveness of the proposed CM in the I-COACH system [5], highlighting its potential for advancing incoherent holography and computational imaging.

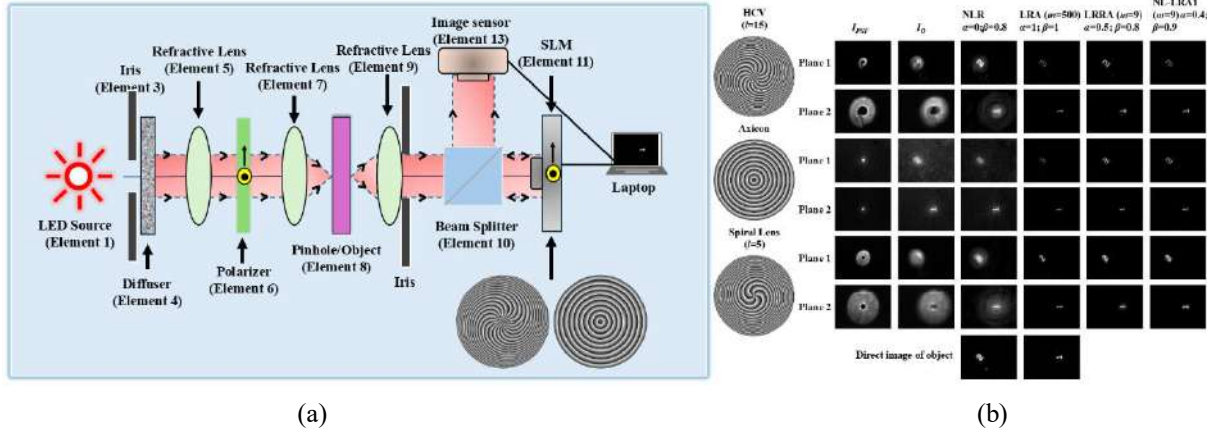


Fig. 1 (a) Schematic optical diagram for I-COACH system. (b) Column 1: Coded masks; Column 2: point spread function (I_{PSF}); Column 3: Object hologram (I_O); Column 4 –Column 7 Reconstruction of image by NLR, LRA, LRRRA, NL-LRA1; At the bottom, the direct image of both objects is given.

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Polarization-Enhanced Dual Field-of-View Digital Holographic Microscope

Akash Debnath, Shivam Kumar Chaubey, Rakesh Kumar Singh

Laboratory of Information Photonics and Optical Metrology, Department of Physics, Indian Institute of Technology (Banaras Hindu University), Varanasi, 221005, Uttar Pradesh, India

We present a single-shot dual field-of-view (DFoV) module with an integrated polarization-resolved digital holographic microscope (PDHM), designed for simultaneous wide and narrow-scale imaging of calibrated birefringent charts. Angular and polarization multiplexing enable high-resolution phase anisotropy mapping in a single exposure.

The digital holographic microscope (DHM) enables label-free, non-invasive retrieval of amplitude and phase for quantitative imaging. Still, it is limited by a sensor-constrained field of view and lacks single-shot polarization contrast [1]. Previous solutions expanded FoV or added polarization via sequential or multi-path optics [2], yet none have combined dual-scale coverage with instantaneous, multiplexed polarization in one compact system.

The DFoV-PDHM system utilizes a Mach-Zehnder layout with a 632.8 nm He-Ne laser split into object and reference arms. In the object path, a cube beam splitter (BS2) angularly multiplexes two spatially distinct fields of view (FoV-M and FoV-N), which are aligned to overlap and recorded on a single CMOS sensor. The reference beam enters a Sagnac loop via a polarizing beam splitter, generating orthogonally polarized beams at different spatial carrier frequencies that interfere with the object beam, enabling single-shot acquisition. This equation can describe it:

$$I = |E_{Mx} + R_x|^2 + |E_{Nx} + R_x|^2 + |E_{My} + R_y|^2 + |E_{Ny} + R_y|^2 + |E_M + E_N|^2$$

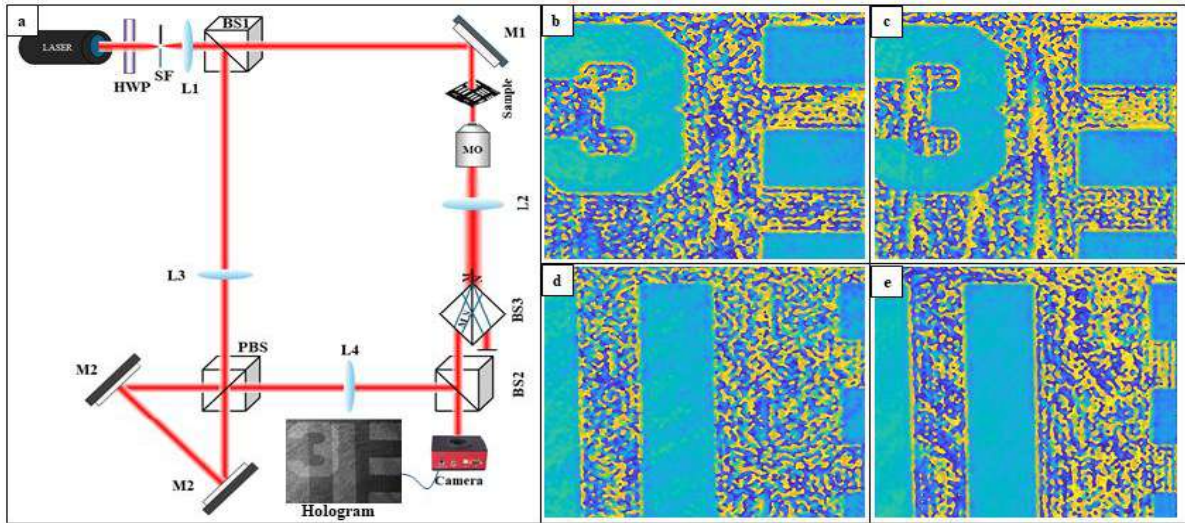


Fig. 1: Fig (1-a) describes our DFoV-PDHM setup, fig (1-b, c) and (1-d, e) shows the X and Y reconstructed phase of FoV-M and FoV-N respectively.

To validate the system's performance, we employed a standard 1951 USAF resolution chart under DFoV configuration. The reconstructed phase maps from both FoV-M and FoV-N reveal the clear spatial separation of polarization channels without crosstalk. Notably, the X and Y polarization components produce a high-resolution image across both fields, confirming precise decoding in a single exposure. The ability to retrieve structurally identical yet independently polarized images from two spatially distinct regions demonstrates the robustness of the angular-polarization multiplexing approach. It sets a benchmark for quantitative birefringence analysis in optical metrology.

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Evaluation and Validation of LIBS-Raman-LIF Technology and Instrumentation for Monitoring Malnutrition in Children

S D Varalakshmi¹, K S Choudhari¹, Leslie Edward S Lewis², V K Unnikrishnan^{1*}

1. Manipal Institute of Applied Physics, Manipal Academy of Higher Education, Manipal, India

2. Department of Pediatrics, Kasturba Medical College, Manipal Academy of Higher Education, Manipal, India.

*Email: unnikrishnan.vk@manipal.edu

Malnutrition is vast spread disease commonly assessed using anthropometry and lab-based tests, where anthropometry does not provide nutrient based information and lab-based tests require multiple techniques, large samples, high costs, and bulky instruments, making them unsuitable for rapid use in resource-limited settings. A portable, multi-modal approach can address these challenges [1]. A combined LIBS–Raman system with a single laser and spectrograph is a promising solution. LIBS, an elemental technique, enables rapid detection of minerals, while Raman, a molecular technique, provides information on macronutrients like proteins and carbohydrates. Using pulsed Raman spectroscopy with gated detection (ICCDs) it reduces bulky nature of the combined system, while further improves sensitivity thereby making system highly effective for biofluids such as serum.

In this realm a single laser-single spectrograph LIBS-Raman setup for malnutrition detection was assembled using a high-energy Q-switched Nd: YAG pulsed laser (Q-smart 450, Quantel) operating at 532 nm excitation wavelength, 6ns pulse width, and 10 Hz repetition rate. The transmitted light from laser is directed on an optical layout consisting of a lens, edge filter, and prism arranged in a 180° back collection geometry. The incident laser is focused onto the sample using a 6cm focal length biconvex lens and a 2-inch, the LIBS/Raman signal is collected by the same lens, directed through an edge filter, and then focused onto the spectrograph using a second lens. The second lens (focal length=20 cm, dia=2inch and f-number=f/4) is chosen such that it aligns with f-matching of Czerny-Turner spectrograph (Shamrock 193i) which is equipped with a 600 and 1200 grooves/mm gratings blazed at 500 nm, coupled to an Intensified Charged Coupled Device (ICCD, DH734, Andor, Ireland) is used to record the spectrum.

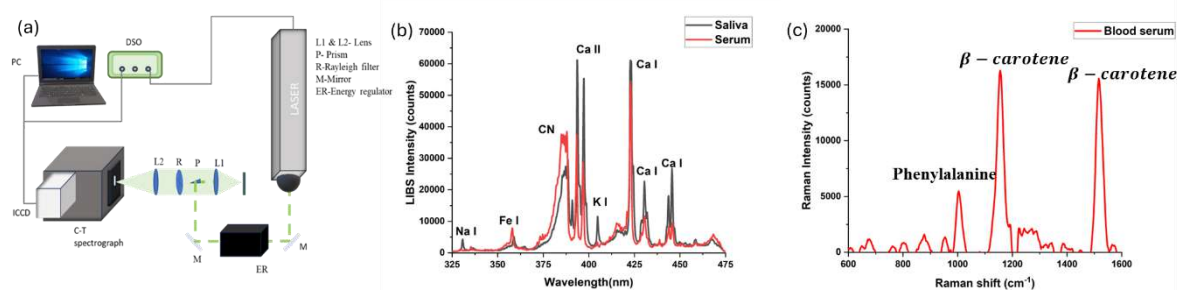


Fig: (a) LIBS-Raman bi-modal system for malnutrition diagnosis, (b) LIBS and (c) Raman spectra of body fluids.

Body fluids such as saliva and blood serum were drop-coated on a superhydrophobic substrate [2], and their LIBS and Raman spectra were recorded using the bi-modal LIBS–Raman system shown in Fig. (a). LIBS analysis revealed the presence of essential minerals, including Calcium (393.4, 396.2, 421.9, 430.2, and 445.5 nm), Sodium (330.1 nm), and Potassium (404.2 nm). In contrast, pulsed Raman spectroscopy detected molecular signatures such as phenylalanine at 1002 cm⁻¹, indicating total protein content, and β-carotene at 1152 and 1526 cm⁻¹, a precursor of Vitamin A. A multi-modal LIBS-Raman-LIF system, combined with chemometric algorithms and spectral databases of micro- and macronutrients, can enable early screening of malnutrition and efficient assessment of its extent in children and prenatal groups. Thus, the custom-built portable system enables simultaneous identification of proteins, vitamins, and minerals from body fluids.

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Entanglement in Flying Modes and Quantum Correlations

Greeshma Gopinath, Sankar Davuluri

Department of Physics, Birla Institute of Technology and Science, Pilani, Hyderabad Campus, Jawahar Nagar, Kapra Mandal, Medchal District, Telangana 500078, India

Quantum correlation plays an important role in quantum technologies, such as Quantum metrology, quantum computing, and quantum information processing. Entanglement is one of such quantum correlations and it can be destroyed when exposed to environmental noise and decoherence. However, quantum correlations can exist without entanglement [1].

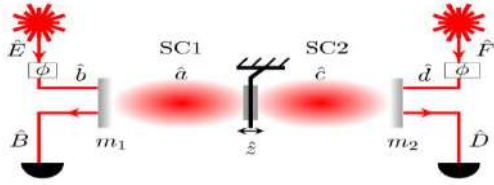


Fig. 1: The double optomechanical system with movable MIM

Using quantum back-action nullifying meter technique [2], entanglement is created [3] between two optical fields coming out of the double optomechanical system as shown in Fig.1. The m_1 and m_2 are partially transparent fixed mirrors, while the mirror in the middle (MIM) is perfectly reflective and it oscillates sinusoidally with instantaneous position $\hat{z}$. The MIM divides the cavity into subcavity 1 (SC1) and subcavity 2 (SC2), each with eigenfrequency ω_e , and cavity fields described by annihilation operators $\hat{a}$ and $\hat{c}$, respectively. The subcavities are driven by input lasers

with annihilation operators $\hat{b}$ and $\hat{d}$, while the output fields with annihilation operators $\hat{B}$ and $\hat{D}$. Entanglement is verified using the sufficient condition proposed by Duan [4]: $\hat{B}$ and $\hat{D}$ are entangled when $\left((\hat{X}_B + \hat{X}_D)^2 + (\hat{Y}_B - \hat{Y}_D)^2 \right) < 4$, $\hat{X}_B, \hat{X}_D$ are the in-phase components, and $\hat{Y}_B, \hat{Y}_D$ are the quadrature components of the output fields $\hat{B}$ and $\hat{D}$ respectively. Duan Criterion is plotted along with logarithmic negativity, the necessary and sufficient condition [5], as shown in Fig. 2(a). Our results show that entanglement lost with the increase in temperature, whereas correlations survive and can even increase with the temperature as shown in Fig. 2(b). The blue dotted line shows the value of Duan criterion as a function of temperature, where the optical fields will be entangled when the y axis is less than four. The purple line shows cross-correlation between $\hat{X}_B$ and $\hat{X}_D$. The plots are simulated with experimentally feasible parameters [6]. This method does not require resolved sideband driving. The creation of strong correlations without entanglement can be useful for quantum technologies like quantum illumination[7].

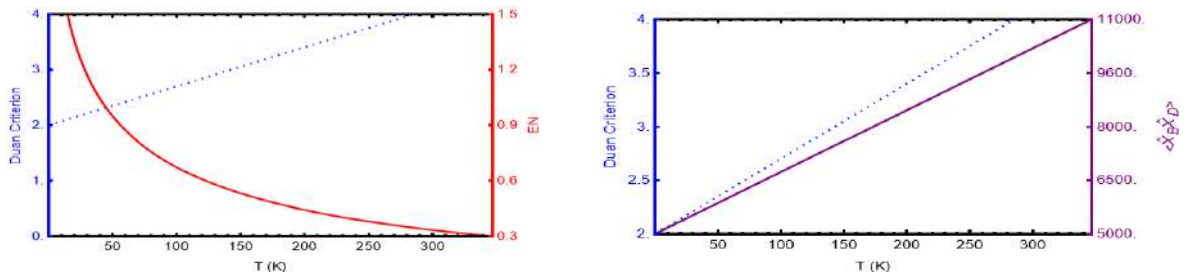


Fig. 2 (a) Comparing the entanglement criterions logarithmic negativity (EN) and Duan Criterion. (b) Plot of correlation vs entanglement. Blue dotted curve shows Duan criterion for entanglement and red curve shows the correlation in in-phase component of the output fields as a function of temperature.

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Measurement of Magnetic Field Orientation via Beam Phase Matching

Nayan Sharma¹, Ranjit Kumar Singh^{1,2} and Ajay Tripathi¹

¹Department of Physics, Sikkim University, 6th Mile Samdur, East Sikkim, India -737102

²Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

The ground-state Hanle effect (GHSE)[1] is widely used in magnetometry for detecting arbitrary magnetic fields. With π -polarized light, resonance splitting occurs in presence of a transverse magnetic field [2]. Full vector reconstruction typically employs intensity modulation [3], external bias fields [4], Stark shift detection [5], among other methods. We present a method for measuring the azimuthal phase (angle) of an unknown magnetic field by

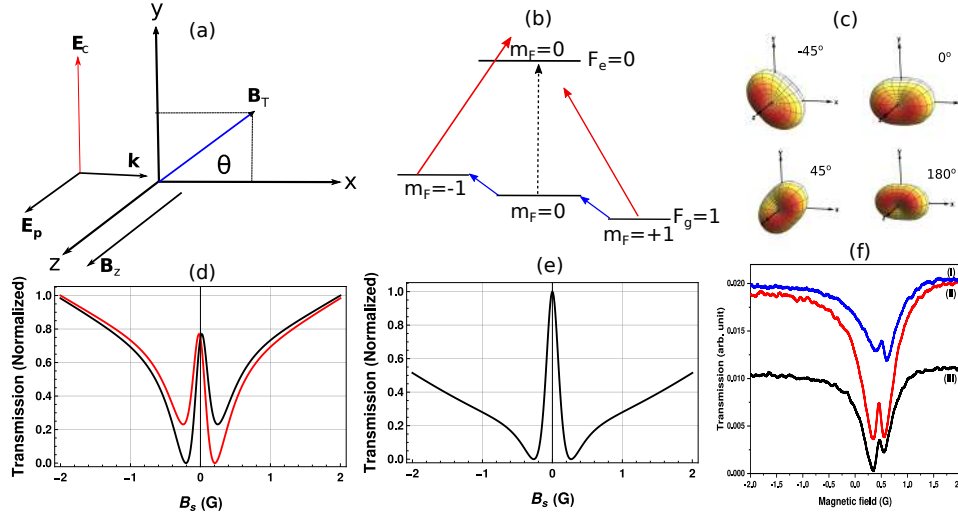


Figure 1: (a) Light and magnetic field orientation. (b). Energy level diagram. (c) Angular momentum probability surfaces (AMPS) showing axial symmetry for single beam case. (d) Numerical transmission showing the effect of θ for multi beam case: Red trace: $\theta = -45^\circ$, Black trace: $\theta = +45^\circ$. (e). resonance when $\theta = 0$. (f) Preliminary experimental result showing the vanishing of asymmetry for $\theta = 0$ (Curve II).

utilizing phase matching of optical beams in a closed-loop tripod atomic system, as illustrated in Fig. 1(a) and (b). To describe the system theoretically, we begin by writing the Hamiltonian,

$$H = \left[\Delta(|1\rangle\langle 1| - |3\rangle\langle 3|) + \frac{\Omega_T}{\sqrt{2}} e^{-i\theta} (|1\rangle\langle 2| + |2\rangle\langle 3|) + h.c. \right] + \left[\frac{e^{i\pi}}{2} (\Omega_+ e^{i\phi_+} |1\rangle\langle 4| + \Omega_p e^{i\phi_p} |2\rangle\langle 4| + \Omega_- e^{i\phi_-} |3\rangle\langle 4|) + h.c. \right]$$

For single beam case ($\Omega_+ = 0 = \Omega_-$), a unitary transformation $U = \text{diag}(e^{i\theta}, 1, e^{-i\theta}, e^{i\phi_p})$ makes the system θ -independent, reflecting axial symmetry (see Fig. 1(c)). In the multi-beam case, θ -independence occurs only when $\phi_p - \phi_+ = \theta$ and $\phi_p - \phi_- = -\theta$. Fig. 1(d) illustrates how unmatched phases introduce resonance asymmetry, while phase matching restores symmetry (Fig. 1(e)), enabling measurement of θ . Experimentally, Fig. 1(f) shows that the resonance becomes symmetric (Curve II) when $\theta = 0$, confirming the concept, even without direct phase control. This method can be integrated with other established techniques to realize a full vector magnetometer. It also enables detection of the optical phase difference between two beams.

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Quantum Emitters in Two-Dimensional Materials via Ion Implantation

Ikshvaku Shyam¹, Amrita Majumder¹, Janhavi Jayawant Khunte¹, Ekta¹, A.M. Sonawane², Akash Khaire², S.S. Dahiwal², and Anshuman Kumar^{*1}

¹Laboratory of Optics of Quantum Materials, Department of Physics, Indian Institute of Technology Bombay, Mumbai 400076, INDIA

²Low Energy Ion Beam Laboratory, Department of Physics, Savitribai Phule Pune University, Pune 411007, INDIA

Two-dimensional materials such as hexagonal boron nitride (hBN) and transition metal dichalcogenides (TMDC) host optically stable defect centres for integrated quantum photonics, yet precise control over their creation remains challenging. We demonstrate ion implantation using several noble gases as a chemically inert and tunable route for generating specific luminescent defects in hBN. By systematically varying implantation fluence and energy, we tune photoluminescence (PL) between a band near ~ 820 nm, associated with negatively charged boron vacancies (V_B^-) [1, 3], and a band near ~ 625 nm, attributed to nitrogen–boron–vacancy complexes ($N_B V_N$) or V_B-V_N complexes [2, 4]. These emissions are correlated with implantation-induced Raman modes at ~ 1290 cm^{-1} (V_B^- marker) [1] and ~ 1600 cm^{-1} (complex-defect-related) [2]. Temperature-dependent PL yields activation energies for nonradiative quenching processes, while correlative structural and compositional analyses, supported by SRIM simulations [5], confirm implantation-induced morphology changes, ion retention, and vacancy distributions. Ion implantation thus offers a species-inert, controllable route for tailoring defect type in hBN, enabling deterministic defect engineering for scalable quantum photonics.

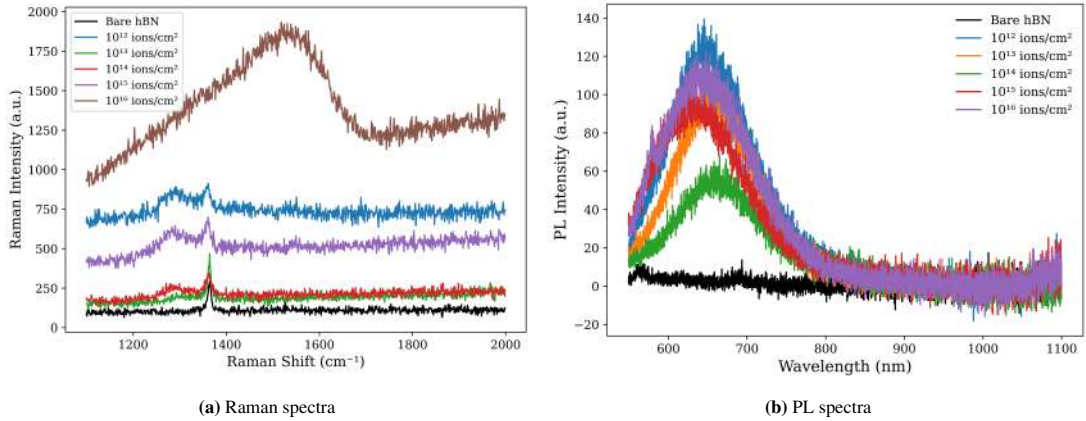


Fig. 1: Raman and PL comparison for bare and ion-implanted hBN. (a) Room-temperature Raman spectra ($1100\text{--}2000$ cm^{-1}) showing implantation-induced disorder features and their fluence dependence. (b) Corresponding PL spectra ($550\text{--}1100$ nm) highlighting the emergence and growth of defect-related emission bands with increasing fluence.

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*anshuman.kumar@iitb.ac.in

Effect of atmospheric turbulence on optical singularity

Kushal Kumar Tripathi, & Praveen Kumar*

Department of Physics, Indian Institute of Technology Bhilai, Durg, 491002, Chhattisgarh, India

*Correspondence: praveen@iitbhilai.ac.in

Abstract

Optical beams with singularities, such as vortex beams, exhibit a unique phase structure that makes them useful in communication and imaging. When these beams propagate through atmospheric turbulence, random distortions occur, which can shift or even eliminate the singularity. In addition to phase changes, turbulence can also alter the polarization pattern of the beam, leading to variations from linear to elliptical or circular states. This work examines how turbulence affects the overall beam structure under different conditions. Simulation results show that turbulence significantly modifies the intensity, phase, and polarization distribution, resulting in noticeable changes in singularity behaviour. Beams with higher topological charges are more sensitive, showing greater distortion in their structure. In strong turbulence conditions, both the phase and polarization patterns change significantly, making the singularity less stable. These findings highlight the need to understand such changes for improving the stability and reliability of optical beams in real-world applications like communication and imaging.

Keywords: Optical vortex, phase singularity, polarization, turbulence.

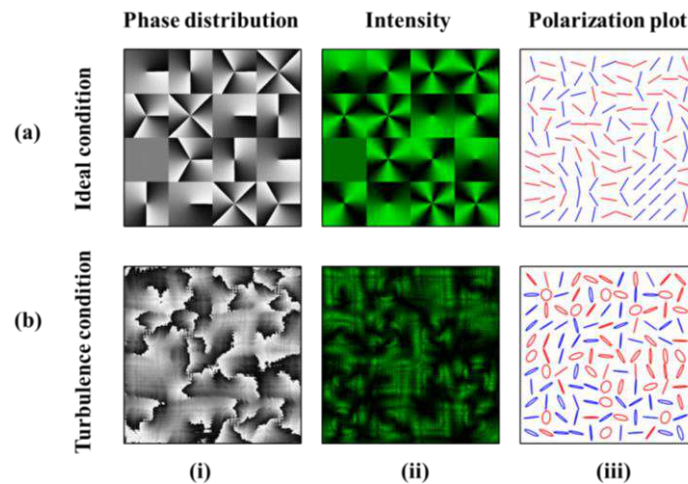


Fig. 1. Simulation results of optical vortex beam under ideal and turbulent conditions. Columns (i–iii) show phase distribution, intensity, and polarization plots. Rows (a) and (b) represent ideal and turbulent cases, respectively.

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Extraction of Anisotropic Properties of Onion Epidermal Cell Using Single Shot Jones Matrix Microscopy

Neha Joshi¹, Nandan S. Bisht

1. Applied Optics & Spectroscopy Laboratory

Department of Physics, SSJ University Campus Almora (263601), Uttarakhand, India

ABSTRACT: We demonstrated a single-shot Jones matrix microscopic imaging technique with intensity interferogram for label-free and non-invasive diagnosis. This technique able to extract anisotropic properties of the sample from the measured 2×2 Jones matrix.

INTRODUCTION:

Polarization contains significant and most effective properties of non-invasiveness and label-freeness for extracting complex optical responses of a sample. Jones matrix microscopy has an advancement in polarimetry by characterizing [1-2] and providing valuable insights into the polarization properties of light [3].

METHODOLOGY:

Jones matrix (J_{ii}) formalism is based on the assumption that the output field, which emerges from the object field (E_{0x}, E_{0y}) and the input field (E_{ix}, E_{iy}), is related to the following formula:

$$\begin{bmatrix} E_{0x} \\ E_{0y} \end{bmatrix} = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix} \begin{bmatrix} E_{ix} \\ E_{iy} \end{bmatrix} \quad (1)$$

An onion epidermal cell is anisotropic in nature. Quantitative imaging using the off-axis holography technique in single-shot Jones matrix microscopy with two Sagnac interferometers in the reference and object arm, characterizing complex properties of the onion cell from 2×2 Jones matrix. The capability of this technique is to use the carrier frequency in orthogonal components for spatial variation in a single acquisition. Using the Fourier fringe analysis approach in recorded interferogram, we can extract the Jones matrix elements of a sample.

The interference pattern can be mathematically written as:

$$I = |(JE_{45} + JE_{-45} + R_x + R_y)|^2 \quad (2)$$

$JE_{\pm 45}$ and R_i represent the output field from the object arm and reference arm, respectively.

RESULTS AND DISCUSSION: The validation of this technique depends on the extraction of the Jones matrix elements of the known sample, such as a quarter-wave plate and polarizer. So far, we have successfully characterized the complex optical properties of the quarter-wave plate (QWP) with the fast axis at 0° in terms of Jones matrix elements and also extracted the corresponding amplitude and phase, which match with theoretical values. We are actively engaged in working with an onion epidermal cell as a sample for the utilization of Jones matrix microscopy and aiming to present findings in the conference.

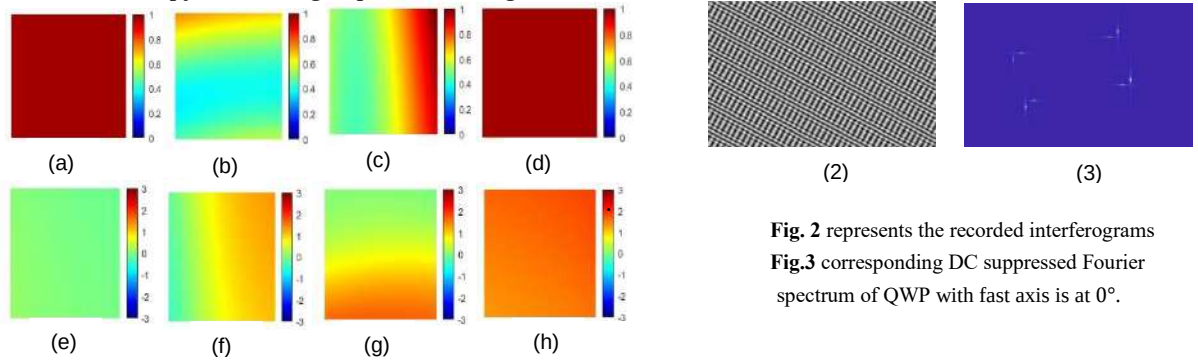


Fig.1 (a-d) represents amplitude distribution and (e-h) represents the phase distribution of Jones matrix elements QWP with fast axis is at 0°.

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Investigation of Zero Phonon Line (ZPL) and Phonon Sideband Characteristics of Nitrogen Vacancy Centers in Nano Diamonds From 300K-4K

Faizan H. Lone¹, Durga Dasari² and Rajesh V. Nair¹

1. Department of Physics, Indian Institute of Technology Ropar 110025, Punjab

2. Department of Physics, University of Stuttgart, Allmandring 13, 70569 Stuttgart, Germany

Nitrogen Vacancy (NV) center is a prominent solid-state defect in a diamond crystal and a very promising candidate for quantum enabled technologies due to its optically accessibility and exceptionally long spin coherence times. They occur in two charge states NV^0 and NV^- with zero phonon lines (ZPL) at 575nm (2.16eV) and 637nm (1.95eV) as shown in Fig.1(a, b) at room temperature and 4K, respectively. These serve as the key optical lines which have been exploited for quantum processing and quantum sensing technologies. Although coherent spin-spin interaction between different NV centers have been demonstrated and implemented to create entangled and quantum qubit gates [1], implementing high-fidelity two-qubit gates is a challenging task when the centers are separated by few nanometres, due to the weakness of direct magnetic dipole-dipole coupling. To address these challenges, intrinsic acoustic phonons have been proposed as a means to connect and control different NV centers for various quantum gate operations [2].

In this work, we perform a detailed temperature dependent photoluminescence (PL) experiment on NV's for different concentration in DI water. This allows us to probe and study the evolution of the phonon sideband (PSB) characteristics associated with the NV^0 and NV^- ZPL's. As the temperature is decreased, the phononic contributions accompanying the two ZPL's still remain weakly coupled to the center, particularly the strong quasi-localised defect-related phonon mode (63meV) which appears at around 660nm as shown in Fig1(c). We analyse the optical transition line width, transition wavelength and the excited state life-times of these phononic modes as a function of temperature. The observed trends provide insight into which phonon modes remain relevant and their corresponding coupling strength for low-temperature NV dynamics and thus should be taken into consideration not only in designing phonon-assisted coupling schemes for scalable quantum networks. but also for enhancing the coherence times of NV-based qubits [3].

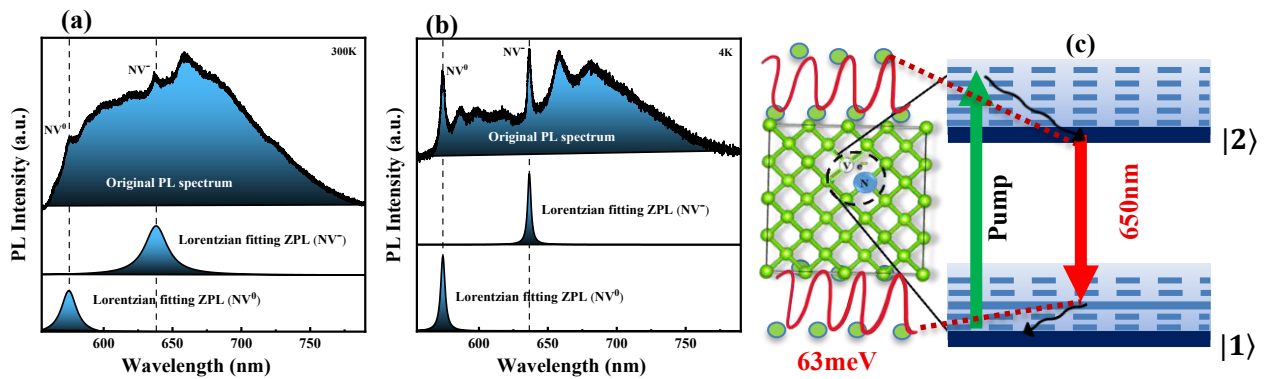


Fig. 1 (a) PL spectrum of NV center at room temperature with two Lorentzian components at 575nm and 637nm (b) PL spectrum acquired at 4K, showing substantial narrowing of the ZPL components. (c) shows the radiative 660nm mode coupled to 63meV quasi-localised acoustic mode of the lattice

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Hybrid Neural Network and SPGD Approach for Efficient Coherent Beam Combining

Khushboo Soni and Nithyanandan Kanagaraj

Ultrafast Fiber optics & Smart Photonic Technologies Lab, Department of Physics,
Indian Institute of Technology Hyderabad, Kandi -502285
Ph23resch01006@iith.ac.in

High-power laser systems with excellent beam quality are crucial for advanced technologies like space communication, LiDAR, and directed energy [1]. Coherent beam combination (CBC) can achieve high output power and tightly focused beams by aligning the phases of multiple lasers [2]. However, in real experiments, especially at long distances, placing a power detector at the target is often impossible, making direct measurement of beam combining performance difficult. Typically, only far-field intensity images from a camera are available, which show brightness but not the critical phase information. Without phase knowledge, traditional methods like SPGD must start from random guesses, making them slow and sometimes unable to reach optimal solutions [3]. To address this, we trained a Generative Adversarial Network (GAN) on many examples of random phase patterns and their corresponding intensity images. The GAN learns to estimate the hidden phase from intensity patterns [4]. While its predictions are not so perfect, they provide a strong starting point for SPGD [5]. Using this NN-predicted phase, SPGD converges faster and achieves better results. This hybrid NN+SPGD method combines speed and accuracy, overcoming a key limitation in real CBC systems where direct phase measurement is impractical. By integrating intelligent learning with traditional optimization, we achieve improved beam quality, higher target-region power, and faster convergence, making the approach highly practical for real-world laser applications.

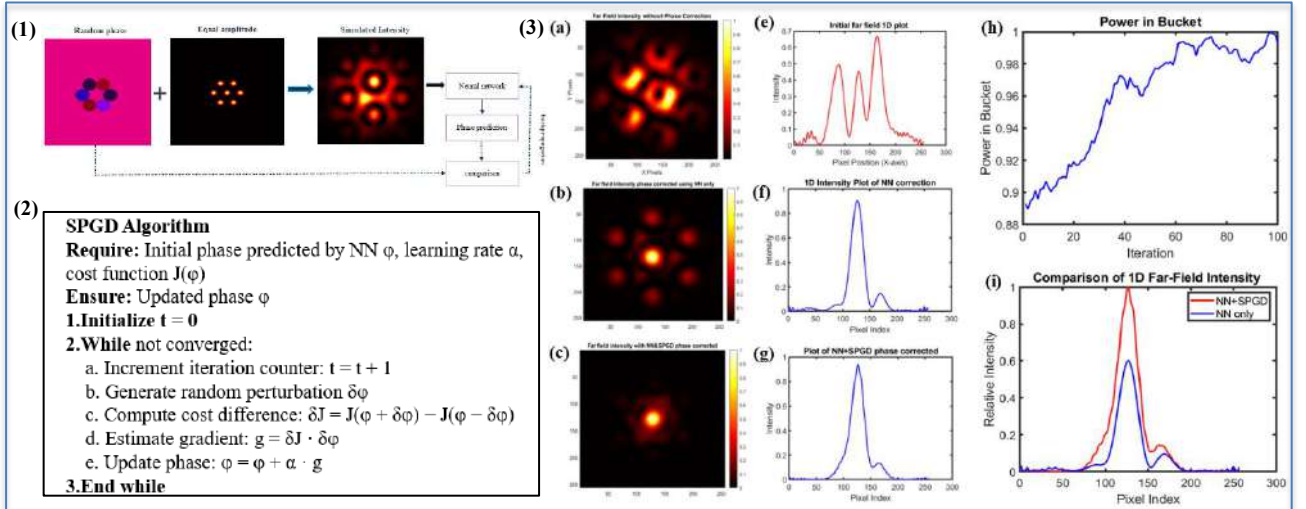


Figure: (1) Training model (2) Algorithm, (3) Simulation results of phase correction using NN and SPGD: (a) Far-field without correction, (b) corrected by NN, (c) corrected by NN+SPGD, (d-f) corresponding 1D intensity profiles, (g) convergence of PIB with SPGD after NN correction, (h) comparison of relative beam intensity after NN and NN+SPGD correction.

Figure 1 illustrates training of our pix2pix GAN network on simulated intensity–phase pairs, learning to predict far-field phase from a single-shot intensity. This prediction initializes SPGD optimization, boosting both speed and beam quality. Figure 2 show the pseudo code for SPGD algorithm. Figure 3 shows beam combining at various stages. Without phase correction (Fig. 3a), the far-field is fragmented with low central energy. Using the NN alone (Fig. 3b) improves structure and localization, but not fully. Initializing SPGD with the NN phase (Fig. 3c) produces a sharply focused beam with minimal sidelobes. 1D cross-sections confirm this: the uncorrected profile (Fig. 3d) is broad and low-contrast, NN-corrected (Fig. 3e) shows a central peak, and NN+SPGD (Fig. 3f) gives a sharp, Gaussian-like distribution. PIB evolution (Fig. 3g) demonstrates stable convergence, and 1D comparison (Fig. 3h) shows the hybrid beam is narrower, more intense, and better confined than NN alone. Overall, the hybrid NN+SPGD approach combines fast, data-driven phase estimation with optimization, achieving high-quality coherent beam combining where direct phase sensing is impractical.

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Exploring Fast Spectral Dynamics of Single Quantum Dots

Abhishek Yogi^{1,*}, Nikhil Shrivastava¹, Tommaso Milanese², Ermanno Bernasconi², Claudio Bruschini², Edoardo Charbon², and Venkata Jayasurya Yallapragada¹

¹Department of Physics, Indian Institute of Technology Kanpur, Kanpur 208016 India

²School of Engineering, Ecole Polytechnique Fédérale de Lausanne (EPFL), Neuchâtel 2002, Switzerland

*yogiabhi@iitk.ac.in,

Quantum dots (QDs) are semiconductor nanocrystals whose emission spectra can be tuned by changing their size. The rapid spectral fluctuations of a single quantum dot provide insight into the fluctuations of electric fields in the vicinity of the quantum dot. To study these fluctuations, we have built a setup based on a single photon avalanche diode (SPAD) array that measures the energy and arrival time of emitted photons by a single quantum dot [1]. Our experimental setup consists of two main parts: first, a home-built microscope through which we collect emission spectra of quantum dots, and second, a home-built monochromator which spectrally resolves the photoluminescence and maps specific wavelengths to each pixel of the SPAD array. By illuminating the QD with a diffraction limited spot from a picosecond laser beam, we record photon detection times in each SPAD array channel. This enables us to record detection timestamps with ~ 20 ps resolution while simultaneously achieving a spectral resolution of ~ 3 nm.

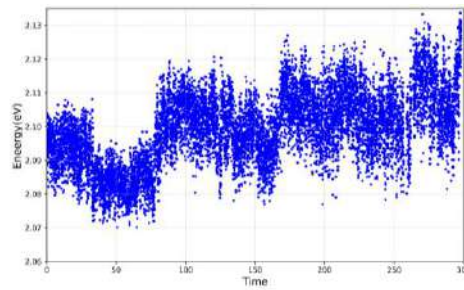


Fig. 1 Evolution of the photoluminescence spectrum of a single quantum dot measured through our experimental setup

Using this setup we measured the photoluminescence of a single CdSe-ZnS quantum dot. To remove the contributions of artefacts to the results, a series of post-processing steps have been performed, which reduce the effects of timing nonlinearities and crosstalk. From the processed spectrally resolved timestamps we estimate the timescales of spectral fluctuation, and clearly identify microsecond scale spectral dynamics, which is an order of magnitude better than the best CCD based spectrometer. In figure 1 we can see the mean spectral fluctuation of quantum dots measured through our experimental setup. From this data, we are able to quantify spectral fluctuations at timescales ranging from microseconds to tens of seconds. Our results pave the way for new potential applications for quantum dots as sensors of electric fields in their immediate environment without the need for calibration of their response.

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STUDY OF CELL MEMBRANE PROPERTIES USING NORMAL AND SLOPE FLUCTUATIONS IN OPTICAL TWEEZERS

We have recently demonstrated the detection of out of plane rotational motions in optically trapped particles at high angular resolution and temporal bandwidth. In this work, I will demonstrate determination of cell membrane properties like the bending rigidity and the membrane tension by determining the vertical (or normal) fluctuations of the cell membrane and a new concept called slope fluctuations. We show that we can successfully see changes in bending rigidity for cells under the influence of softening and other drugs. This can be extended to detection of cell membrane properties at various length scales. The technique has a higher spatial resolution than video microscopy because it does not actually image the cell membrane but rather infers the position from photonic force microscopy available with optical tweezers. The slope fluctuation technique is further useful because the power spectral density has just one parameter in the high frequency limit, namely the bending rigidity in the coefficient. Thus the measurement is more accurate than the normal fluctuations.

Weak measurement differential microscopy

Ritwik Dhara¹, Sujit Rajak¹, Niskarsh Kumar², Dheeraj Yadav¹, Ujjal Karmakar¹, Nirmalya Ghosh¹

1. Department of Physical Science, IISER Kolkata, Mohanpur 741246, India

2. Department of Physics, IIT Kanpur, Kanpur 208016, India

Detecting the edge or boundary of phase objects is challenging because they are generally invisible and transparent in bright-field microscopy due to their weak scattering and minimal absorption properties in the presence of light. To overcome this problem the idea of differential microscope has been proposed. A differential microscope gives the differentiation of the input electric field as output. As a result, it acts as an edge detector for a phase object. Even if there are many digital techniques available for differentiating a specific item or image, the analog or optical method is still practical because of its quick operation and low energy requirements [1]. In this work, we proposed a new kind of analog or optical differential microscope based on the method of weak measurement.

We consider a Gaussian beam of wavelength λ , incident on a birefringent plate tilted by an angle θ with respect to the beam's propagation direction. The analysis is carried out in a local Cartesian coordinate system, referred to as the beam frame, where the beam propagates along the positive z -axis. In this frame, the transverse profile of the beam lies in the $x - y$ plane and polarization along y axis as o -ray and polarization along x axis as e -ray. Under this configuration, the one-dimensional transverse distribution of the complex electric field along the x -direction can be expressed as $E_0(x, z) = E_{0x}(x, z)\hat{x} + E_{0y}(x, z)\hat{y}$. Where $E_{0x} = E_{0y}$ for $+45^\circ$ polarization state that is $(1 \ 1)^T$. A birefringent plate with optic axis oriented at an angle ϵ with respect to x direction will introduce an additional phase ϕ_0 in x component as the e -ray has different refractive indices depending on ϵ . Now, if we introduce a tilt in birefringent plate by an angle θ along the $x - z$ plane, the various transverse momentum components k_x of the Gaussian beam experience different phase anisotropies as there will be a constant gradient of phase throughout the plate. As a result a weak coupling between the transverse momentum k_x and polarization is introduced. The weak coupling Hamiltonian can be written as $H = \Delta_x \sigma_z k_x$. Here σ_z is polarization operator and Δ_x is coupling coefficient. In this weak measurement scenario we use polarization states as pointer that provides the weak value of the transverse momentum k_x . The weak value of transverse momentum has the form $\langle k_x \rangle_w = \frac{\langle x | k_x | E \rangle}{\langle x | E \rangle} = \frac{\partial \ln E(x)}{\partial x}$ this is nothing but the differentiation of the electric field with respect to x coordinate. Using some simple calculation it can be shown that the real and imaginary part of the weak value of the momentum can be found using the basic stokes vector measurement.

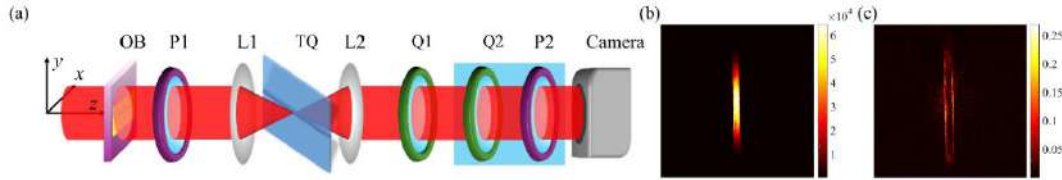


Figure 1.(a) Schematic experimental setup for weak measurement microscopy experiment. The blue shadow region is indicating the Stokes parameters measurement part. (b) The image of the object (Slit) OB recorded by the camera. (c) Stokes vector element S_1 of the object that is the amplitude Differential image of the object.

We perform the experiment using a He-Ne laser having wavelength 632 nm . We pre-select the input beam using a polarizer P1 in order to obtain the polarization dependent shift from the tilted quarter waveplate - TQ. A $4 - f$ system consisting of two spherical lenses L1 and L2, with both having focal lengths 400 mm is introduced to get the real image of the object (OB), kept at the back focal plane of L1. TQ is placed between imaging lenses L1 and L2, aligning with the front Fourier(focal) plane of L1. An additional quarter waveplate Q1 is used to remove the extra phase coming from TQ. The polarizer P2 and quarter waveplate Q2 together serve as a platform for measuring the Stokes parameters that are the post selected state of our system. A CCD camera with pixel size $24 \mu\text{m}$ is placed at the front focal plane of L2 to collect the image of OB.

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Focusing properties of Hybrid-Order Poincaré Sphere Beam

R. Sakthi Maheswari¹, T.K. Lena Shree¹, Amal M¹, K.B. Rajesh², M.Lavanya^{1*}

¹ Department of Physics, PSGR Krishnammal College for Women, Coimbatore, 641001.

² Department of Physics, Chikkanna Government Arts College, Thiruppur, 641602.

The tight-focusing properties of hybrid-order Poincaré sphere (HPS) beams at a dielectric interface are numerically analyzed using vector diffraction theory. The focal intensity distribution is strongly influenced by the signs and magnitudes of the constituent topological charges. Superposed beams with opposite-sign topological charges produce multiple bright lobes, whereas like-sign charges generate irregular ring-like patterns. A quantitative relationship is established: two polarized beams with opposite-sign orbital angular momenta (OAM) yield $|m - n + 2|$ azimuthally distributed lobes when $m \neq -n$, and $2|m + 1|$ petal-shaped lobes when $m = -n$. For $|m| < |n|$, increasing $|m|$ significantly enlarges the central dark core radius, while variations in n have minimal effect. The HPS framework describes the total angular momentum (AM) of light as a superposition of orthogonal circularly polarized OAM eigenstates with distinct phase charges [1-3]. Under tight focusing, spin-orbit coupling facilitates interconversion between spin angular momentum (SAM) and OAM, leading to complex vectorial field structures [4-7]. Complete polarization characterization and spin-related topological effects are examined, providing insights into beam-interface interactions. These results highlight the potential of HPS beams in nanoparticle manipulation, surface plasmon excitation, and high-resolution microscopy.

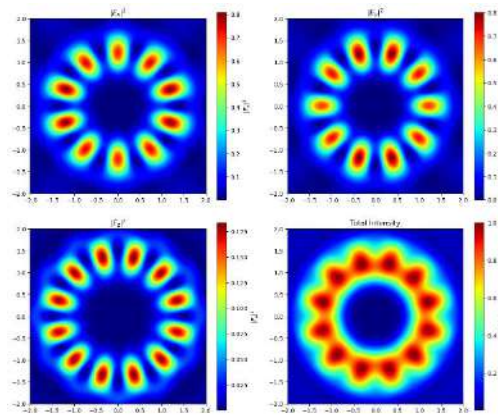


Fig.1 Focal intensity distribution when $m = 4$, $n = -6$.

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Plexcitonic Systems for Enhanced Sensing

Sibasankar Sahoo¹, Subrat Sahu¹, and Rajan Jha^{1*}

¹Nanophotonics and Plasmonics Laboratory, School of Basic Sciences, IIT Bhubaneswar, Khurda 752050, Odisha, India

*Email: rjha@iitbbs.ac.in

The requirement for biomolecule sensing has grown rapidly due to emerging health threats, new diseases, and the need for fast, accurate detection of pathogens or harmful substances [1, 2]. Different polaritonic systems enable ultrasensitive, real-time, and label-free biomolecule detection. One such method for sensing is plasmon, a field that studies Surface Plasmon Polaritons (SPPs), an electromagnetic wave formed when *p*-polarised light interacts with the free electrons in metals [1]. SPPs are surface waves that offer strong confinement and high sensitivity. Due to these properties, plasmonics has seen significant growth and has been applied in various areas, including imaging, sensing of the external medium, and spectroscopy. Another polaritonic system, i.e., Surface Exciton Polaritons (SEPs), are surface wave derived from electromagnetic waves and excitons in semiconductors or quantum wells, used in devices like lasers and biosensing [1]. However, a hybrid system called Plexcitonics is an emerging research field that combines SPPs and SEPs, focusing on hybrid polaritons, or surface plasmon exciton polaritons (SPEP). These polaritons are formed through coupling between metal plasmon and semiconductor exciton modes, being explored for light harvesting devices and sensors [1].

This paper focuses on the interaction between plasmon and exciton modes by designing and analysing a Plexcitonic system for biological sensing. A Kretschmann configuration based on the angle interrogation method is used, as shown in Fig. 1(a). It comprises a plasmon-active metal like gold (Au) covered with a thin layer of the organic semiconductor J-aggregate cyanine dye (TDBC), and the whole configuration is set up on a momentum matching (prism). The biomolecule region is in contact with the TDBC layer. Here, biomolecule sensing is considered in terms of variation of change in the refractive index of the analyte (n_a) in the range of 1.330-1.390. The system is excited through one face of the prism with a *p*-pol light of $\lambda = 532$ nm, and the reflected light is detected at the other face of the prism. Due to the high sensing capability of the SPEP structure, the changes in the output end can be observed. Fig. 1(b) shows the variation of the reflection spectra with a change in $n_a = (1.330, 1.360, 1.390)$. As can be seen, the dip of the reflection spectra shows a red shift in the response, showing the sensing mechanism of the proposed Plexcitonic structure. Also, one can notice that the on-resonance reflectance increases and shows a broader spectrum with an increase in the n_a -value, which signifies the loss induced at the higher n_a -value. Further, Fig. 1(c) shows the change in the resonance angle (θ_r) with the n_a -value. Using these values, the sensitivity (S) of the system is estimated to be $S = \delta\theta_r / \delta n_a \sim 220^\circ/\text{RIU}$. The sensitivity of this Plexcitonic system is noticeably higher than the traditional plasmonic sensor and can be used for food degradant analysing and sensing of volatile organic compound (VOC). [2]

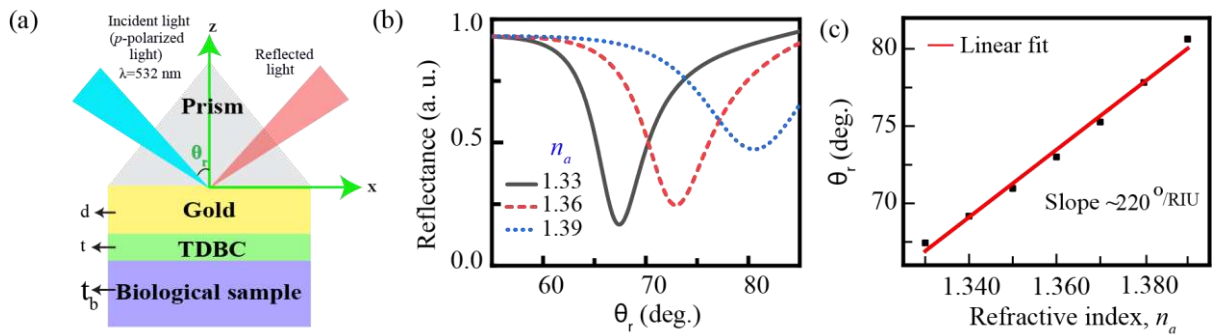


Fig. 1 (a) Proposed structure of the Plexcitonic system where $d = 50$ nm, $t = 10$ nm, $t_b = 240$ nm and the refractive indices: $\eta_{\text{prism}} = 1.7948$, $\eta_{\text{Au}} = 0.0990 + i2.99521$, $\eta_{\text{TDBC}} = 0.0465 + i1.5900$, $n_a = 1.33$ -1.39. (b) Variation of reflectance with respect to the angle of incidence for different n_a -values. (c) Variation of on-resonance angle for different refractive indices.

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Implementation Of Quantum Walk with Nanostructure Using Orbital Angular Momentum Beams

Pranay Agrawal¹, Apurv Chaitanya Nellikka¹

1. Dr Vishwanath Kard World Peace University, Pune, Maharashtra 411038, India

Recently it has been shown that quantum walk can be demonstrated using bulk optics [1]. Quantum walk is the quantum analogue of the classical random walk where gaussian distribution is not obtained [2]. Quantum walk has wide applications for realising quantum algorithms which seen increased attention with the advent of quantum computing.

We propose to use nano structures instead of bulk optics as it will reduce the size and removes alignment complexity. The structure we propose is addition to the work done by Patrice Genevet et al where they demonstrate that V shaped nano antennae can be used for making wave plates particularly half wave and quarter wave plates [3]. Orbital angular momentum (OAM) beams form an excellent candidate for performing quantum walk as the polarisation can be used as the coin toss unit. The bulk optics realisation of the quantum walk is done using a q-plate, a half wave plate (HWP) and a quarter wave (QWP) plate where, depending on the structure the half wave plate can be omitted [1,4].

Our nanostructure comprises of a q-plate, QWP and HWP based on the following references [3,5]. These three plates will be made as a single unit and depending the number of stages required for the quantum walk can be easily stacked on each other.

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Phase Dependent of Entanglement Entropy in the Decay of $B_s^0 \rightarrow \phi\phi$

Divya Sharma¹, Vaibhav Rawoot¹, Sudip Kumar Haldar¹

1. Department of Physics and Materials Science and Engineering, Jaypee Institute of Information Technology, Noida, Uttar Pradesh, India.

Abstract:

We present a comprehensive study of quantum entanglement in vector-vector final states of meson decays, with a primary focus on the process $B_s^0 \rightarrow \phi\phi$. Utilizing helicity amplitude inputs, we reconstruct the bipartite density matrix and compute the reduced density matrix ρ_A of the subsystem. The entanglement is quantified using both von Neumann entropy and Renyi entropy, capturing the degree of quantum correlation between the decay products [1].

Using the von Neumann entropy, we obtained a value of **1.093**, which indicates **strong quantum entanglement** in the system. Similarly, the Renyi entropy of order 2 yielded a value of **0.674** [2]. Both of these entropy measures played a crucial role in confirming the presence of entanglement in the bipartite system.

We have Obtained the plot of Entanglement entropy in decay of $B_s^0 \rightarrow \phi\phi$ with $\delta_{\parallel} = 0$ radians. The entropy exhibits a clear oscillatory pattern, reaching a maximum of **1.093** near $\delta_{\perp} = \pi$, and a minimum of **0.666** near $\delta_{\perp} = 0$ and 2π [3]. This behavior reflects the sensitivity of quantum entanglement to the underlying phase structure of the decay amplitudes [4].

Keywords:

Quantum entanglement, Bs0 decay, vector states, helicity amplitudes, entropy.

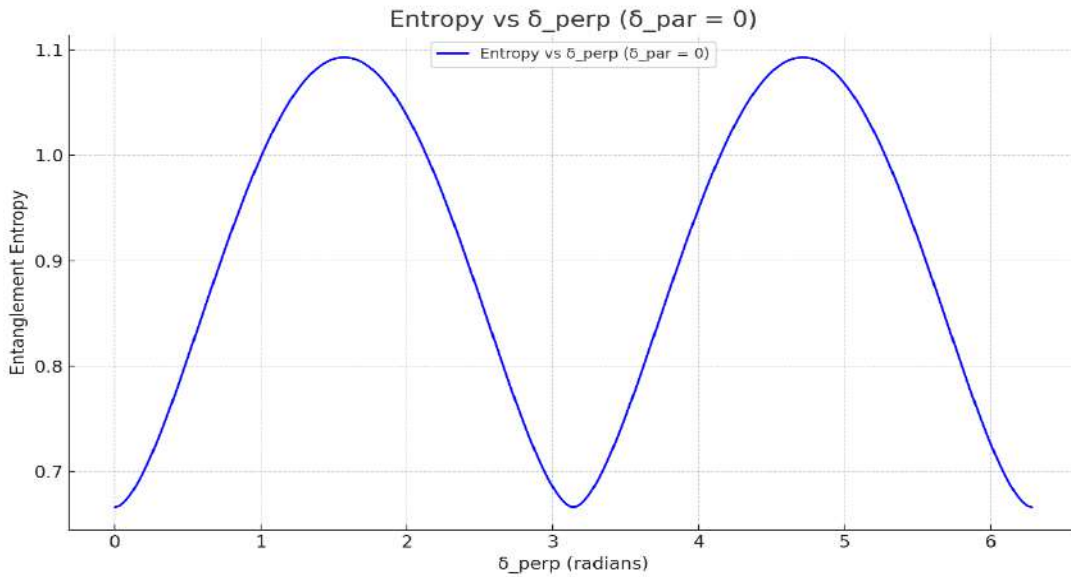


Fig. 1 Entropy changes with $\delta_{\perp}$ (when $\delta_{\parallel}=0$) in $B_s^0 \rightarrow \phi\phi$ decay. The graph shows that entanglement increases and decreases in a wave-like pattern, with peaks at $\delta_{\perp}=\pi$ and lowest values at $\delta_{\perp}=0$.

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Optimizing Hermite Gaussian Laser Mode for Mode Division Multiplexing in FSO Systems

¹Kirti Bhargava, ¹Shivangi Bande, ²Gireesh G.Soni

¹Department of Electronics & Telecommunication, Institute of Engineering & Technology, DAVV, Indore, M.P., India

²Department of Electronics & Instrumentation, Shri G S Institute of Technology and Science, Indore, M.P., India

kirtirks@gmail.com, sbande@ietdavv.edu.in, gireeshsoni@gmail.com

Abstract—Mode Division Multiplexing (MDM) is a growing multiplexing technique where different transverse modes of Laser carries the data of different users on a single transmission frequency. MDM technique widely used in multi-mode fibres is now gaining importance in Free Space Optical Communication (FSO). This paper investigates the order of Hermite Gaussian (HG) Modes that can be used for MDM based communication over FSO link. The beam quality factor denoted by M^2 is considered for the investigation. It is an important parameter for evaluating the laser beam performance when it propagates through turbulence. The analysis reveal that the beam quality factor have a huge influence on the peak intensity when laser beam propagates in free space. The analysis is carried out using Optisystems simulation software. Q factor for different higher order modes propagating over FSO channel is evaluated and compared to get an optimized solution for taking number of HG modes simultaneously for MDM.

Keywords—FSO, MDM, M^2 , turbulence, HG modes.

I. INTRODUCTION

FSO communication is a technology that uses free space to transmit data using optical signals[1]. When used with Mode Division Multiplexing (MDM) the data carrying capacity is further enhanced. It's a type of line of sight communication which uses different Laser modes to transmit the user data simultaneously over a laser beam of single wavelength [5]. Laser modes are of two types longitudinal and transverse modes that describe the different ways a laser beam can oscillate within the laser cavity. Transverse modes refer to the spatial patterns of the electric field within the cross-section of the laser beam. These modes represent the different intensity and phase distributions across the beam's cross-sectional profile [2]. The distributions characterized by the integers n and m are called the transverse mode and are designated as TEM_{mn}. The fundamental transverse mode, often called the TEM₀₀ mode, is a Gaussian beam and is usually the preferred output of most lasers.

The laser can be treated as a resonant cavity of a particular wavelengths long and wide. Such a resonant cavity has many allowed modes of oscillation. When Laser operates in several modes, total intensity profile is the superposition of all existing transverse modes [2]. These modes are represented as Hermite Gaussian (HG) Mode (for rectangular coordinates) and Laguerre Gaussian (LG) modes (represented in cylindrical coordinates)[4]. Utilizing these

multiple spatial modes to transmit user data over communication channel for a single wavelength forms the basis of Mode Division Multiplexing (MDM). Each mode acts as an independent channel, allowing for the transmission of multiple data streams simultaneously [5-7]. FSO communication provides high communication BW, secure and fast data transfer but heavily affected by the atmospheric factors like rain, fog, mist, aerosols etc. [1]. 8 different HG modes transmitted using MDM at 1550nm and the effect of clear weather, mild to heavy rain and haze is reported [5]. MDM with two basic HG and LG modes is studied to evaluate the maximum distance covered by them [6]. four 2.5 Gbps channels of HG modes that monitored effect for medium fog, medium rain, medium haze, and clear weather conditions, It proposes a decision feedback equalizer (DFE) with MDM for the FSO system [7]. Two LG modes are considered to study the effect Rain, Fog and Haze comparing on-off keying and pol. Shift keying method [9].

The work focuses on the beam propagation factor also called M^2 factor for the use of higher order HG laser modes in MDM over FSO link. The M^2 factor (or beam propagation factor) quantifies how well a laser beam propagates compared to a perfect Gaussian beam. The M-squared (M^2) factor for Hermite-Gaussian (HG) modes, is a measure of beam quality, is directly related to the mode numbers (n , m) in the x and y directions. For HG_{mn}, in 1 dimension, the M^2 factor in the x -direction is [2]

$$M^2_x = 2n + 1 \text{ (in the } x\text{-direction)} \quad (1a)$$

$$M^2_y = 2m + 1 \text{ (in the } y\text{-direction)} \quad (1b)$$

For a two-dimensional beam of order m , n two-dimensional beam propagation factor can be calculated as [2]

$$M^2 = m + n + 1 \quad (2)$$

Larger n and m values will have larger M^2 values, indicating a larger divergence and a departure from the ideal Gaussian beam profile [8].

Optical signal propagating through free space channel is sensitive to atmospheric conditions like fog, rain etc. Attenuation of optical signal in atmosphere is due to scattering & absorption introduced by molecular constituents (gases) and aerosols [10]. Beam quality factor (M^2) is an important parameter for evaluating the laser beam when propagates through turbulence. Laser beam with different M^2 factor propagating through atmospheric turbulence experience different beam spreading and beam wander at target plane [12].

The output from real-life lasers is not truly Gaussian. To understand the variation a quality factor; M^2 factor has been

defined to describe the deviation of the laser beam from a theoretical Gaussian. M^2 is a calculated value that defines the divergence of the actual distribution from the Gaussian ideal. It results in a value where 1 is a perfect, theoretical beam and higher values signifies degrading quality. A lower M^2 & lower divergence value indicates a higher beam quality [2]. Where Divergence is a measure of how much the beam spreads as it travels through space. HG modes are also classified as ordinary and elegant HG modes based on the complex argument [11]. The M^2 factor for standard and elegant modes is derived [2] and their effect in turbulent environment is also studied [12]. The beam propagation factor has been calculated for higher order ordinary HG beams [2, 9]. 1 D higher order HG_{0n} modes (where n varies from 0-9) were experimentally generated [13] and studied for their beam quality factor [4].

In this paper, effect of M^2 factor for different ordinary low (1D) and high order (2D) HG modes for MDM transmission over FSO link is investigated. Quality (Q) factor, a crucial metric used to evaluate the reliability of optical transmission through the atmosphere is evaluated for varying transmission distance. Wavelength of 1550nm is preferably chosen as this wavelength region fulfills the eye safety requirements and falls within the transmission window [1].

The paper is organized as follows: Section II discusses the transmission and reception system architecture with its specifications. Section III presents the Results and Discussion, analyzing the performance HG modes under low turbulence and geometrical losses using Q factor as the performance metric. Finally, Section IV concludes the study with key findings and recommendations for enhancing MDM FSO communication reliability.

II. SYSTEM ARCHITECTURE

The architecture models the behavior HG laser modes in a Free Space Optical (FSO) communication link. It includes a transmitter with HG Mode generator, an FSO communication channel and APD based receiver circuit.

Fig. 1 represents block diagram for transmitter circuit used for simulation purpose. A continuous wave Laser source of 1550nm wavelength with 10mW power is used for transmitting the user data. The desired higher order HG modes are generated by using HG Mode generator circuitry with a power array of 1 and mode polarization X=Y. Laser source of 1550 nm is preferred for relaxed eye safety requirements and reduced interference from ambient light source. Pseudo random bit sequence generator is used to generate the user data which is encoded at a rate of 1, 2.5 and 10 Gbps using a Non-Return-to-Zero (NRZ) encoding scheme. Encoded user data is intensity modulated by a specific generated HG mode and transmitted with transmitter aperture diameter of 5cm over FSO communication channel.

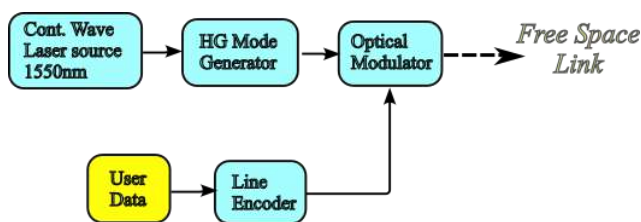


Fig. 1. Transmitter block diagram

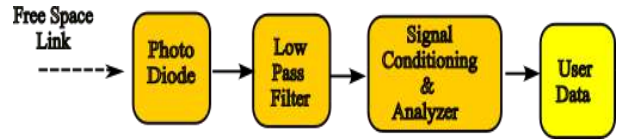


Fig. 2. Block Diagram for Receiver

The communication channel is considered to have an attenuation factor of 7dB/km, which is a typical value for existing commercial outdoor FSO communication [1]. The channel shows geometrical losses and intensity scintillation in low turbulence environment with a beam divergence factor of 2mrad.

Fig 2 depicts the block diagram for receiver circuit that includes a PIN photodiode with circular aperture and receiver aperture diameter of 20cm. Obtained electrical signal is fed to II order low pass filter to get the desired signal at the output. Spatial intensity distribution of various HG modes under consideration are shown in fig 3.

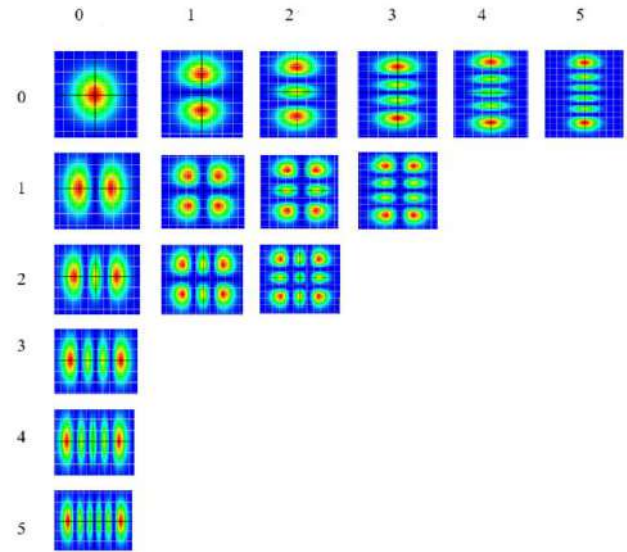


Fig. 3. Spatial intensity distribution of HG modes

RESULTS AND DISCUSSION

Fig. 4 shows the variation of Maximum Q Factor with the transmission distance for FSO link. The data rate is considered 1Gbps for graph in fig 4. The graph represents higher HG modes viz HG 01, HG 10, HG02, HG20, HG03, HG 30, HG04, HG40, HG05 and HG 50. The graph represents 1 dimensional HG modes where for HG mn, either m=0 and n ≠0 or m≠0; n=0. The results shows that 1D ordinary modes shows nearly same values (e.g. HG 01 = HG 10 etc.) for Q factor for varying transmission distance. Though orthogonal in nature these modes shows similar results as they possesses same beam factor. Lower HG modes (e.g. HG 01 & HG 10) shows good Q factor upto a transmission range of 1.2Km. Higher order HG modes (till Mode m or n =5) shows good Q factor upto a transmission distance of 1Km. Thus for lower data rates of 1Gbps more modes can be multiplexed together on a single laser frequency to get higher data rate per frequency per channel.

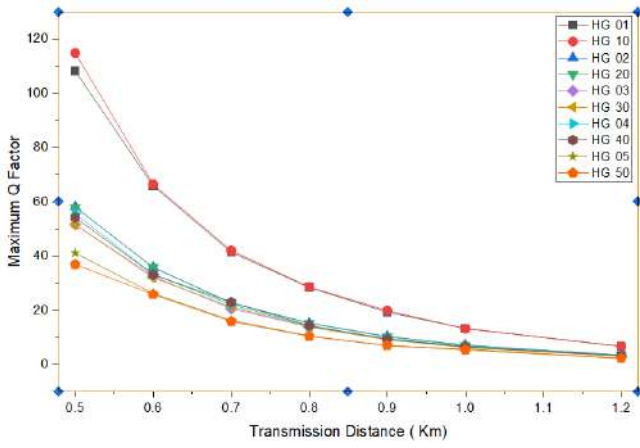


Fig. 4. Q Factor variation with Transmission distance for Higher HG laser modes for FSO Link.

Fig. 5 represents the M2 factor for 1D HG 01, HG 02 and 2D HG 11, HG 13 and HG22 modes. The values for beam factor (M2 factor) is evaluated by using equation 1a, 1b & 2 for 1D and 2D HG modes. Bars represents same M2 value for HG 01 and HG 11 and similarly M2 factor for 1D HG 02 is equals to 2D HG 13 and HG 22 modes.

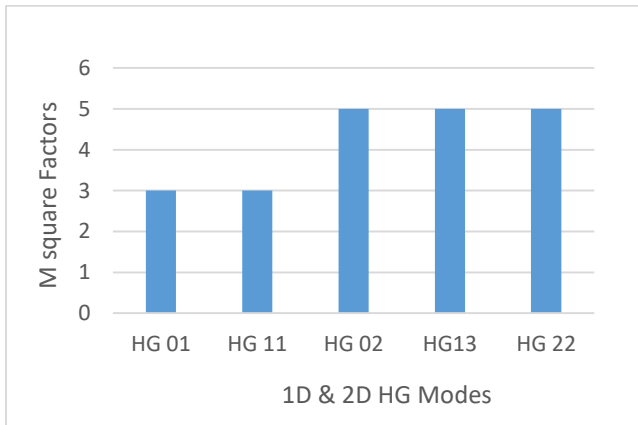


Fig 5: 1D & 2D HG Modes for its M 2 factor values.

Fig 6 represents behaviour of 1D HG 01 and 2D HG 11 both having same beam factor represented by blue colour. Similarly, Q factor vs transmission distance for 1D HG 02 and 2 D HG 13 and HG 22 all having same beam factor represented by red colour. The graph clearly indicates that although the beam factor is similar for the mode values (represented in fig 5) they show different behaviour for Q factor for varying transmission distance of FSO channel. Hermite-Gaussian (HG) beams with the same beam factor can exhibit different ranges due to variations in their mode order (n, m) that results in variation in their diffraction behavior. Although the beam factor (M2 factor) influences the overall beam size and divergence, the mode order dictates how the beam will spread and propagates in FSO, resulting to variations in the effective transmission distance.

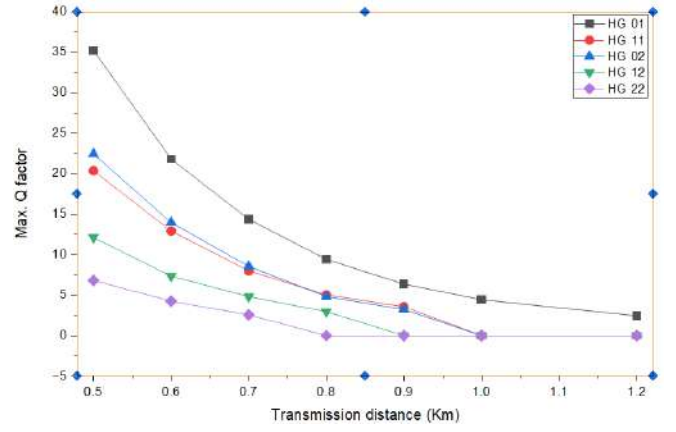


Fig 6: Max Q factor vs Transmission distance for 1D & 2 D modes with same Beam factor

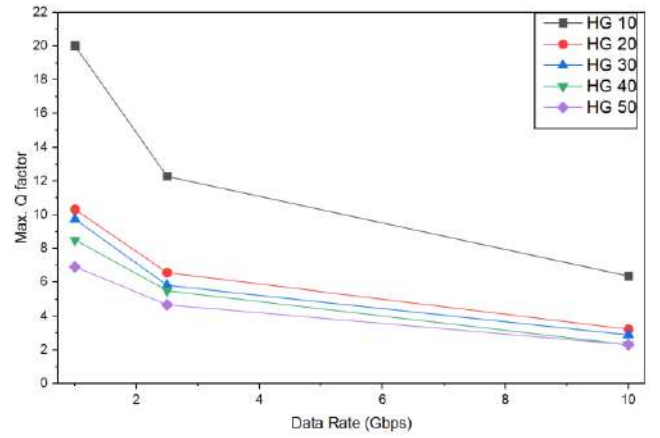


Fig. 7. Q factor performance of HG modes across varying transmitted Data rate

Fig 7 depicts the analysis of HG modes namely HG 0, HG 20, HG 30, HG40 and HG 50 for variable transmitted data rate (1, 2.5 & 10 Gbps) over a transmission distance of 900m over FSO communication channel. HG 10 shows high value of Q factor for all the data rate values as it shows greater beam factor value as compared to higher HG modes. The analysis shows that for low data rate values more modes can be multiplexed over FSO channel as compared to higher data rates.

III. CONCLUSION

In this work, the intensity profile of HG modes that depends on beam factor (M2 factor) of the modes is studied for ordinary HG modes. The analysis shows that beam propagation factor increases rapidly with increase in the mode value thus reducing the overall data transmission range over FSO system. For 1 dimensional HG modes the M2 factor is same thus they show similar behaviour for varying transmission distance. Beam propagation factor for 2 dimensional HG mode is also considered for simulation. The analysis shows that though 1D and 2D modes share same beam factor but they show different behaviour over varying transmission distance. Although as the mode value increases, a significant decrease in Q factor is observed that limits the use of more number of mode to be used for MDM FSO link. The simulation results also reveals that for lower data rate transmission more number of modes can be multiplexed using MDM over a single wavelength and a higher data rate

can be achieved. The research concludes that to use 1D ordinary HG modes with beam propagation factor that lies near the beam propagation factor of Gaussian beam ($M2 = 1$) gives better results for MDM based FSO communication link.

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Machine Learning-assisted Fiber Bragg Grating-based Throat Microphone for Speech Recognition

Rituparna Jana, Nithin V. George, Arup Lal Chakraborty

Electrical Engineering, Indian Institute of Technology Gandhinagar, Gandhinagar-382355, India

Fiber Bragg grating (FBG)-based throat microphones effectively suppress background noise [1], making them suitable for wearable automatic speech recognition (ASR) applications. However, the low-pass filtering effects of the throat tissue and bones attenuate high-frequency components essential for clarity and naturalness, reducing speech recognition accuracy. This paper employs a convolutional long short-term memory (ConvLSTM) network to improve the accuracy of throat microphone speech recognition. The throat microphone comprises a prestrained FBG with a center wavelength of 1529.9 nm. A 1530 nm discrete-mode tunable laser diode was used for intensity-based FBG interrogation. The vocal cord vibrations cause spectral shifts of the FBG's reflection spectrum that translate to intensity changes recorded by a photodetector [2]. The block diagram of the experimental setup for speech recording using the FBG-based throat microphone is shown in Fig. 1(a).

Four participants were asked to speak twenty command words, five times each. The throat microphone recorded the spoken words. The recorded speech signals were then processed by a high-pass filter with a 100 Hz cutoff frequency to remove system noise. Then, the speech data was augmented by time shifting to enhance the training set. Frequency domain features, Mel-spectrogram, and Mel frequency cepstral coefficients (MFCC), were extracted from the speech data. Fig. 1(b) illustrates the raw and filtered speech signal for the word “stop” captured by the FBG-based throat microphone, and its Mel-spectrogram and MFCC representations, respectively. All the features extracted from the dataset were used as input to our proposed ConvLSTM-based speech recognition model. The model then processed 5D inputs combining Mel-spectrogram and MFCC features to capture spatiotemporal patterns. It employs two ConvLSTM2D layers (32 and 64 filters) with leaky ReLU activation and batch normalization, followed by global average pooling and a 64-unit dense layer. A softmax output layer enables multi-class classification, optimized using Adam with sparse categorical crossentropy loss.

The confusion matrix shown in Fig. 1(c) summarizes the word classification accuracy, and the recognition accuracy reached 72%. We then compared our model's performance with the baseline convolutional neural network (CNN) and CNN with gated recurrent unit (GRU) hybrid models. The performance metrics of these models are shown in Fig. 1(d). A maximum accuracy of 72% and a precision of 75% were obtained using the ConvLSTM2D model. The ConvLSTM2D model outperformed baseline CNN and CNN-GRU models, highlighting its potential for robust ASR performance. The future work will focus on miniaturizing the microphone system and optimizing the model for faster, more accurate performance in noisy environments.

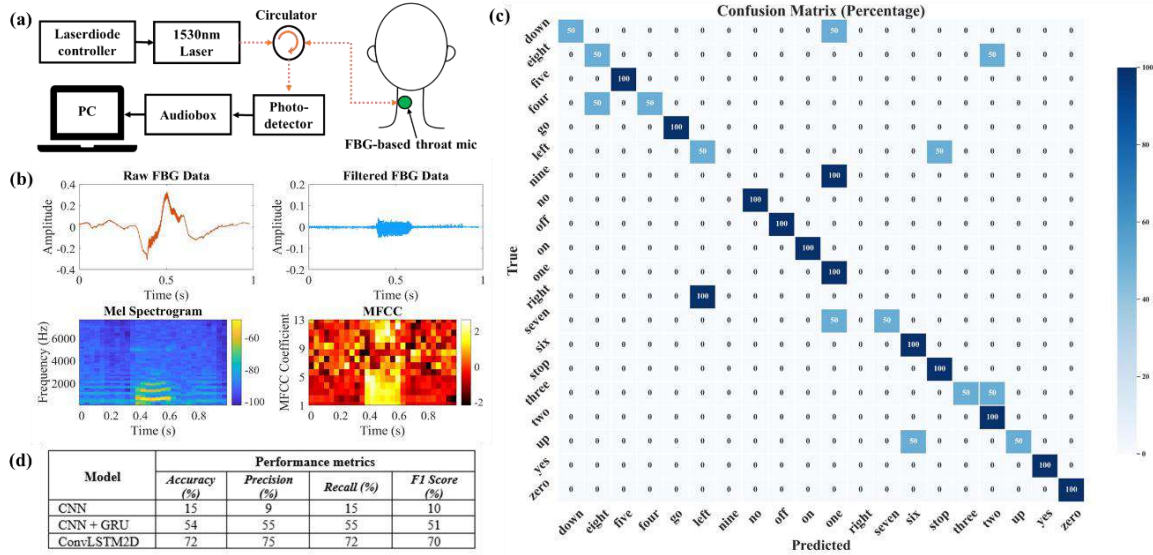


Fig. 1 (a) Block diagram of the experimental setup. (b) The raw and the filtered speech signal for the word “stop,” recorded by the FBG-based throat microphone and its Mel-spectrogram and MFCC. (c) Confusion matrix of the word classification task. (d) Performance metrics of the proposed ConvLSTM model compared with baseline CNN and CNN-GRU models.

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Quantum Spin Hall Topological Photonic System in the Visible Range for Robust Quantum Light–Matter Interfaces

Ekta¹, Abhishek kumar^{2*}, Anshuman kumar^{1*}

1. Laboratory of Optics of Quantum Materials, Indian Institute of Technology, Bombay, Mumbai, 400076, India

2 Ultrafast Terahertz Spectroscopy and Photonics lab, Jawaharlal Nehru Centre for

Advanced Scientific Research, Bengaluru, 560064, India

*Email : abhishekkumar@jncasr.ac.in, anshuman.kumar@iitb.ac.in

ABSTRACT

A visible-range spin Hall topological photonic system is demonstrated, supporting robust counterpropagating edge states at the interface of topologically distinct oxide- and nitride-based photonic crystals. By interfacing these edge states with single quantum emitters and 2D materials, chiral single-photon emission into opposite-propagating topological channels is achieved, with robustness confirmed against sharp bends. The structure is fabricated via electron beam lithography (EBL), and photoluminescence (PL) along with k -space measurements is performed to experimentally verify the presence of topological edge states. This disorder-immune light–matter interface provides inherent protection for integrated quantum optical circuits, offering promising pathways for quantum simulation and scalable quantum photonic devices.

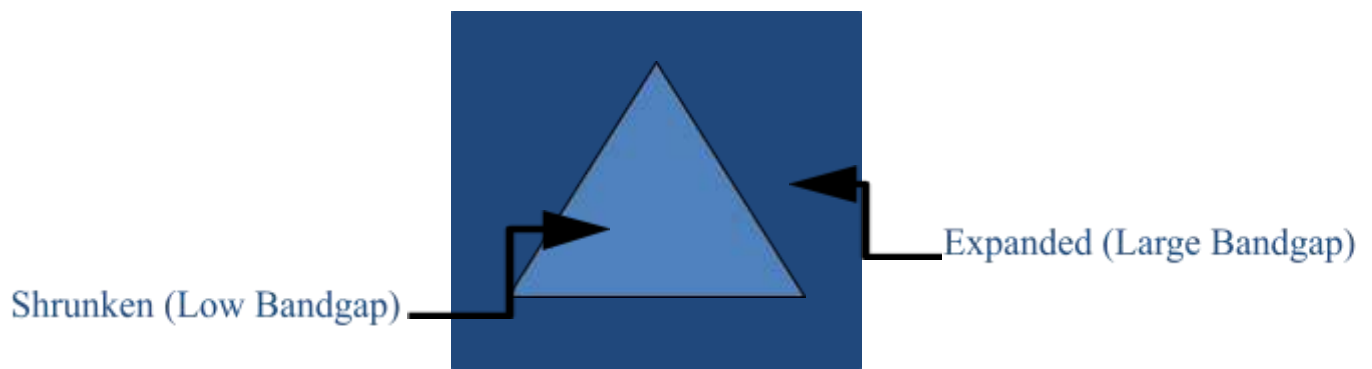


Fig1. Topological cavity

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Optical Design of Dyson Lens based Imaging LWIR Spectrometer for Remote Sensing Applications

Madhavi Thakre, Moumita Dutta, Amit Vikram Kurulkar, Senthil Kumar, S S Sarkar

Space Applications Centre (ISRO), Ahmedabad, Jodhpur Tekra, Gujrat, 380015

Abstract: This paper describes the optical design of Dyson imaging spectrometer operating in the long-wave infrared region of 7.7 – 11 micron with spectral resolution of 7-8 nm. An imaging optics was designed for 37.5 mm focal length, F/2 catering to field of view of 12 degrees. For practical implementations, optical configuration is worked out with sufficient clearance between slit and focal plane. Present configuration of Dyson spectrometer gives good image quality in terms of MTF and less distortion (smile and keystone).

Keywords: Dyson, spectrometer, LWIR, infrared, concave grating, imaging, MTF, distortion

Introduction: Imaging spectrometers are optical instruments which combine conventional imaging with spectroscopy to record the spectrum of every point in a scene. Past and future planned imaging spectrometer systems have successfully implemented the Offner design [1-2]. Although an excellent performer, for the TIR the Offner design would be relatively large and would require a bulky temperature controlled dewar and large power supplies to maintain adequate thermal control. J. Dyson published a paper in 1959 outlining a seidel corrected unit magnifier which was composed of a single lens and concave mirror [3]. Amongst the imaging spectrometers, Dyson configurations stand out for simple construction and high throughput. Due to this, recently some practical designs have been addressed for space-borne applications [4-5].

Optical Design and Technological Challenges

Dyson spectrometer comprises of an optical imaging system called fore optics which images the scene on a narrow slit located on the plane surface of a hemispherical lens, a concave diffraction grating and a two-dimensional detector located near the rear surface of the lens. The Dyson lens based hyperspectral imager was designed to meet focal length of 37.5mm, F/no 2, field of view of 12 deg and spectral dispersion of 6.48 mm to cover spectral range of 7.7 – 11 micron. The optical schematic of Dyson lens based imaging spectrometer is as shown in Figure 1(a) and obtained minimum design MTF is as shown in Figure 1(b).

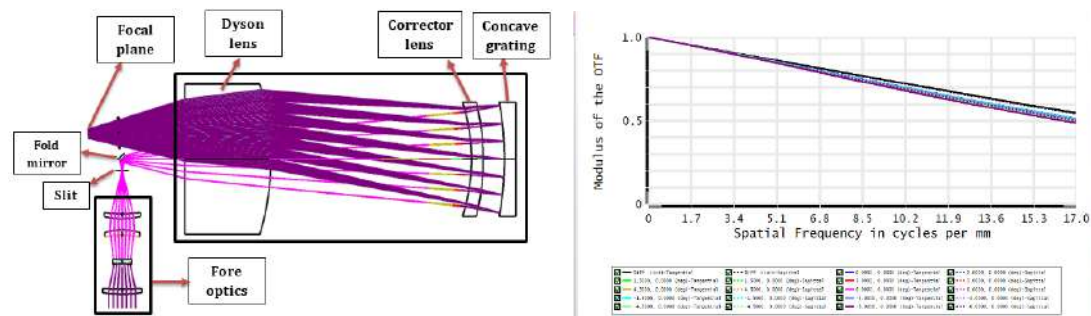


Fig 1 (a) Optical Schematic of Imaging Dyson Spectrometer (b) Minimum design MTF

Optical performance of the Dyson spectrometer is optimized and evaluated over defined wavelength range and slit length. Minimum 48% design MTF obtained over a full wavelength range at Nyquist frequency with distortion less than 0.5 pixel.

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Stochastic Modeling of Laser Speckles with Spatio-Temporal Correlations: A GPU-Based Approach

Anindita Chandra¹, Soumyajit Sarkar, Murali K., Susweta Das, Hari M. Varma

1. Department of Bio Science and Bio Engineering, Indian Institute of Technology Bombay, Maharashtra, India

Dynamic speckle imaging is a powerful tool for assessing microcirculation in biological tissues. One commonly used method for measuring surface blood flow is Laser Speckle Contrast Imaging (LSCI), which analyses intensity fluctuations under uniform illumination, probing depths up to ~ 1 mm. For deeper tissues, Diffuse Correlation Spectroscopy (DCS) uses focused laser light and varying source-detector separations to detect speckle fluctuations [1,2].

A robust model is essential to characterize intensity fluctuations, which in turn requires the simulation of dynamic speckle patterns. Existing methods-such as Fourier transforms of phase matrices and COPULA-based algorithms that have limitations in flexibility and realism [3,4]. In this context, we previously developed an SDE-based framework to simulate temporal speckle intensity fluctuations, which was validated through both simulations and in vivo experiments [5]. This is formulated as: $dI(t) = -\alpha(I(t) - \mu)dt + (2\alpha\mu I(t))^{1/2} dW(t)$, $I(0) = I_0$

where $I(t)$ denotes the speckle intensity at time t , μ is the mean intensity, α is a decay constant governing the rate of relaxation, and $W(t)$ represents a standard Wiener process. This formulation captures both deterministic relaxation toward the mean and stochastic fluctuations consistent with the desired intensity statistics.

We have further extended it to model spatial correlations, forming a unified spatiotemporal speckle simulation [6]. Spatial correlation is defined by $C = \exp(-Kd)$ where K is the decay constant and d is the pairwise distance matrix derived from pixel coordinates. The decay constant K is defined to match the speckle size (S_s) with the pixel size (P_s) using the Airy disc formula. We have computed K value at 20%, 50% and 90% decay thresholds.

Cholesky decomposition is applied to a theoretical correlation matrix to convert uncorrelated Gaussian samples into spatially correlated ones, which are then transformed into gamma-distributed images and used as initial conditions for the SDE.

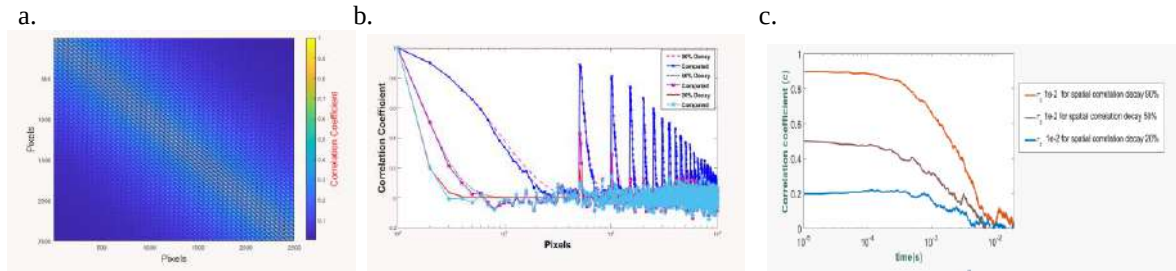


Fig. 1: a) The theoretical correlation matrix $C = \exp(-Kd)$ demonstrates that diagonal elements exhibit full correlation, while the correlation progressively decreases with increasing inter-pixel distance. b) Comparison between the theoretical correlation matrix C and the numerically simulated correlation shows good agreement, indicating consistency between the model and simulation. c) Spatial correlations CC corresponding to 20%, 50%, and 90% decay constants are plotted for a fixed flow condition with $\tau_c = 1 \times 10^{-2}$ s.

Simulations were performed using the Milstein scheme to numerically solve the stochastic equations on a high-performance computing system configured with 1 TB RAM, a 64-core CPU, and MATLAB 2022b. Leveraging parallel processing, we generated 500 realizations of spatio-temporal speckle data with dimensions $50 \times 50 \times 5000$, which took approximately 330 minutes. The spatial and temporal resolutions were limited by the substantial computational time required per realization.

To develop a more realistic and comprehensive model-incorporating denser temporal datasets and a larger region of interest (ROI), we are currently extending this framework using CUDA-based GPU computing. GPU acceleration has the potential to drastically reduce computation time, enabling high-resolution simulations with significantly more spatial pixels and time points. This enhancement will allow for the simulation of larger ROIs and longer temporal sequences, thereby improving the fidelity and applicability of the model for complex physiological scenarios.

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Controllable single-photon scattering via coupling of a driven Λ system with a topological waveguide

Gunjan Yadav, Madan Mohan Mahana, and Tarak Nath Dey

Department of Physics, Indian Institute of Technology Guwahati, North Guwahati, Assam 781039, India

Strong light-matter interactions and single-photon scattering are at the heart of many emerging technologies in quantum information science, including quantum computing, secure communication, quantum simulation, and advanced sensing [1,2]. Achieving efficient coupling between an emitter and a structured environment is crucial for realizing these applications. Over the past few decades, the coupling of emitters with cavity structures, linear waveguides, and photonic crystals, has been studied quite well. Among these waveguide quantum electrodynamics (QED) is promising for enhancing light-atom interactions by confining light to a single dimension. However, a key challenge in building practical quantum systems is maintaining robustness against imperfections and disorder. One promising approach is to combine topological concepts with quantum systems. This integration enables more advanced features, which are challenging to achieve in conventional systems. The interaction between a two-level quantum emitter and a topological waveguide has recently attracted significant attention, with experimental realizations demonstrated in superconducting circuits [3]. However, it cannot show controllability in single-photon scattering. Hence, we have used a three-level atom in Λ configuration, to get controllability in scattering.

Our proposed model consists of a topological waveguide coupled with a Λ system. The topological waveguide consists of alternating coupled resonators, A and B, where each pair (A and B) forms a unit cell, as shown in Fig. 1(b). These resonator interactions (intracell t_1 and intercell t_2) arise from evanescent-field coupling. By using the scattering formalism, we derive an expression of transmittance and study the single-photon transmission spectrum at different control field strengths. In the weak field regime of A and B sublattice-site configurations, a dip in the transmission spectrum is observed, centered at the atomic resonance frequency. At this frequency, the input photon is completely reflected. However, as the control field strength increases, an Electromagnetic Induced Transparency (EIT) emerges due to quantum interference of different pathways. Further increasing the control field strength widens the transparency window reaches the Autler-Townes Splitting (ATS) regime, as shown in Fig. 1(c). Thus, the transmission at the atomic resonance frequency can be switched from zero to one by tuning the control field strength. This tunability makes this configuration suitable for single-photon switching devices. In the AB sublattice-site configuration, the system can switch between trivial and nontrivial phases, depending on the sign of the dimerization constant. It leads to a topology-dependent transmission spectrum. In the weak-control field regime, we observe perfect reflection with a Lorentzian line shape at the Lamb-shifted frequency. As the control field strength increases, a Fano line shape appears and shifts to ATS at higher control field strength, as shown in Fig. 1(d). Notably, we observe that the Fano line shape is significantly sharper for the nontrivial case, which we refer to as a ‘‘Topological Fano line shape.’’ Due to the sharpness of the Fano line shape, even a slight change in detuning can shift the transmission from zero to one, which can enable high-speed switching with good efficiency. In this nontrivial phase, the system is robust against small disorders within the system. Different configurations of this model can yield various desired outcomes and can be experimentally realized in systems such as superconducting circuits and photonic crystal cavities.

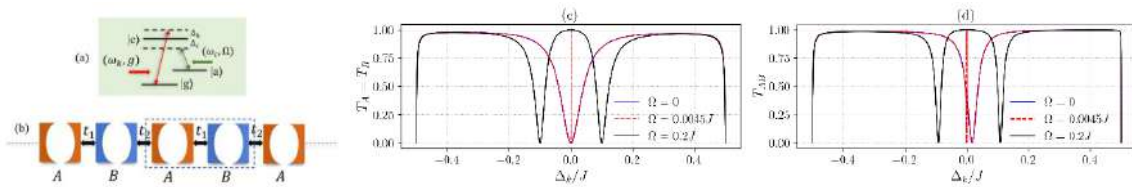


Fig. 1 (a) The three-level atom in Λ configuration. The transition $|g\rangle \rightarrow |e\rangle$ is coupled to the topological waveguide mode with coupling strength g (solid red line), while the transition $|a\rangle \rightarrow |e\rangle$ is driven by a classical control field of frequency ω_c and Rabi frequency Ω (green arrow). (b) Schematic of the topological waveguide composed of an array of coupled resonators labeled A (orange) and B (blue). The A and B sites together form a unit cell, highlighted with a dotted black box. The black double arrows indicate the intracell and intercell hopping amplitudes $t_1 = J(1 + \delta)$ and $t_2 = J(1 - \delta)$, respectively, where δ is the dimerization parameter and J is the characteristic energy scale (c) Transmission spectrum $T_A = |t_A|^2$, $T_B = |t_B|^2$, for the A and B sublattice-site coupling as a function of the incident photon detuning $\Delta_k/J = (\omega_k - \omega_e)/J$. The atomic transition frequency is set to $\omega_e = 1.5J$. (d) Transmission spectrum $T_{AB} = |t_{AB}|^2$ for the A and B sublattice-site coupling as a function of the incident photon detuning $\Delta_k/J = (\omega_k - \omega_e)/J$ for $\delta = -0.5$.

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Slotted Optical Nanofiber Integrated with External Grating for Cavity QED

Golak Bihari Bage¹, Subrat Sahu¹, and Rajan Jha^{1*}

¹Nanophotonics and Plasmonics Laboratory, School of Basic Sciences, IIT Bhubaneswar, Khurda 752050, Odisha, India

*Email: rjha@iitbbs.ac.in

Nano-waveguides have become the platform of choice for various contemporary research fields involving light-matter interaction, primarily in quantum photonics. Realization of a cavity structure on nano-waveguides is a crucial requirement to enhance the interaction strength and manifest cavity quantum electrodynamics (QED) effects [1-3]. In this prospect, optical nanofiber (ONF, a subwavelength diameter fiber) based cavities are promising candidates because of their ability to provide automatic coupling into single-mode fibers in the optical fiber network. The spontaneous emissions from a quantum emitter (QE) can be enhanced by introducing a cavity structure on the ONF, which facilitates longitudinal confinement and realization of cavity QED [1-2]. Furthermore, the ONF-based cavities can be readily integrated into existing optical fiber networks for efficient transmission of guided signals over long distances.

Here, we propose a slotted photonic crystal cavity (SPCC) structure on the ONF using external gratings for cavity QED. Figure 1(a) shows a schematic of the proposed device. Here, two different components, such as ONF and external grating, are integrated with each other. The structure has been designed assuming a QE emission wavelength around 640 nm and an optimized set of physical parameters using finite difference time domain (FDTD) simulations. Here, two sets of Bragg mirrors with a defect region are considered in the external grating, and a slot is corrugated in the middle of the ONF. Introducing the slot not only facilitates QE to be localized in the strongly intensified field but also significantly enhances the spontaneous emission rate of QE [2-3]. Here, the system is considered as a symmetric cavity structure, and hence the single photons coming out of it can efficiently couple into both sides of the ONF guided mode. Figure 1(b) shows the electric field distribution in the SPCC structure. A strong enhancement in electric field intensity can be observed inside the slot region, which can increase the spontaneous emission rate of the QE [2]. Further, single photon coupling characteristics can be seen from Fig. 1(c), which illustrates the variation of the coupling efficiency (η) from the QE into the ONF guided mode as a function of N . As can be seen, maximum $\eta \sim 85\%$ is achieved at $N = 100$, and after that it starts decreasing due to the grating losses. Thus, the presently designed SPCC structure with a single QE may open new possibilities in quantum information science [1-3].

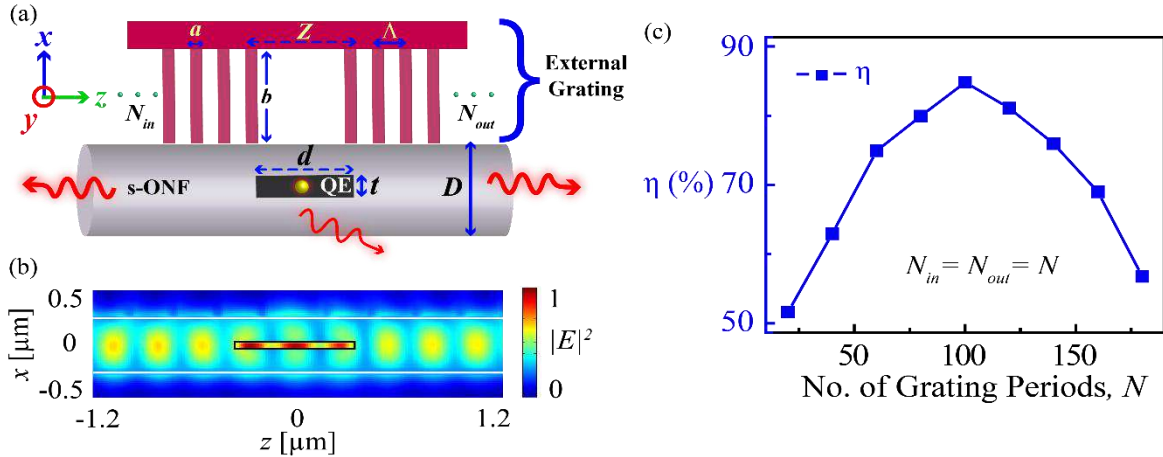


Fig. 1 (a) Conceptual Diagram of the SPCC structure on a ONF. Optimized dimensions of the system are, $a = 50$ nm, $Z = 378$ nm, $\Lambda = 252$ nm, $t = 10$ nm, $d = 600$ nm, $D = 510$ nm. N_{in} and N_{out} are grating periods on the input and output side respectively. Here, $N_{in} = N_{out} = N$. Yellow sphere in the slot denotes the QE. (b) Electric field (E -field) enhancement within slot region for the x-pol mode. Black (white) lines mark edges of the slot (ONF). (c) Variation of η with N .

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Neural Network Enabled Fiber Interferometers for Smart Roadways

Kalipada Chatterjee¹, Arvind Kumar Maurya², Rajan Jha²

¹Department of Electrical and Photonics Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark.

²Nanophotonics and Plasmonics Laboratory, Indian Institute of Technology Bhubaneswar, Odisha 752050, India

Introduction: Efficient management of vehicular flow in urban roadways has substantial impact on the overall development of a region[1]. Conventional weigh-in-motion (WIM) systems [2] are limited by their sensitivity, which compromises with the detection range of vehicle categories, and stability in harsh environments. To overcome such limitations, this work introduces a fiber modal interferometer based WIM system enabled by trained artificial neural networks for smart road traffic monitoring [3]. The sensitivity of the interferometer combinations fosters detection of multiple vehicle parameters across broad range, while the trained computational networks enable real time signal assessment and data mining. This system aims to establish digital traffic infrastructure for smart roadways.

Working Principle: The system comprises of inline fiber modal interferometers combined in a parallel arrangement with single input and output ports, as shown in figure 1(a). Each modal interferometer is fabricated by fusion-splicing a length of solid-core photonic crystal fiber (SCPCF) along a single-mode fiber channel, and then rigidly encapsulated in a metal casing [3]. The heterostructure fiber configuration causes excitation and superposition of SCPCF modes with finite phase difference, and the resultant interference pattern is sensitive to change in SCPCF length. The parallel arrangement is embedded in road layer perpendicular to traffic flow direction with fixed spatial separation (L). Each axle of a passing vehicle exerts strain on the pavement, deforming the embedded interferometers. The phase change due to interferometer deformation causes distinct shifts in the interference peak wavelength over time, that are recorded using a wavelength interrogator. The number of shifts for each passing vehicle is twice the number of axles separated by fixed wheelbase and have a temporal separation proportional to vehicle average speed. For real time average speed estimation from the temporal datasets, two independent artificial neural network (ANN) models were developed and trained. The first ANN predicts average vehicle speed from the time interval (t) between characteristic spectral shifts regardless of vehicle class. The second ANN predicts the wheelbase length (w) from the data and thus determines the relevant vehicle category. Both models were trained using over 2,000 processed time-series data for each vehicle class travelling at various speeds. The sequential model structure (Fig. 1(b)) employs ReLU activation, Adam optimization, and use mean absolute error or mean squared error as loss functions.

Results: Fig.1 (c) presents the comparison between predicted vehicle speed and wheelbase as compared to their actual values. The tolerance limit for speed prediction is 2 km/h and the model accuracy is >90% for different vehicle classes. The distinct spectral shift due to interferometer sensitivity helps effective training of the ANN models. On the other hand, the ANN models evaluate speed and wheelbase directly, without using any threshold levels of peak detection, which allows direct vehicle categorisation and provides scope for design customization. The system has stable performance over repeated vehicle crossings and works for broad vehicle classes, from bicycles to commuter bus. The system is highly suitable for integration with IoT platforms for live traffic analytics.

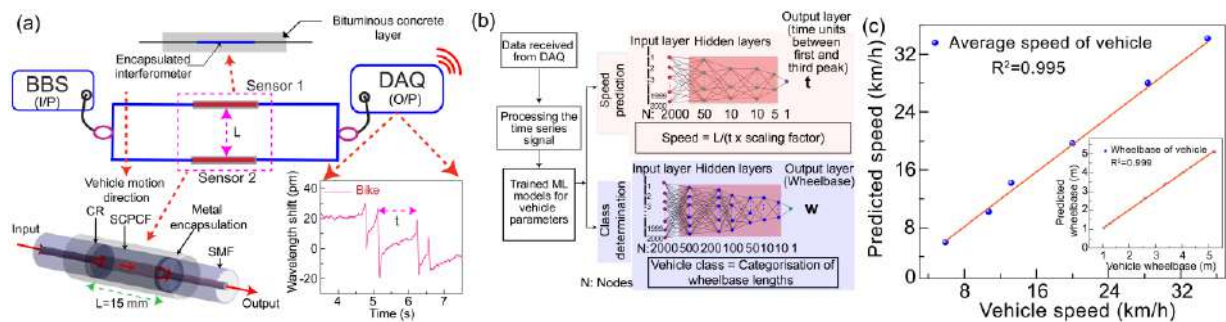


Fig. 1 (a) Experimental setup with embedded fiber interferometer in bituminous concrete layers. BBS: Broadband light source, DAQ: Data acquisition (inset) Representative time series signal recorded at the output. **(b)** Schematic representation of the developed trained ANN models for vehicle average speed and wheelbase prediction. **(c)** Comparison plot between ANN-predicted average vehicle speed and actual vehicle speed. (inset) Comparison plot between ANN-predicted vehicle wheelbase and the actual value.

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Characterization of nanosecond laser induced shockwave dynamics from the rear side of soda-lime glass

Subhankar Nanda *, Poulami Das, Satyaranjan Satyajit, Amitava Adak

Indian Institute of Technology (Indian School of Mines), Dhanbad

*Email: 22dr0333@iitism.ac.in

Intense pulsed laser-matter interaction has wide range of applications, including clean nanoparticle synthesis [1], thin-film deposition [2], Laser-Induced Breakdown Spectroscopy (LIBS) [4], micromachining [4], Laser-Induced shockwave [5,6]. Systematic study and optimization of Laser-Induced shockwave is essential for the efficacy of its applications. In this study we focused a pulsed Nd:YAG laser operating at 1064 nm, with pulse duration (FWHM) of 6 ns and a fluence of 95 J/mm² to the rear surface of 1 mm thick soda-lime glass in ambient conditions. The damage threshold of the soda-lime glass is very high for which shockwave formation is very sensitive to the focusing conditions of the pump laser. In our experimental conditions the pump beam achieves threshold fluence for soda-lime glass at the rear surface. The induced shockwave on the rear side of the sample was investigated using Pump-probe transmission technique. In our setup a focused continuous-wave (CW) diode laser at 405 nm was used in transverse geometry to probe the shockwave dynamics. Figure 1(a) shows the time-resolved probe transmission signal at several longitudinal distances from the rear side of interaction plane. Time ‘zero’ was defined at the arrival of the incident pump laser peak at the interaction plane (rear surface of the soda-lime target). As we probe farther from the sample the onset of perturbation in the probe signal shows temporal delay. This spatiotemporal variation shows the shockwave propagation dynamics. We analysed the shockwave behaviour and parameters like shockwave velocity (figure 1(b)). It shows the shockwave propagates in fast supersonic velocity which gradually slows down as we go farther from the rear side of the sample.

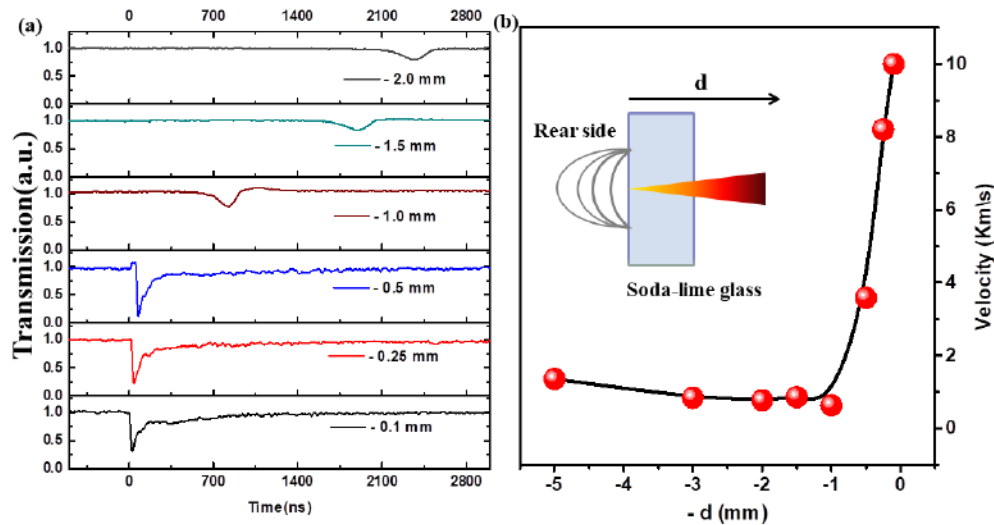


Fig. 1 (a) Transmission signal of probe at different spatial position from the rear-side of the sample representing the shockwave absorption. (b) The velocity of Shockwave w.r.t various probing distance. The inset shows schematic representation of shockwave propagation on rear side

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Physics-Aware Deep Learning Assisted Digital Inline Holographic Microscopy

Ritish Kamboj¹, Abhishek Verma¹, Chhavi¹, Aryesh Rai¹, Prashant Shukla¹, Satish Kumar Dubey¹

¹ Centre for Sensors Instrumentation and Cyber-Physical System Engineering (SeNSE),
Indian Institute of Technology Delhi, India

Digital Lensless Inline Holographic Microscopy (DLIHM) enables quantitative imaging by recording interference patterns that encode both amplitude and phase. It provides a large field of view, numerical refocusing capability, and a compact, low-cost system architecture, making it highly suitable for biomedical and point-of-care imaging applications [1-2]. However, phase recovery in DLIHM remains computationally intensive and parameter-sensitive, and the twin-image artifact poses additional challenges that motivate physics-aware learned reconstructions [6]. In this work, we propose a Physics-Assisted Neural Network (PANN) that unrolls a physics-based gradient descent solver into a compact sequence of iterations with learnable parameters [3]. The model learns optimal step sizes and regularization weights directly from paired training data comprising complex object fields and their corresponding holograms. Forward modelling is based on free space propagation of object field (X) using angular-spectrum. The resulting diffraction intensity I_z at object-sensor distances z as described as:

$$I_z = |P_z(X)|^2 + \eta \quad (1)$$

Where $P_z(\cdot)$ is propagation operator and η is measurement noise. The inverse problem is formulated as:

$$\hat{X} = \underset{X}{\operatorname{argmin}} \sum_{z_i} \|\sqrt{I_{z_i}} - |P_{z_i}X|\|^2 + \lambda TV(X) \quad (2)$$

Where λ is regularization weight of Total Variation regularization ($TV(X)$), which penalizes the spatial gradients of the complex field X to suppress noise and preserve structural edges. Equation (2) is typically solved iterative reconstruction method such as gradient descent (GD). The proposed PANN replaces fixed-step iterations with a learned descent update:

$$X^{(k+1)} = X^{(k)} - \alpha_k \cdot \nabla \left[\sum_{z_i} \|\sqrt{I_{z_i}} - |P_{z_i}X|\|^2 + \lambda_k TV(X) \right] \quad (3)$$

Here, both the step size α_k and regularization weight λ_k are learnable, iteration-specific parameters. The model is trained on simulated inline holograms generated from a dataset of natural images (sourced from Kaggle [7]). Simulations assume a pixel size of 1.85 μm , a wavelength of 535 nm, and $z \in \{1, 2, 3, 5, 10\}$ mm using training dataset of 250 images. Additive white Gaussian noise with a signal-to-noise ratio (SNR) of 30–35 dB is introduced to emulate realistic acquisition conditions and enhance robustness against measurement noise. On simulated data, the proposed PANN achieves high-quality amplitude reconstructions with as few as five unrolled iterations, whereas conventional GD typically requires over 100 iterations for comparable results. Learning both the step sizes and regularization weights [3] across iterations stabilizes convergence and effectively suppresses twin-image artifacts, as illustrated in Fig. 1. These results demonstrate that integrating holographic physics with learned optimization reduces computational cost by an order of magnitude without compromising reconstruction fidelity. The framework supports flexible configurations during both training and inference, including variable-resolution inputs and either single or multiple holograms acquired at different propagation distances. Future work will incorporate experimentally acquired training data to enhance applicability for imaging of real-world biological samples.

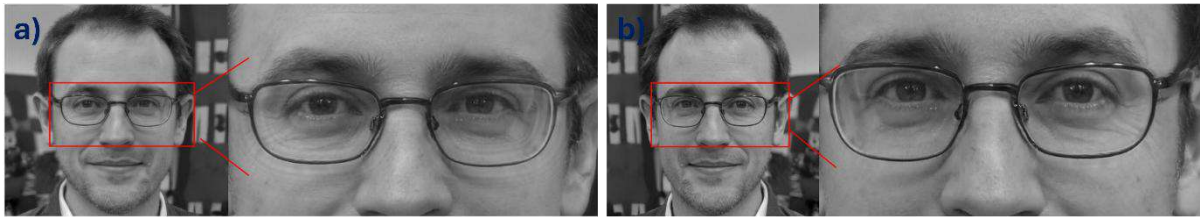


Figure 1 Comparison of reconstructed object amplitude using conventional gradient descent based iterative reconstruction (a) and Physics Assisted Neural Network based Reconstruction of Object Amplitude with learned step size (α_k) and TV regularization parameter lambda (λ_k) shown in (b).

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Effect of Thermal Deformation on Beam Quality in High-Power Laser Optics

Purva Sharnagat, Arpit Gupta, Deblina Sabui, Jasleen Lugani, Gufran S Khan

Centre of Sensors, Instrumentation and Cyber Physical System Engineering (SeNSE),
Indian Institute of Technology Delhi, Hauz Khas, New Delhi, 110016, India

Abstract: Thermo-optic effects in multilayer dielectric gratings under high-power laser irradiation cause significant wavefront distortion leading to beam quality degradation. The experimental validation facilitates predictive modeling essential for designing optical components for high-power laser applications.

Summary:

High-power laser systems are increasingly utilized in material processing, biomedical applications, and advanced scientific research, where efficient operation demands robust thermal stability of optical components[1]. Multilayer dielectric gratings (MDGs), commonly used in spectral beam combining, are subject to thermally induced deformations due to partial absorption of high-intensity laser radiation. This leads to temperature rise followed by structural expansion, thus causing rise in wavefront aberration, ultimately degrading beam quality and sometimes directionality[2]. In extreme cases, such effects may result in delamination, cracking or catastrophic failure of optical components. In this study, we present a comprehensive optical and thermal analysis of MDGs irradiated with a 1064 nm laser over a 30-second duration. The electromagnetic power absorption, reflection and transmission is evaluated using a frequency-domain wave optics simulation. The volumetric absorption losses are calculated and treated as a Gaussian heat source in the full-scale ($65 \times 65 \times 8$ mm³) finite element thermal model. Further, thermoelastic deformation is computed by coupling multiphysics simulations and its impact on beam quality is quantified using the second-moment method. Experimental measurements show a 2–3% deviation from simulated diffraction efficiency and temperature rise, validating the model. Figure 1(a) illustrate the multilayer dielectric grating structure under laser irradiation, alongside the computed electric field distribution (TM) and volumetric electromagnetic power loss within the grating. Figure 1(b) displays the thermally induced deformation profile due to laser-induced heating on the MDG surface, highlighting peak deformation buildup at the beam center, (c) compares the input and thermally distorted output beam intensities, highlighting the degradation due to phase distortion. Insets depict the Gaussian input beam and the phase error map due to deformed surface, indicating the impact of thermal loading on the output wavefront integrity. These results confirm that thermally induced phase distortions in MDGs significantly affect output beam parameters, emphasizing the need for predictive thermal-optical modelling in high-power laser Optics.

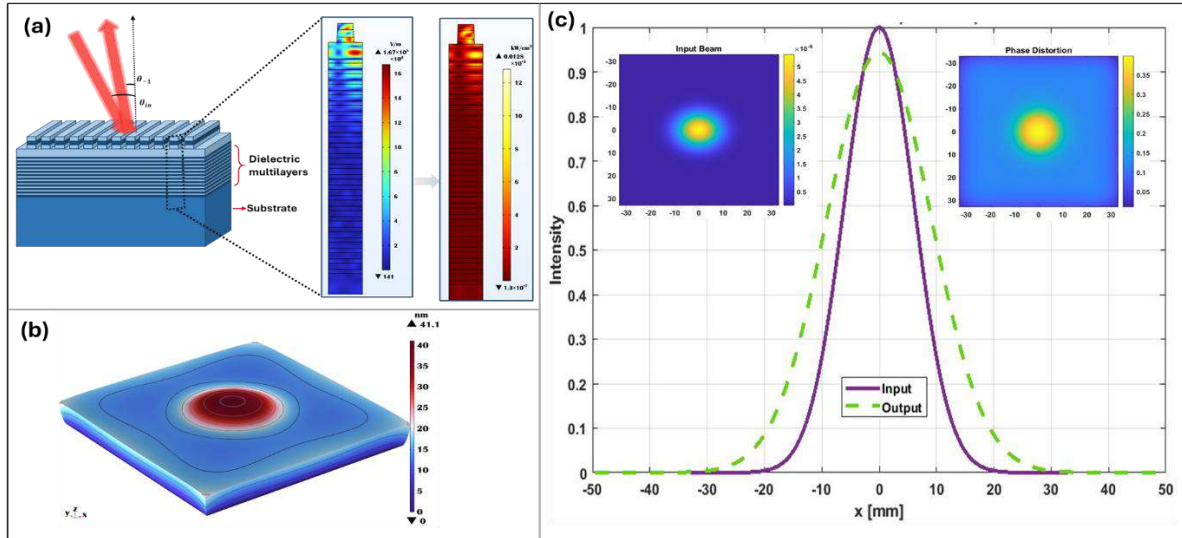


Figure 1: (a) MDG structure with $1\mu\text{m}$ periodicity bilayers of Ta_2O_5 and SiO_2 with electric fields and electromagnetic loss distribution in single grating element. (b) shows the thermally induced deformation (c) Shows the wavefront distortion and phase change due to induced deformations.

Conclusion: In the presented work, we provide thermal study and experimental validation of the performance of multilayer dielectric gratings. We found that thermal deformation is high in the irradiation area, resulting displacement of 41 nm under the given conditions. This deformation leads to a degradation of the far-field M^2 value of the beam, which decreases from 1.2 to 1.7. Such degradation compromises beam quality, sometimes directionality, and overall system performance in high-power laser systems. This analysis can further be expanded to include a wavelength-dependent study, providing insights for designing more thermally robust optical components for high-power laser applications such as spectral beam combining.

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Broadband Supercontinuum Generation in the 2 μm Region Using a Ultra-fast Thulium Fiber Laser

Shubhranil Maity^{1,2}, Debasis Pal¹, Abdul Malek Mallick¹, Prakruthi TK¹, Sourav Das Chowdhury¹, Atasi Pal^{1,3}

1. Fiber Optics & Photonics Division, CSIR-Central Glass and Ceramic Research Institute, Kolkata 700032, India

2. Department of Physics, Jadavpur University, Jadavpur, Kolkata 700032, India

3. Academy of Scientific & Innovative Research (AcSIR), Ghaziabad, Uttar Pradesh 201002, India

Broadband supercontinuum sources centred around 2 μm have garnered significant attention for their versatile applications. Their extended spectral coverage makes them ideal for advanced molecular spectroscopy, environmental sensing, biomedical imaging, stand-off detection, mid-infrared (mid-IR) LIDAR systems and defence technology, especially directional infrared countermeasure [1-2]. These sources enable precise detection and analysis across a broad range of absorption features in the mid-infrared region.

An ultrafast thulium-doped fiber laser has been developed using nonlinear polarization rotation (NPR) as the mode-locking mechanism. Core-pumping of the thulium-doped gain medium is achieved using a custom-built erbium-ytterbium co-doped fiber amplifier at 1550 nm. The mode-locked laser serves as the master oscillator in a master oscillator power amplifier (MOPA) configuration to achieve higher output power of 150 mW. The amplified ultrafast pulses are then launched into an ultra-high numerical aperture single-mode fiber (UHNA7, core dia./ clad. dia.: 2.4 μm / 125 μm , NA: 0.41) to generate a broadband supercontinuum. A schematic of the experimental setup is presented in Fig. 1(a).

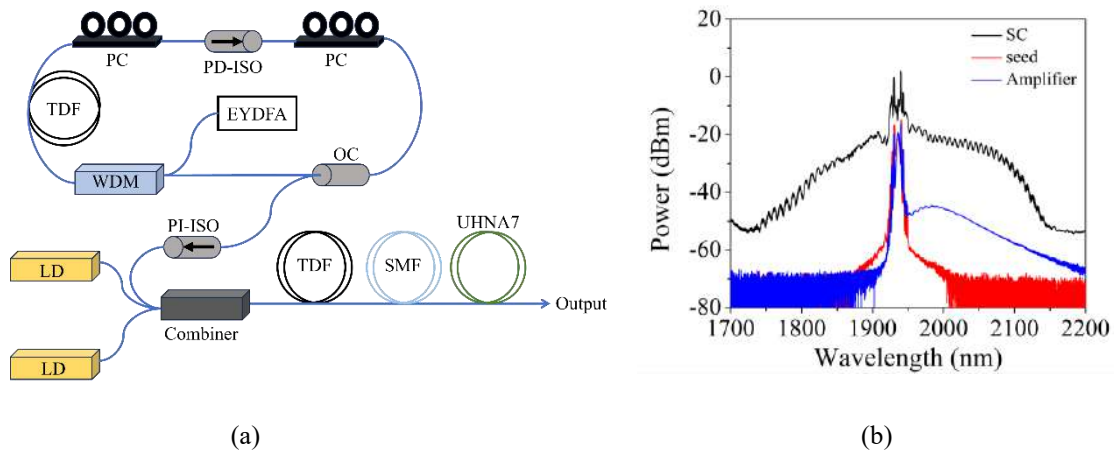


Fig. 1 (a) Schematic experimental setup of the supercontinuum generation, (b) Spectrum of ultra-fast mode-locked seed, amplifier and supercontinuum generation; EYDFA: Erbium Ytterbium Doped Fiber Amplifier, PC: Polarisation Controller, TDF: Thulium Doped Fiber, PD-ISO: Polarisation Dependent Isolator, OC: Output Coupler, PI-ISO: Polarisation Insensitive Isolator, LD: Laser Diode, SMF: Single Mode Fiber, UHNA7: Ultra-High NA single mode optical fiber

In the master oscillator (MO), the combination of two polarization controllers (PC) and polarization-dependent isolator (PD-ISO) act as the artificial saturable absorber by producing an intensity-dependent transmission to initiate and stabilize mode-locking. The MO operates in a net cavity dispersion of -1.18 ps^2 and produces pulses with a 13 MHz repetition rate centred at 1936 nm with a spectral width of 4.8 nm. The amplified ultra-fast laser, delivering an average output power of 150 mW with a gain of 21 dB and pulse width of sub ps range. This pulse train were launched into a 7-meter-long UHNA7 fiber, which provides strong nonlinear interactions within the fiber. Due to the ultra-high numerical aperture, the light remains tightly confined, enhancing the nonlinear effects such as self-phase modulation, soliton formation, and four-wave mixing occur in sequence, leading to the generation of a broadband supercontinuum, exhibiting a 30-dB spectral width of 265 nm in the wavelength range of 1832-2097 nm. The spectrum of seed laser, amplifier and broadband supercontinuum generation are shown in Fig 1(b). The observed spectral broadening is limited by the available pulse energy, and efforts are currently underway to further amplify the pulses and generate a broader spectrum, aiming to extend the system's performance for different applications.

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All optical exceptional line semimetals in hot atomic vapour

Arannya Ghosh¹, Soumik Nandi², Ashok K. Mohapatra² and Ritwick Das¹

1. Optics and Photonics Centre, Indian Institute of Technology Delhi, New Delhi, 110016, India

2. School of Physical Sciences, National Institute of Science Education and Research, Bhubaneswar, 752050, India

When a strong laser beam a_p is incident on a medium that possesses third-order nonlinearity (non-zero $\chi^{(3)}$), the perturbation in the medium creates two ansatz fields a_+ and a_- that co-propagate with the pump beam. The total refractive index is modulated by the pump intensity such that these two ansatz fields are coupled, and the propagation of the waves is characterized by the equation, which has a perfect resemblance to the Pauli-Schrodinger equation [1]. In the spatial frequency space, the Hamiltonian is

$$\tilde{H} = \begin{pmatrix} 4\pi^2 f^2 - 2\Gamma|\tilde{a}_p|^2 & -\Gamma\tilde{a}_p^2 e^{2i\Phi} \\ \Gamma\tilde{a}_p^{*2} e^{-2i\Phi} & -4\pi^2 f^2 + 2\Gamma|\tilde{a}_p|^2 \end{pmatrix}$$

where, $f^2 = f_x^2 + f_y^2$ and f_x, f_y are the spatial frequencies along the x and y directions. $\Gamma = \frac{3\chi^{(3)}\omega_p^2}{2k_p c^2}$, where ω_p and k_p are the frequency and wavevector of the pump beam respectively and the phase of the pump is $\Phi = \frac{\omega_p}{c} \int_0^z (n_0 + n_2 I_p) dz'$, where $n_2 \propto \chi^{(3)}$ is the nonlinear refractive index of the medium. It is worth noting that

$\tilde{H}$ exhibits non-Hermitian dynamics. The eigenvalues of $\tilde{H}$ are $\lambda_{\pm} = \pm \left((4\pi^2 f^2 - 2\Gamma|\tilde{a}_p|^2)^2 - \Gamma^2 |\tilde{a}_p|^4 \right)^{1/2}$.

For negative values of Γ , the eigenvalues are always real but for positive Γ , the eigenvalues could be complex which is a signature of PT-symmetric dynamics with biorthogonal eigenvectors.

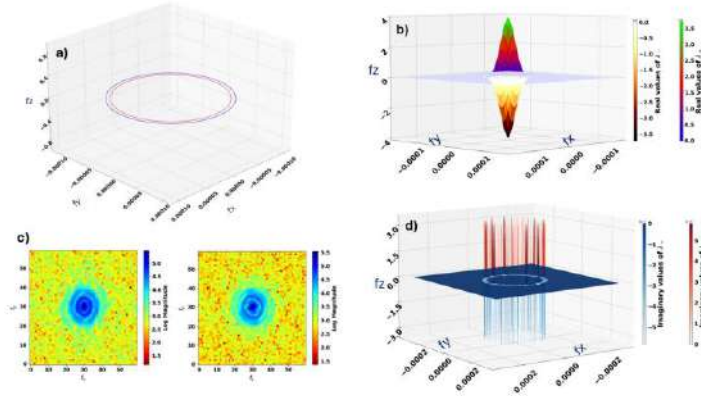


Fig. 1. (a) f_1^2 (red line) and f_2^2 (blue line) in $f_x - f_y$ space. (b) Real part of the eigenvalues. (c) FFT of the beam intensity at the output facet of the vapour cell. (d) Imaginary part of the eigenvalues.

The eigenvalue spectrum depicts that, for $f_1^2 = \frac{\Gamma|\tilde{a}_p|^2}{4\pi^2}$ and $f_2^2 = \frac{3\Gamma|\tilde{a}_p|^2}{4\pi^2}$, the eigenvalues coalesce and since, $f^2 = f_x^2 + f_y^2$ spans 2D-Fourier space, we obtain exceptional (spatial) equifrequency contours [see Fig.1(a)] [3]. The region enclosed by the exceptional equifrequency contours exhibit an imaginary eigenvalue spectrum depicting strongly attenuated modes. Figure 1 (b)-(d) represents mutually exclusive real and imaginary eigenvalue spectrum, where the band-degeneracy appears in the form of a nodal line with absence of any symmetry. The drumhead-like band structure in Fig. 1(a) is representative of a non-Hermitian dynamical interaction and this corresponds to an all-optical analogue of exceptional-line semimetals [2].

In order to verify our theoretical predictions, a continuous wave laser beam of $\lambda = 852 \text{ nm}$ is incident on thermal cesium (Cs) atomic vapor system. The excitation wavelength matches with the D_2 transition line of Cs. By maintaining a constant temperature of Cs vapour cell (105°C), we gradually increased the pump power from 40 mW to a maximum of 140 mW , while recording the transmitted beam structure at the output facet of the cell using a $4-f$ imaging configuration. The spatial frequency spectrum of the transmitted beam at pump power of 88 mW and 140 mW are shown in Fig. 1(c), where the bright regions represent the regions with real eigenvalues and the zero (null) intensity regions correspond to the imaginary eigenvalues, respectively.

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Effect of Light's Orbital Angular Momentum on Random Spin-Split Modes in Disordered Anisotropic Optical Media

Anwesha Panda¹, Sneha Dey², Yogishree Arabinda Panda³, Aditya Anurag Dash¹, Alope Jana⁴, Nirmalya Ghosh¹

1. Department of Physical Sciences, Indian Institute of Science Education and Research Kolkata, Mohanpur 741246, India

2. Department of Physics, Università degli Studi di Napoli Federico II, Via Cintia, 80126 Napoli, Italy

3. Cluster of Excellence Physics of Life, Dresden University of Technology, Dresden 01307, Germany

4. Department of Physics, Colorado School of Mines, 1500 Illinois St, Golden, CO 80401, United States of America

The spin-orbit interaction of light in a disordered anisotropic medium leads to the formation of spin-split modes in momentum space, driven by the random spatial variation of the light's geometric phase [1]. In this study, we analyze the statistical behavior of these spin-split modes for light beams carrying intrinsic orbital angular momentum by evaluating the momentum domain entropy and examining its dependence on different beam parameters. Specifically, we explore how the beam's spatial profile and phase vortex affect the mode statistics by using Laguerre–Gaussian and Perfect Vortex beams [2] transmitted through a disordered anisotropic medium. The input disorder was precisely controlled by modulating a liquid crystal-based spatial light modulator [3]. Our systematic investigations reveal that among the various beam parameters - beam waist, spot size, and topological charge - the spot size plays the most significant role in the generation of random spin-split modes.

Here, we present a figure with perfect vortex beam in spatial domain and in momentum domain (k-domain) with different disorder by changing the disorder parameter ϵ with different topological charges $l=3, 5, 7$.

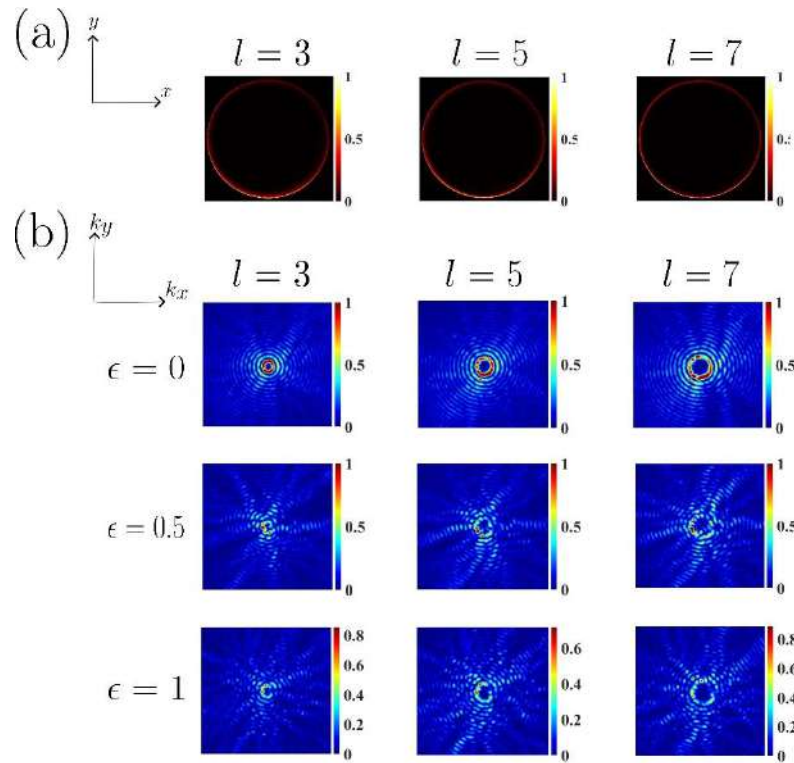


Fig. 1 (a) Input perfect vortex beam in the spatial domain where the spatial structure of the beam remains same for different topological charges $l = 3, 5, 7$. (b) The corresponding momentum space intensity distribution after the input perfect vortex beam with the $l = 3, 5, 7$ passes through inhomogeneous anisotropic media (projected in SLM) with disorder parameter ϵ values = 0, 0.5, 1.

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Geometry Driven Spin Polarization Effects in Waveguided Plasmonic Crystals

Suman Mandal^{1,*}, Nishkarsh Kumar², Sujit Rajak¹, Shyamal Guchhait³, A. Vaidyam¹, Nirmalya Ghosh¹

¹Department of Physical Sciences, Indian Institute of Science Education and Research Kolkata, Mohanpur, India, 741246

²Indian Institute of Technology Kanpur, Department of Physics, Kanpur, Kanpur, India

³Department of Bioengineering, University of Washington, Seattle, WA, USA

email—*sm22rs100@iiserkol.ac.in

We have recently reported Forward and Inverse Spin Hall effects of light in waveguided plasmonic crystal (WPC) systems [1]. In this study, we have investigated the origin of such effects by carrying out numerical simulations of polarization-dependent scattering effects in the WPC system using Finite Element Method (FEM) based modelling using COMSOL [2]. Specifically, we have investigated the polarization response of the WPCs by constructing and analysing Mueller matrices over the entire visible spectral region (400-800 nm) for different incidence geometry as presented in Figure 1 below. The results demonstrated emergence of circular diattenuation and circular polarizance effects in the WPC despite the absence of any intrinsic chirality in the WPC system. These rather intriguing circular anisotropy effects are shown to have geometrical origin, which are at the heart of Spin Hall effect of light in such systems [3].

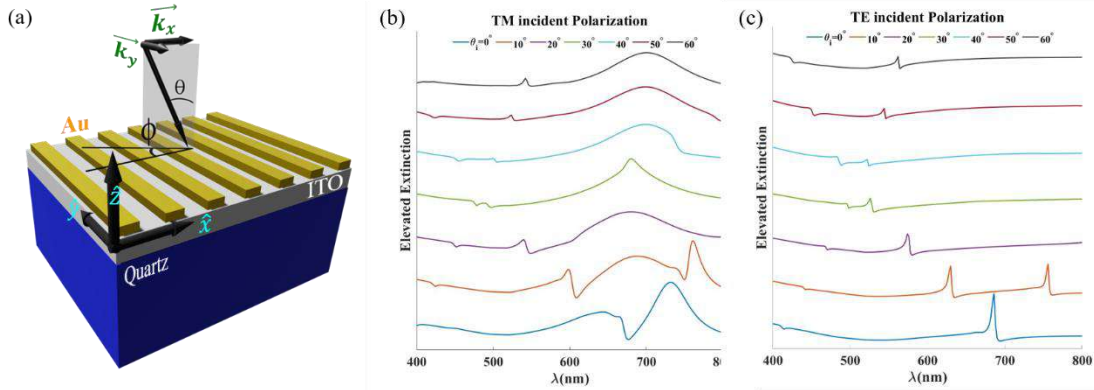


Fig. (a) Schematic illustration of the WPC geometry. The width and the height of the gold (Au) gratings are 100 nm and 20 nm, respectively, and the thickness of the underlying ITO layer is 140 nm. (b) and (c): The extinction spectra from the WPC for varying angle of incidence (changed from 0° to 60° in step of 10°) for incident TM polarization (b) and TE- polarization (c) are shown for wavelength region 400-800 nm. Incident angle has been.

The constructed Mueller matrices, for varying incidence angle θ (for azimuthal angle $\phi = 0$) demonstrated prominent linear diattenuation and linear retardance effects at wavelengths corresponding to the peak of the resonances (hybridized plasmon and waveguide resonances in the WPC) and at intermediate spectral regions respectively. The circular polarization anisotropy effects were however found to be absent for angle of incidences with $\phi = 0$. Interestingly, under non-zero azimuthal (at $\phi \neq 0$) angle of illumination, prominent circular anisotropy effects emerged which were quantified using M_{14} and M_{41} Mueller matrix elements that represent circular diattenuation and circular polarizance effects, respectively. Moreover, the corresponding Mueller matrices exhibited a clear lack in the symmetry of the off-diagonal elements unlike conventional linear diattenuator ($M_{12} \neq M_{21}$, $M_{13} \neq M_{31}$) or linear retarder ($M_{24} \neq M_{42}$, $M_{34} \neq M_{43}$) or linear diattenuating retarder system. The emergence of the intriguing circular anisotropy effects from the non-chiral WPC system is interpreted as a “geometric” LB-LD (sequential linear birefringence- linear diattenuation [4]) effect which purely arises from the geometry of the polarized illumination in our system. This “geometric” LB-LD effect is further shown to be responsible for the previously observed Forward and Inverse Spin Hall effects of light in the WPCs. The details of these results and the Mueller matrix analysis will be presented.

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Redesigned Optical setup and Monitoring System for the continuous operation of the Primary Frequency Standard

Anjali Bisht^{1,2}, Manoj Das^{1,2}, Amitava Sen Gupta^{1,3} and Poonam Arora^{1,2}

¹CSIR-National Physical Laboratory, New Delhi, India

²Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, India

³The North Cap University, Gurugram, Haryana, India

The NPLI-CsF1 is an approved Primary frequency standard developed in India and has contributed to TAI.

The operation of the cesium fountain clock is a sequential process involving laser cooling, trapping, launching and detection of the cesium-133 atoms – with the optical system being one of the most critical and complex subsystems. In order to improve the signal-to-noise ratio (S/N), enhance long-term reliability, and enable continuous operation to meet the requirement of at least 10-day (24/7) runs for contributing to International Atomic Time (TAI) with minimal downtime, we have implemented a comprehensive redesign of the lasers and optics setup [1-3].

The external cavity diode laser has been upgraded with a high-power (2 W) tapered amplifier (TA) system. The amplified output is coupled into polarization-maintaining fibers to achieve an improved beam profile, resulting in enhanced AOM efficiency. Frequency shifters in the detection path have been removed to reduce losses and improve stability. Simultaneous wavelength monitoring of the two lasers is carried out using a wavelength meter connected to an optical switch, and frequency stabilization is implemented through both saturated absorption spectroscopy (SAS) and analog PID locking using the wavelength meter. To support real-time diagnostics and enable fast recovery, monitor photodiodes have been strategically placed at several critical points in the optical path. A 16-channel data logger has been indigenously developed to continuously monitor the powers of six cooling beams, two detection beams, and all monitor photodiodes. In addition, frequency stabilization of the lasers has been implemented, as laser unlocking is one of the major contributors to operational interruptions. Ongoing challenges with polarization fluctuations in the detection beams are being addressed by introducing a 50:50 beam splitter that enables simultaneous seeding of the TA and direct derivation of detection beams from the diode laser output, thereby enhancing their polarization and power stability. We are in the process of integrating liquid crystal electro-optic (EO) modulators to suppress intensity noise in linearly polarized light and to enable active power stabilization of the detection beams. This paper presents the first performance results of the NPLI-CsF1 clock with these optical system upgrades and monitoring enhancements, demonstrating significant improvements in system's robustness and reliability.



Fig. 1: The present optical setup for the reliable operation of NPLI-CsF1

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Morphological and Optical Properties of Au-Ag Bimetallic Nanoparticles Synthesized Under Different Experimental Conditions

Palak*, and Venkata Ramanaiah Dantham

Department of Physics, Indian Institute of Technology Patna, Patna, Bihar 801106, India

**Presenting author: gargpalak1313@gmail.com*

Nanoplasmonics is an emerging and rapidly evolving branch of nanophotonics that delves into the unique optical behaviors exhibited by metallic nanostructures at the nanoscale [1]. This field focuses on the interaction between light and the collective oscillations of conduction electrons, known as plasmons, mainly within noble metals such as Au and Ag nanoparticles [2]. A related phenomenon, known as localized surface plasmon resonance (LSPR), occurs in individual metallic nanoparticles [3]. The LSPR wavelength of any metal nanoparticle strongly depends upon the size, shape, and the electric permittivity of the nanoparticle and the electric permittivity of the surrounding medium. It also depends upon the orientation of the nanoparticle with respect to the polarization of the incident light in the case of asymmetric structures. The LSPR-based systems are found useful in various applications such as surface-enhanced Raman scattering and fluorescence, biosensing, non-linear optics, optical tweezers, etc.

Recently, Au-Ag bimetallic nanoparticles have attracted the researchers' attention due to their unique optical properties. These nanoparticles provide an additional degree of freedom for tuning the LSPR wavelength (by changing the ratio of the two metals) as compared with monometallic nanoparticles. In addition, these bimetallic nanoparticles are more stable than pure Ag nanoparticles, and the electric field enhancement at their hot spots is higher than that of pure Au nanoparticles. However, Ag is a more effective plasmonic material as compared to Au; Au is more chemically stable than Ag. Thus, bimetallic Au-Ag nanoparticles possess the best plasmonic and chemical properties [4].

A few years ago, our research group experimentally proved that the prolate spheroid-shaped Au-Ag bimetallic nanoparticles were efficient for the single molecule surface enhanced Raman scattering (SERS) technique [5, 6]. The SERS detection limit was brought down to femtomolar (fM). The bimetallic nanoparticles, which were used for these experiments, were synthesized using a wet chemistry method. However, the role of experimental conditions such as reaction time, temperature, and Au-Ag ratio on the morphological and optical properties of the nanoparticles has not been explored so far. Therefore, herein, we report the synthesis of bimetallic nanoparticles using different experimental conditions. More importantly, the role of the above-mentioned experimental conditions on the morphological and optical properties of Au-Ag bimetallic nanoparticles is reported here. The morphological properties of these nanoparticles are studied using a field emission scanning electron microscope (FE-SEM) and transmission electron microscope (TEM). On the other hand, the optical properties of these nanoparticles are studied using a UV-Visible absorption spectrometer and a dark-field optical microscope in transmission mode. We strongly believe that the experimental results and observations reported here will help the research community to improve the signal-to-noise ratio (S/N) of SERS signals of single molecules significantly.

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Optical Design of a wide field-of view lens assembly system for camouflage detection from a drone based platform

Agnija Dutta Gupta¹, Rajarshee Roy¹, Kanik Palodhi¹

1. Department of Applied Optics and Photonics, University of Calcutta, JD-2, Sector-III, Salt Lake City, Kolkata-700106, India
Email: kpaop@caluniv.ac.in

Abstract:

Wide field-of-view (FOV) lens assembly system is designed in the multi-configurations of infrared spectrum to detect camouflage based hazard, being mounted on a drone system. The system has a maximum field-of-view $\pm 90^\circ$ with effective focal length of 3.3mm and F# 3.0. The designed is so optimised for MTF of 40% at higher frequency of the Nyquist frequency.

Keywords: Wide FOV, multi-configuration, Nyquist Frequency

A wide FOV lens assembly system can be mounted on a drone based platform to image the surroundings with infrared (IR) spectrum to detect camouflage. This lens assembly system, was designed in optical design software (Ansys OpticStudio) in multi-configuration setup with lens whose dispersion properties were calculated using the Conrady formula as given in the equation:

$$n = n_0 + \frac{A}{\lambda} + \frac{B}{\lambda^{3.5}}$$

(Where, λ is the wavelength, n is the refractive index at λ ; and n_0 , A and B are variables)

The system has a field-of-view $\pm 90^\circ$ with an effective focal length of ~ 3.3 mm with F# 3.0 in the three IR bands, which are short-wave infrared (SWIR: 1.4-3.0 μ m); mid-wave infrared (MWIR: 3.0-5.0 μ m); and long-wave infrared (LWIR: 8.0-14.0 μ m). Ray aiming method was used to determine the ray propagation directions of the off-axial fields. The system performance was made such that the spot size is within the airy disc radius for all the fields for all the configurations.

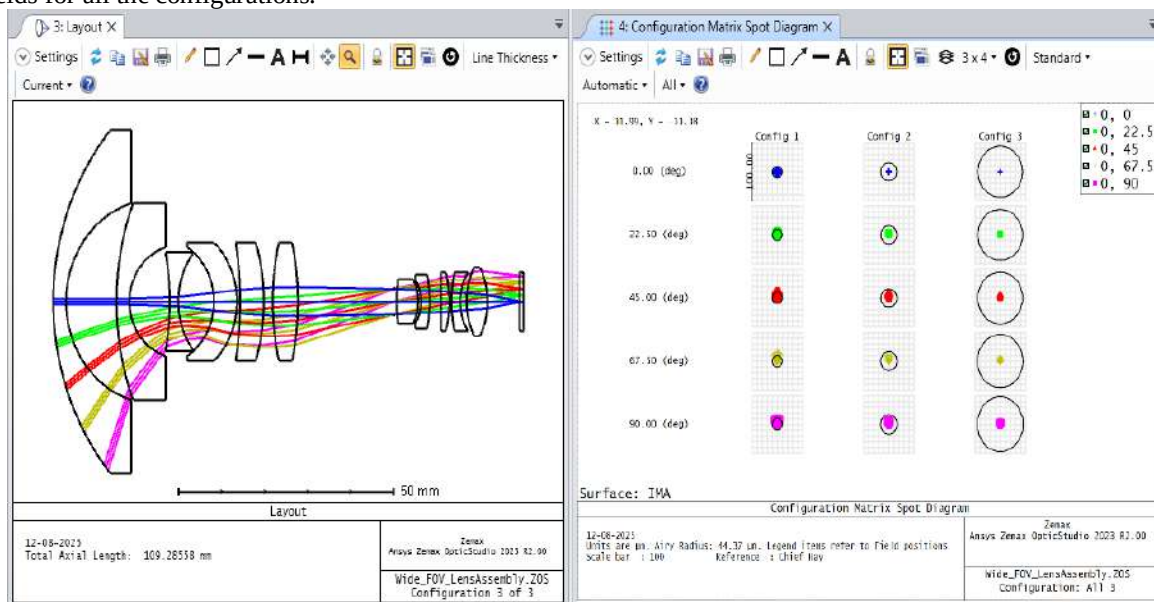


Fig. 1: The optical design of the lens assembly and the spot diagram of the different fields of the system

The design is optimised so that the MTF of 40% is achieved at higher frequency of the Nyquist frequency, for all the configurations.

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Optical Clock without a Frequency Comb using Dual Interferometry

Sreeshna Subhash, and Sankar Davuluri*

Department of Physics, Birla Institute of Technology and Science, Pilani, Hyderabad Campus,
Jawahar Nagar, Kapra Mandal, Medchal District, Telangana 500078, India

*sankar@hyderabad.bits-pilani.ac.in

An optical atomic clock (OAC) [1, 2] operating at 357 K temperature is designed using four-wave mixing in alkali metal vapor. Unlike existing OAC designs, this approach utilizes two Mach-Zehnder interferometers with an atomic vapor cell in one of its arms to calibrate two laser frequencies simultaneously. These two frequency-stabilized lasers are mixed to generate a radio-frequency beat signal for a portable OAC [3] without a frequency comb. Using the D2 transition of ^{87}Rb , the standard quantum-limited frequency sensitivity and stability of the OAC are calculated to be $3.2 \sqrt{\text{Hz}}$ and $1.3 \times 10^{-15} \sqrt{\text{Hz}^{-1}}$, respectively. A double-lambda atomic system with co-propagating laser fields are used to reduce the Doppler broadening effect. When the Doppler broadening at 357 K and atomic collisions are included, the OAC stability decreases to $3.3 \times 10^{-15} \sqrt{\text{Hz}^{-1}}$, for a laser linewidth of 1 kHz and an input power of 0.54 mW at the vapor cell. The stability as a function of temperature shows that it remains of the same order within the 352 to 362 K temperature range, demonstrating strong robustness against thermal variations, which is beneficial for achieving long-term OAC stability. The effects of laser phase noise shows that, the stability of the OAC reduces from $2.2 \times 10^{-15} \sqrt{\text{Hz}^{-1}}$ to $3.3 \times 10^{-15} \sqrt{\text{Hz}^{-1}}$ as the laser linewidth changes from 10 Hz to 10^3 Hz at a temperature of 357 K. Lasers with 10^3 Hz linewidth are commercially available. Since this OAC is based on a Mach-Zehnder interferometer, it allows well-established quantum optical interferometry techniques to surpass the standard quantum limit. This opens the possibility of developing a non-classical OAC at room temperature.

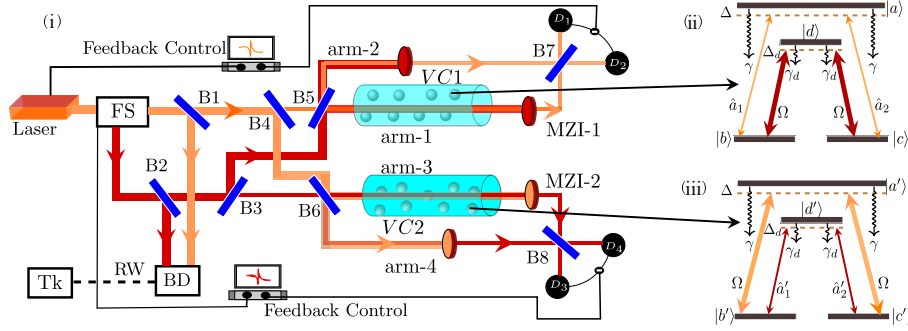


Figure 1: The schematic shows vapor cells (cyan cylinder) containing ^{87}Rb atoms in a double lambda configuration, as illustrated in diagrams (i) and (ii). Components include: FS (frequency shifter), BD (heterodyne beat detector), B_i ($i = 1, 2, \dots, 8$) (50:50 beam-splitters), Tk (timekeeping unit), D_i ($i = 1, 2, 3, 4$) (photodetectors), RW (radio wave), red/orange ellipse: drive field frequency filters, and MZI (Mach-Zehnder interferometer). In (ii) and (iii) the energy levels are $|j\rangle$, $j = a, b, c, d, a', b', c', d'$. Transitions $|b\rangle \leftrightarrow |c\rangle$, $|a\rangle \leftrightarrow |d\rangle$, $|b'\rangle \leftrightarrow |c'\rangle$, and $|a'\rangle \leftrightarrow |d'\rangle$ are dipole-forbidden. The population decay rate of $|d\rangle$ to $|b\rangle$, $|d\rangle$ to $|c\rangle$, $|d'\rangle$ to $|b'\rangle$, and $|d'\rangle$ to $|c'\rangle$ is γ_d , and the population decay rate of $|a\rangle$ to $|b\rangle$, $|a\rangle$ to $|c\rangle$, $|a'\rangle$ to $|b'\rangle$ and $|a'\rangle$ to $|c'\rangle$ is γ . Classical fields with orthogonal polarization and equal Rabi frequency Ω drive transitions as shown in (ii) and (iii). $|b\rangle \leftrightarrow |a\rangle$ and $|c\rangle \leftrightarrow |a\rangle$ in (ii) and $|b'\rangle \leftrightarrow |d'\rangle$ and $|c'\rangle \leftrightarrow |d'\rangle$ in (iii) are coupled by weak quantum fields represented by the annihilation operators $\hat{a}_1$, and $\hat{a}_2$ in (ii), $\hat{a}'_1$, and $\hat{a}'_2$ in (iii), respectively. Whenever the laser frequencies are detuned from the atomic resonance frequencies, a non-zero phase is added to the output field from the atomic scheme. This additional phase shifts the interference fringes, which is used as feedback.

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Quantum optical and spin properties of NV center in diamond for computing and sensing

Ashish Redhu, Rajesh V. Nair*

Laboratory for Nano-scale Optics and Meta-materials (LaNOM), Department of Physics,

Indian Institute of Technology Ropar, Rupnagar, Punjab 140001, India

**email address: rvnair@iitrpr.ac.in*

The nitrogen-vacancy (NV) centers have gained significant attention for their potential in advanced quantum applications [1, 2]. Due to non-zero spin in the ground state, it can act as a qubit that can be both optically manipulated and addressable [3-5]. The ability to perform all-optical initialization and readout distinguishes NV center from other solid state quantum emitters. Here, we discuss optical and spin properties of NV centers in bulk diamonds that evolve with varying charge state ratios. We show that NV charge state ratio strongly correlates with zero-phonon line (ZPL) intensity of NV^- , which is supported by an emission dip at 2.87 GHz. Figure 1(a) shows the intensity-intensity correlation curve for an ensemble of NV centers within the excitation volume, indicating multi-emitter behavior. The ensemble of NVs is useful for high-sensitivity quantum sensing applications requiring strong, stable optical signals. The correlation curve demonstrating antibunching, confirming the presence of a single NV center, crucial for quantum information applications, is presented in Fig 1(b).

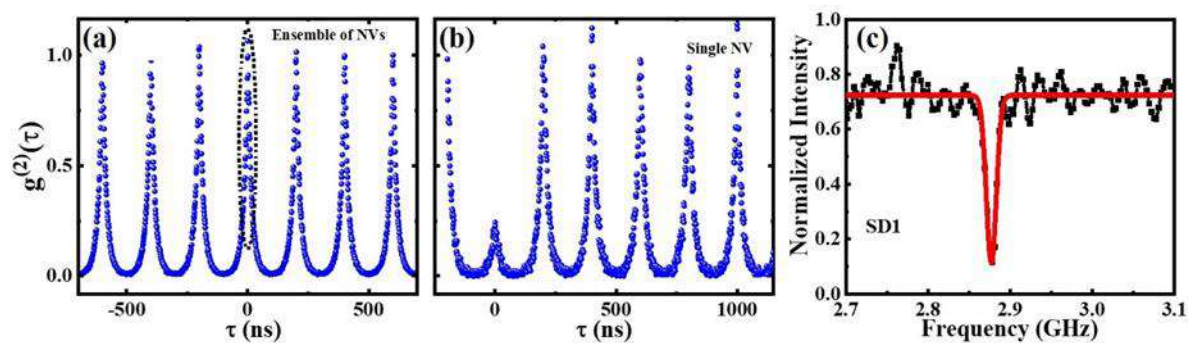


Figure 1. Intensity-intensity correlation curve (a) for an ensemble of emitters and (b) that for a single NV center. (c) Spectra present the optical readout of spin states.

Our results also show that the Debye-Waller (DW) factor of NV centers depends on the charge state ratio, and it increases for NV^- with an increase in charge state ratio. A high DW factor ensures coherent, transform-limited photons, ideal for interference-based operations like entanglement swapping. Figure 1(c) shows the spin-dependent optical readout with a dip at 2.87 GHz corresponds to a spin-flip transition in the NV^- ground state, a key feature for quantum sensing and computing. The excited state lifetime of NV^0 remains constant, whereas NV^- lifetime decreases with an increase in charge state ratio, with an overall decrease of 37%.

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Omnidirectional frequency gap in nanophotonic structures with short-range spatial correlations

Mohd Aleem and Rajesh V. Nair*

Laboratory for Nano-scale Optics and Meta-materials (LaNOM),

Department of Physics, Indian Institute of Technology Ropar, Rupnagar, Punjab 140001, India

*Email: - rvnair@iitropar.ac.in

Light transport in nanophotonic structures with disorder is an exciting area due to its relevance in controlled light scattering, lasing, and localization. Addition of short-range correlation in disordered nanophotonic structures can unveil new phenomena like photonic band gap, stealth nature, and easy access to Anderson localization regime. Herein, we discuss the light transport in nanophotonic structures with short-range spatial correlations in the visible wavelength range. In such media, the structure factor peak corresponds to measured, simulated, and analytical frequency gaps, implying an inherent short-range order in the structure. The measured reflectivity peak remains consistent with variation in the incident angles and wave polarizations, implying an omnidirectional frequency gap. The transmission for different samples of variable thickness has been measured to study the effect of thickness on the frequency gap and to observe a feasible diffusive transition. It is found that photon localization behavior occurs at the gap with fast decay of light transport, as compared to the diffusive transport in the long-wavelength limit. The numerical simulation results of ordered and correlated disorder align well with measurements. Our results reveal the existence of omnidirectional frequency gap with reduced density of optical states with applications in communications, lasers, and emission control.

keywords: - Correlated disorder, Omnidirectionality, Local density of states.

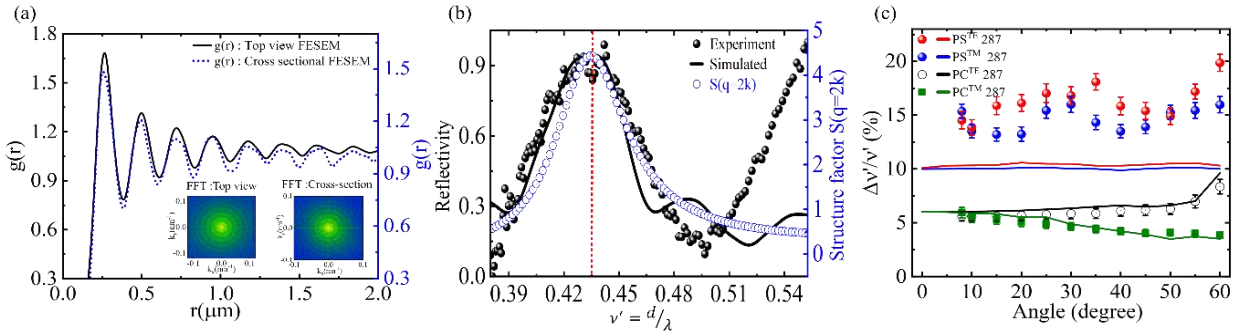


Figure: (a) The calculated pair correlation function $g(r)$ using the SEM images confirms the short-range order up to $2 \mu\text{m}$. (Inset) The concentric rings obtained from the FFT of the image confirm the isotropic nature there is evidence of short-range ordering in the depth of the sample. (b) Measured (black solid circle) and simulated (black solid line) show reflectivity peak at $\nu' = 0.435$ in agreement with analytically calculated frequency gap (vertical dotted line) and optimized structure factor (open blue circle). (c) The optimum fractional bandgap width as a function of angles of incidence. The width variation in photonic crystal samples (black circle and green square). The gap width remains the same in structures with short-range correlation (red and blue solid circle). Similarly, the simulated fractional width variation in photonic crystal (solid black and green line) and width is almost constant in structures with short-range correlation (solid red and black line) for TE and TM waves.

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Deep Learning-Enabled High-Dimensional OAM Mode Recognition in Standard Multimode Fiber

Purnesh Singh Badavath and Vijay Kumar

Department of Physics, National Institute of Technology-Warangal, Telangana 506004, India

A high-dimensional OAM mode recognition method is demonstrated over 1 km of $62.5\mu\text{m}$ multimode fibre, utilizing 1D temporal speckle sequences detected by a fast photodiode. A custom 1D CNN achieves 97% accuracy across seventeen $LG_{p,l}$ modes.

Structured light [1], and specifically beams carrying orbital angular momentum (OAM), has emerged as a promising avenue for enhancing the capacity of optical fibre communication systems [2]. OAM modes provide a high-dimensional basis, enabling the multiplexing of multiple data channels within a single optical fibre and thus significantly improving spectral efficiency. The standard telecommunication fibres do not maintain the helical phase profile of OAM modes over extended distances. Modal dispersion and random mode coupling within the fibre lead to complex speckle patterns at the output, scrambling both intensity and phase information and making reliable OAM mode recognition extremely challenging [3]. To address the issue of mode scrambling, previous research has focused on specialized fibres such as ring-core or hollow-core fibres, which are engineered to preserve OAM states during transmission [4]. Upgrading current telecom networks with specialized fibres and complex detection schemes is economically and logistically impractical. To utilise the OAM beams in standard telecommunication fibres and to improve the data transmission rates in a single channel, here we propose OAM recognition in temporal domain via fibre-based speckle-learned recognition as demonstrated in free-space [5–7].

Laguerre-Gaussian ($LG_{p,l}$) modes were generated by directing a 3mW He-Ne laser's Gaussian beam through a spiral phase plate, producing OAM charges from $l = -8$ to $+8$. The resulting OAM beams were transmitted through a rotating diffuser to create dynamic spatiotemporal speckle fields. These speckle fields were then transformed into far-field patterns using a convex lens with a 10 cm focal length. The far-field speckle patterns were subsequently coupled into a 1 km length of standard MMF using a microscope objective. The random spatial distribution of the speckle field is characteristic of each OAM mode, and coupling this field into the MMF excites a unique set of higher-order modes. As a result, the spatiotemporal evolution of the speckle field at the fibre output retains information about the original OAM mode in both spatial and temporal domains.

For each OAM mode, 20 temporal speckle sequence (TSS) samples were recorded at the fibre output using a fast photodiode connected to a digital oscilloscope, sampling at 1000 Hz. The captured TSS data were then processed using a wavelet scattering transform to extract robust features, which served as input for a custom-designed 1D convolutional neural network (CNN) for supervised training and classification. The 1D CNN trained on WSN-extracted features from fibre TSS accurately classified 17 LG modes ($p = 0, l = -8$ to $+8$) through a 1 km MMF, achieving 97% accuracy with just 15,000 parameters. Its compact design enables deployment in highspeed optical fibre communication channels using low-memory, non-GPU microcontrollers and processors.

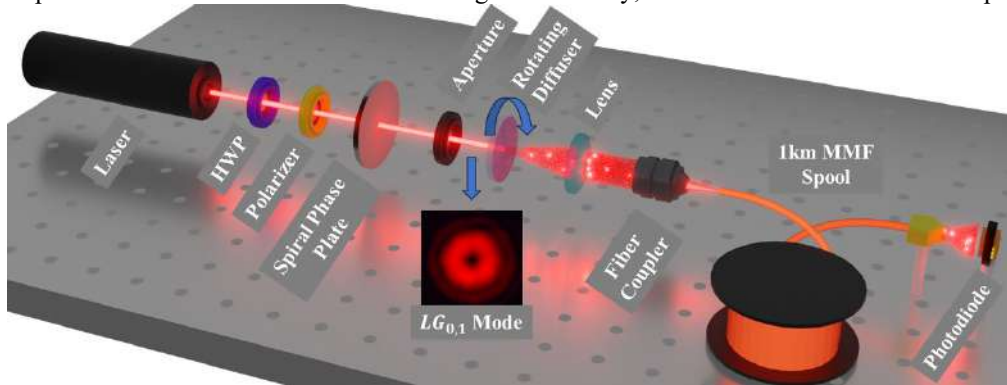


Fig. 1 Schematic diagram of the 1km multimode fibre channel and speckle learned OAM recognition in temporal domain using photodiode.

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SCOPOSIS 2025

Generation and characterization of unconventional optical standing wave patterns outside a photonic microresonator for spectroscopy applications

Arya Kumar Siddharth* and Venkata Ramanaiah Dantham

Department of Physics, Indian Institute of Technology Patna, Bihar 801103, India

Presenting author: arya_2321ph02@iitp.ac.in

In general, whispering gallery modes (WGMs) or conventional optical standing wave patterns (COSWPs) are optical resonances that occur when light is confined within a photonic microresonator (dielectric microresonator) via continuous total internal reflection. These microresonators have exceptionally ultra-high quality factors, small mode volumes, and narrow linewidths, enabling strong field confinement and prolonged photon lifetimes [1]. Each WGM in a photonic microresonator is described by its polarization, e.g., transverse electric (TE) or transverse magnetic (TM), and a set of three numbers (principal, radial, and azimuthal mode numbers).

It is important to note that the maximum electric field of the WGMs resides inside the microresonator, and only a faint field exists outside the microresonator; it decays exponentially with the distance away from the microresonator surface. Hence, the field outside the microresonator is called the evanescent field of the WGM. In most of the applications related to WGMs, the signal-to-noise ratio (S/N) is directly proportional to the electric field of the WGMs. For all the practical applications [2-4], only the evanescent field of WGM is “accessible”. Therefore, S/N is expected to be lower in all applications. However, for the first time, we have theoretically generated the unconventional optical standing wave patterns (UOSWPs) outside a photonic microresonator under a suitable optical illumination [5]. In detail, the UOSWPs are generated by placing a photonic microresonator on a metal substrate and illuminating it with resonant light. The confinement of intense UOSWPs far from the microresonator is due to the constructive interference of the incident light, scattered light by the microsphere, and reflected light from the metal substrate. UOSWPs are observed when the evanescent field of the conventional WGM of the photonic microresonator interacts with the metal substrate. This means the reflection of evanescent waves from the metal substrate plays an important role in the formation of UOSWPs. The observed UOSWPs are characterized using the electromagnetic theory. The electric and magnetic field intensities of the UOSWPs are substantially higher than the evanescent field intensity of WGMs, making UOSWPs highly effective for enhancing light-matter interaction. These will especially be helpful in enhancing the Raman scattering, fluorescence, and nonlinear optical properties of the molecules placed outside a metal-substrate supported photonic microresonator.

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Experimental and Theoretical Investigation on Whispering Gallery Mode Coupling in Photonic Molecules

Simanta Baishya* and Venkata Ramanaiah Dantham

Department of Physics, Indian Institute of Technology Patna, Bihar 801103, India

*Presenting author: simanta_2412ph10@iitp.ac.in

A photonic atom (dielectric microsphere) supports optical modes or resonances upon suitable optical illumination. These optical modes are called surface modes or whispering gallery modes (WGMs). The wavelength locations of the WGMs are extremely sensitive to the size and relative refractive index of the microsphere. Therefore, these are also known as morphology-dependent resonances [1]. These WGMs can be visualized as sharp dips in the transmission spectra and sharp peaks in the fluorescence, elastic, and inelastic scattering spectra of single photonic atoms. The WGMs are found to be efficient for several applications such as biosensing, gas sensing, temperature sensing, pressure sensing, nonlinear optics, surface enhanced fluorescence, Raman scattering, etc [2-5]. The characteristic parameters (wavelength locations, quality factor values, and mode volumes) of the WGMs of individual photonic atoms are well studied experimentally and theoretically [6].

However, herein, we report the experimental and theoretical investigation on WGM coupling in symmetric and asymmetric photonic molecules (dielectric microsphere dimers or coupled microspheres) for the first time. The theoretical investigation is carried out by plotting the scattering spectra and electric field distribution of photonic molecules using developed Python codes based on generalized Lorenz-Mie theory. The experimental investigation is carried out by recording the dark-field scattering spectra of single photonic molecules. It is observed that the scattering spectra and electric field enhancement of the photonic molecules are significantly different from those of their individual photonic atoms. The electric field enhancement at the nanogaps in the photonic molecules is exceptionally high due to the constructive overlapping of the evanescent field of WGMs of individual photonic atoms. We believe that the results and observations reported here will enable the research community to use the photonic molecules for nonlinear optics and surface-enhanced fluorescence and Raman spectroscopy applications.

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Strong Quantum Squeezing in Engineered Coupled Microring Resonators

Joy Ghosh^{1,*}, Ayush Mohapatra², Shailendra K. Varshney^{3,1,†}

¹School of Nanoscience and Technology, Indian Institute of Technology Kharagpur, 721302, India

²National Institute of Science Education and Research, Bhubaneswar, 752050, India

³Department of Electronics and Electrical Communication Engineering, Indian Institute of Technology Kharagpur, 580011, India

*joyghos@kgpian.iitkgp.ac.in, †skvarshney@ece.iitkgp.ac.in

Abstract: We present a theoretical investigation of how intracavity quantum squeezing in a system of two coupled microring resonators can be achieved by utilizing a nonlinear degenerate parametric interaction in one of the modes, while the other mode acts as a lossy auxiliary cavity driven by a two-tone field. Our analysis shows breaking of conventional squeezing limit by tuning the ratio of sideband coupling strengths which can be useful for quantum information technology in integrated photonic platforms.

Methods and results: Quantum squeezing is an intriguing technique that reduces noise in one measurable quadrature of light at the expense of increasing vacuum fluctuation in the conjugate quadrature [1]. Intracavity squeezing in integrated platforms is highly desirable as it enhances light-matter interactions and avoids the efficiency losses commonly encountered when using externally injected squeezed light. The standard methods in most degenerate parametric amplifier (DPA) processes are fundamentally capped at a 3 dB limit; as the system creates correlated photon pairs, one photon from each pair is inevitably lost to the environment, halving the effect and limiting noise reduction at 50% [2,3]. Surpassing this limit is challenging which often requires complex hardware or operability in narrow parameter regimes. We present a scheme in two coupled microring resonators that overcomes the conventional limit in steady-state intracavity squeezing. Here, we treat both pump (a_1) and signal (a_2) modes as quantized, and apply a two-tone field to the signal mode. The Hamiltonian of the system can be written as, $\mathcal{H} = \Delta_1 \hat{a}^\dagger \hat{a} + \Delta_2 \hat{b}^\dagger \hat{b} + J(\hat{a}^\dagger \hat{b} + \hat{b}^\dagger \hat{a}) + i\Lambda \hat{a}^{\dagger 2} + iE_1 \hat{a}^\dagger + iE_2 \hat{b}^\dagger + hc.$, where $E_{1,2}$ denote field strengths, Λ is the parametric gain and $hc.$ stands for the Hermitian conjugate terms. By adiabatic elimination of

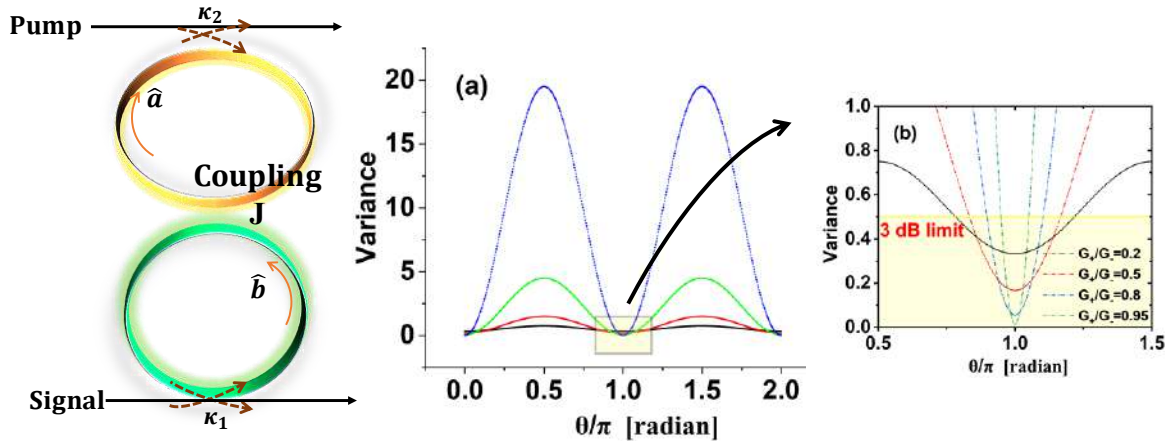


Fig. 1 Schematic of the proposed setup. (a) and (b) shows the variance of the pump mode with quadrature angles for various sideband coupling ratios.

the signal ring (assuming, $\kappa_1 \gg \kappa_2$), and a Bogoliubov diagonalization of the resulting pump-mode Hamiltonian, we derive an effective squeezing interaction that can, in principle, be made arbitrarily large (as shown in Fig.1). The two-tone driving E_2 applied to the signal ring produces effective sideband coupling $G_{\pm}$ which gets transferred to the pump mode by controlling the tunnelling strength J , thus contributing to the squeezing interaction. The parameters used in this work are given as, ring radius $R = 10 \mu\text{m}$, waveguide dimensions $800 \times 400 \text{ nm}$, effective index $n_{\text{eff}} = 2$, mode volume $V_m = 10 \mu\text{m}^3$, quality factor $\approx 10^7$, third order nonlinearity $\chi^3 = 2.5 \times 10^{-19} \text{ m}^2/\text{W}$. Using these parameters, we estimated the Kerr coupling as $2\pi \times 2 \text{ MHz}$ and the effective sideband coupling strengths $G_+ = 2\pi \times 142.8 \text{ MHz}$ and $G_- = 2\pi \times 144 \text{ MHz}$. The squeezing parameter is found as $r = \tanh^{-1} \left(\frac{G_+}{G_-} \right) = 2.80$, from which the quadrature variance obtained nearly 9 dB.

Conclusion: We demonstrated robust quantum squeezing surpassing the conventional 3dB limit by optimizing parameters in a third-order coupled microring resonator system. No external squeezed light is injected or complex modulation schemes are required; the squeezing emerges from the engineered couplings and dissipation only.

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Thermally tunable supercontinuum generation in liquid infiltrated capillary-assisted graded index multimode fiber

Akash Deep Battu and Sudip Kumar Chatterjee

Department of Physics, Bennett University-201310, Uttar Pradesh, India

The broadband supercontinuum generation (SC) in multimode fibers has witnessed a resurgence of interest in recent years. The sheer complexity associated with the presence of hundreds of interacting modes in the presence of nonlinear processes has led to new opportunities in observing a multitude of novel optical effects that would otherwise be impossible to achieve in single-mode fibers [1,2]. Motivated with this fact, here we propose a new design, named Capillary-assisted graded index (Cap-GRIN) multimode fiber, to add an extra degrees of freedom of tunability. Cap-GRIN fiber uses an implanted capillary structure at the centre to modify the internal refractive index distribution in order to attain tailorable dispersion profile, modal interactions and effective nonlinearity. The tunability in the fiber design is achieved by infiltrating the capillary tube with suitable thermo-optic liquid and raising the temperature [4]. Next, an efficient 1+1D nonlinear Schrodinger equation is solved using split-step fourier method to mimic the propagation of ultrashort pulses through the Cap-GRIN fiber [3]. The periodic focusing of spatial Gaussian beam, as a signature the parabolic index profile, has been accounted through periodic nonlinearity. Cap-GRIN fibers enable tunable and efficient spectral broadening than standard GRIN fibers by altering the waveguide dispersion and improving modal confinement. It also shows the potential to produce far-detuned new frequencies govern by the phase matching conditions for nonlinear parametric processes courtesy to the temperature dependence of waveguide dispersion. Cap-GRIN fibers showed promise as platforms for small, efficient, and wide-band supercontinuum sources in ultrafast optics, biological imaging, and spectroscopy.

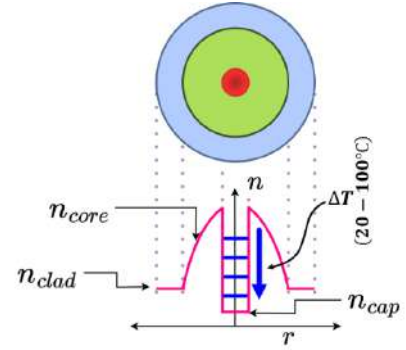


Fig. 1: The cross-section and the refractive index profile of Cap-GRIN fiber

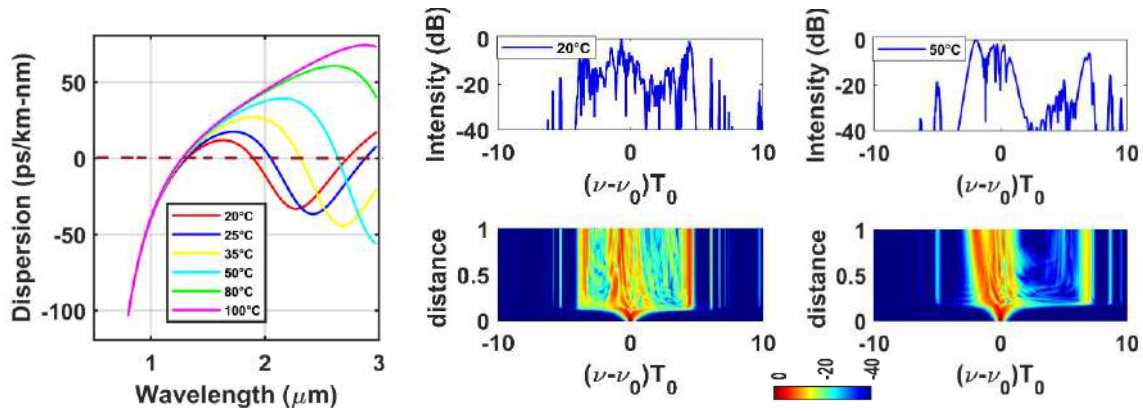


Fig. 2 : (a) Thermally tunable dispersion profile, the spectral evolution and the output spectra of 50 fs sech pulse at (b) 20°C & (c) 50°C

Figure 1 shows the cross-section of the Cap-GRIN fiber along with the refractive index profile. A full vectorial finite-element method utilizing COMSOL Multiphysics is carried out to obtain the modal index and field profiles. A change in the temperature from 20 – 100°C yields a variation in the index contrast between the core and capillary and causes a dynamic modal fields. A significant shifting ($\sim 45\text{nm}$) in the zero dispersion wavelength of the Cap-GRIN fiber with thermo-sensitive liquids has been shown in Fig. 2a. With such liberty in the host fiber, we presented the spectral evolution of a 4th and 3rd order soliton at two different temperature 20°C and 50°C (Fig. 2b, 2c). Interestingly, a wide variation in the output spectra and the pulse profile have been observed. The theoretical understanding of the generated spectra and along with the other notable findings will be discussed in the conference in great details.

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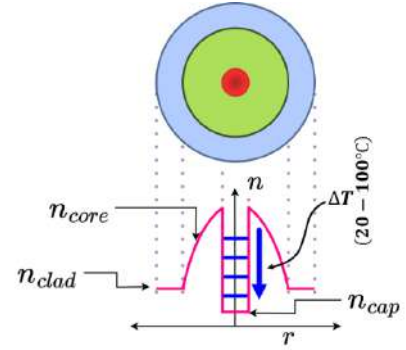


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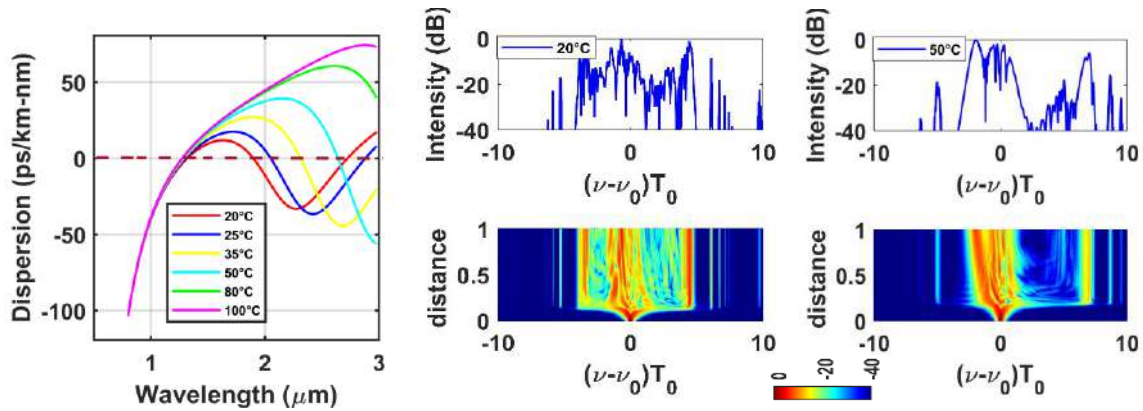


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Implementation of Non-Interferometric Discrete-Modulation CVQKD using the Four-State Protocol

Rachita Nandan^{1,2}, Jayanth R¹, Shashi Prabhakar¹

1. Quantum Science and Technology Laboratory, Physical Research Laboratory, Ahmedabad, Gujarat 380009, India

2. Department of Physics, Indian Institute of Technology Gandhinagar, Gujarat, 382355, India

In the emerging era of quantum communication, quantum key distribution (QKD) provides a secure method for generating cryptographic keys with information-theoretic security [1]. Continuous-variable QKD (CVQKD) encodes information in the quadrature variables (amplitude and phase) of light [2], typically coherent or squeezed states. CVQKD is particularly attractive because it uses standard telecom components, achieves high key rates over metropolitan distances [3], and avoids the need for single-photon sources and detectors. Most reported implementations rely on interferometric designs between the encoded signal and the local oscillator (LO) [3,4], which introduce experimental complexity and long-term phase instability. In this work, we implement a non-interferometric realization of four-state discrete-modulation CVQKD.

Our experimental setup is based on polarization multiplexing, where the signal and LO with orthogonal polarizations co-propagate in the same optical path, eliminating the need for interferometric phase stabilization. As shown in Figure 1, the vertically polarized state $|V\rangle$ from a 795 nm laser is passed through an amplitude modulator (AM), which modifies the initial state ($|V\rangle$) to a new state, $[i \sin(\theta/2)|H\rangle + \cos(\theta/2)|V\rangle]$. We set the modulation phase θ to redistribute the optical power such that approximately 99% forms the LO and 1% the signal. A phase modulator (PM) then generates the four coherent states, $|\alpha_k\rangle$, corresponding to phase values of $0, \pi/2, \pi$, and $3\pi/2$. On the detection side, a half-wave plate (HWP2) and a polarizing beam splitter (PBS2) separate the polarizations and interfere LO and signal before balanced homodyne detection (BHD).

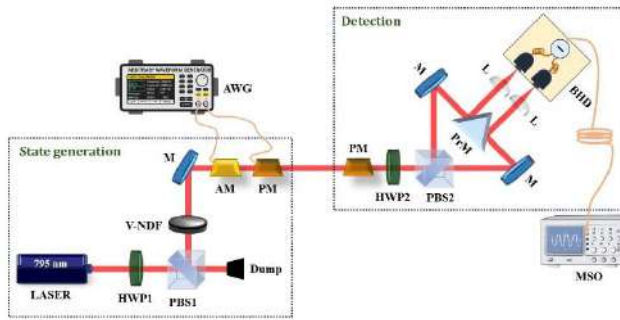


Fig. 1: Schematic of the experimental setup for implementing discrete modulation CVQKD with co-propagating signal and LO.

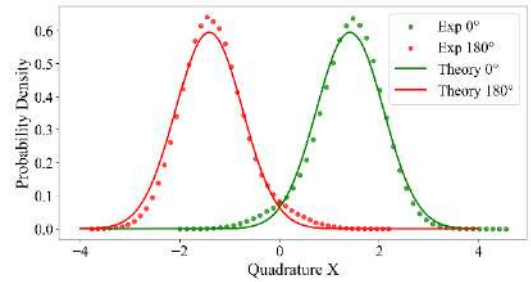


Fig. 2: Theoretical and experimental quadrature distributions for coherent states at 0° and 180° .

The system has been characterized through shot-noise calibration and amplitude modulation measurements, verifying the linear response of the modulation stage. For state implementation, we have successfully generated two coherent states, $|\alpha\rangle$ and $|\alpha\rangle$, corresponding to phases 0° and 180° . State preparation was confirmed through homodyne detection of 10^6 samples per modulation voltage, with the PM used to maintain zero relative phase between LO and signal, thus measuring X quadrature. The measured quadrature distributions (see Figure 2) exhibit Gaussian profiles that agree with theoretical expectations for coherent states. For the state $|\alpha\rangle$ (0°), we obtained $\langle X \rangle = +1.596$ and $\text{Var}(X) = 0.536$, while for the state $|\alpha\rangle$ (180°), we measured $\langle X \rangle = -1.539$ and $\text{Var}(X) = 0.513$, in shot-noise units (SNU), in close agreement with the theoretical values of ± 1.5 and 0.5 , respectively. The future plan is to extend the modulation to all four states and evaluate the secure key rate performance. This approach provides a stable and resource-efficient pathway toward practical CVQKD networks as an alternative to interferometric setups.

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A Single Beam Dead-Zone-Free FID Magnetometer Using Rb Atoms

Shrey Mehta¹, G. K. Samanta², Raghwinder Singh Grewal¹

1. School of Arts And Sciences, Ahmedabad University, Navrangpura, Ahmedabad 380009, Gujarat, India

2. Photonic Sciences Laboratory, Physical Research Laboratory, Navrangpura, Ahmedabad 380009, Gujarat, India

In our recent work, we demonstrated a dead-zone free operation of an atomic magnetometer based on free-induction decay of Rb atoms. Free Induction Decay (FID) magnetometers are simple devices that can be used for sensitive detection of external magnetic fields [1]. However, these magnetometers have an inherent flaw known as a “dead-zone”, wherein, the device cannot accurately measure the applied magnetic field in certain directions. Here, we propose a simple optical pumping technique to address this problem. We use a single laser beam containing equal linear and circularly polarized components, which is amplitude modulated at lower duty cycle. This enabled us to synchronously pump the Rb atoms at both first and second harmonics, which allowed us to observe the Larmor precession at a frequency of Ω_L (orientation) and/or $2\Omega_L$ (alignment) in a single FID signal, depending on the direction of applied magnetic field.

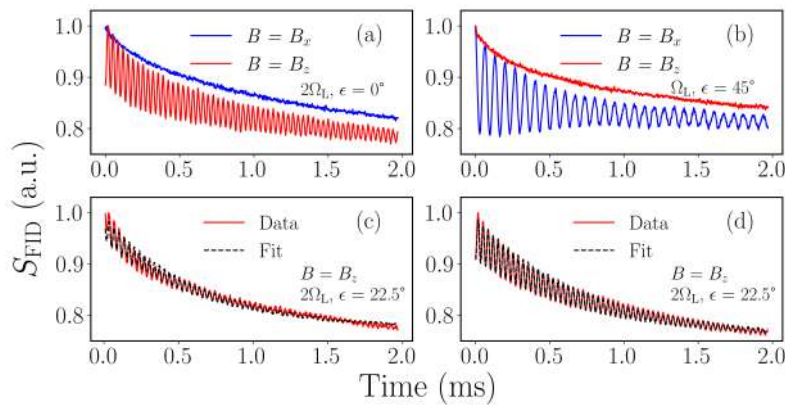


Figure 1: FID signals measured at different experimental conditions. Duty cycle, η , of light modulation: (a)–(c) 50% and (d) 20%. (c) and (d) The dashed black line shows the fit to the FID signals.

As shown in Figure 1 (a) and (b) there are deadzones for both linearly and circularly polarized light, but in different directions of B (applied magnetic field). Hence, while synchronously pumping with both harmonics, and $\epsilon = 22.5^\circ$, we can eliminate the deadzones as it is evident from Figure 1 (d). The magnetometer has a sensitivity in the range of $3.2\text{--}8.4 \text{ pT}/\sqrt{\text{Hz}}$ in all directions [2]. Our experimental scheme can be crucial for developing miniaturized atomic magnetometers for various practical applications, including geomagnetic applications.

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Topological Charge Determination and Propagation Dynamics of Perfect Optical Vortices Using Interferometry

Aswathi K Sivarajan^{1,*}, Harsh Vardhan¹, Sakshi Choudhary¹, Salla Gangi Reddy¹, Ravi Kumar¹

¹Department of Physics, SRM University-AP, Andhra Pradesh - 522502, India

*aswathi_ksivarajan@srmmap.edu.in

Abstract: Optical vortices have gained significant attention due to their potential to carry a well-defined on axis orbital angular momentum (OAM) [1]. A dough nut shaped intensity distribution with a phase singularity at its core is the general representation of a vortex beam. The size of these vortex beams is dependent on the embedded topological charge (TC), which limits their efficiency for several applications. To address this limitation, the concept of Perfect Optical vortex (POV) beams has been introduced [2], which exhibit a TC independent annular intensity profile. Later, it was demonstrated that these POV beams are the Fourier transform of Bessel Gaussian (BG) beams [3]. Various studies have been reported in the literature on determining the topological charges embedded in such beams. Among them interferometric methods provide a convenient way to analyse the topological charge. Different interferometric methods produce various interferogram patterns, such as spiral, fork and petal fringe patterns, offering flexibility in determining the magnitude and sign of TC by simply counting the number of fringes arising from the centre of the vortex [4]. Here, we propose a Mach-Zender interferometer (MZI) arrangement for determining the TC of the POV beam. We are following an in-line interference of a POV beam with a spherical beam. The interferogram can be visualized in such a manner that the POV beam is being split in a spiral strip pattern, and the number of spirals gives us the TC value. The experimental setup for generation and TC determination is shown in figure 1, whereas the interferograms of the POV beams of different orders with a spherical Gaussian beam are shown in figure 2.

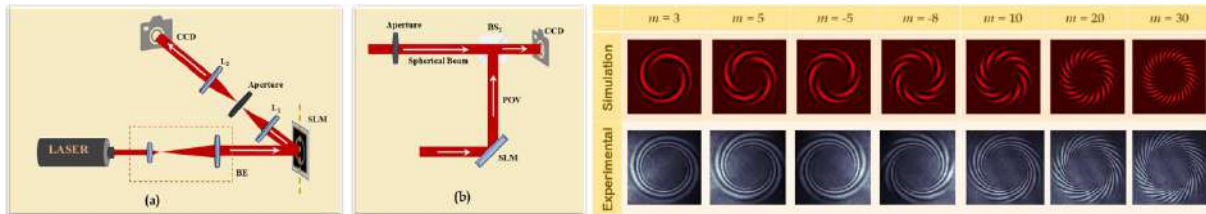


Fig.1. (a) Experimental setup for generation of POV beams; and (b) interference of POV beam with spherical Gaussian beam. BE: beam expander, SLM: spatial light modulator, L1 & L2: Lenses, BS: beam splitter, CCD: charge couple device.

Fig.2. Theoretically (top) and experimentally (bottom) obtained interferograms of the POV beams of different orders with a spherical Gaussian beam.

We also investigated the propagation characteristics of the POV beam. It was reported that POV beams lose its TC-independent intensity structure over distance, forming small concentric rings due to self-focusing effects [5]. While studying interference between the POV beam and a spherical beam, we observed spiral fringes evolving into flower-like patterns whose petal size depends on the POV beam's TC, similar to interference seen with Bessel-Gauss (BG) beams [4]. Additionally, partially blocked POV beams showed self-healing and concentric ring formation after some propagation. These results indicate that the POV beam gradually evolves into a BG beam during free-space propagation, starting where the concentric rings first appear [6].

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Determining Laser induced damage threshold of thin film AR coating @ 1064nm wavelength using pump-probe method

Anil Kumar, A S Upadhyaya, Suman Awasthi, Vinod Kumar, L M Pant

IRDE, Raipur, Dehradun - 248008
anil.irde@gov.in

In this reported work we have designed and developed an anti-reflection coating for 1064nm Nd:YAG laser and subsequently characterized the coating for estimating LIDT using pump-probe technique. Coating was developed using two layers of HfO₂ and SiO₂ via EBG technique over fused silica sample of 3mm thick. Both side coated sample was characterized first for the transmission measurement followed by laser induced damage threshold in pump-probe set-up.

A 632.8nm cw He-Ne laser was used as a probe beam while flash lamp pumped 1064nm, 10ns, 20Hz source was used for damaging the optical sample. The schematic diagram of optical setup is shown in fig.2. CW He-Ne signal is detected and plotted via oscilloscope. A KG3 filter is used to filter out 632.8nm from mixed signals. Parameters of pump and probe beam are depicted in table 1.

Table1. Experimental parameters of set-up

Parameters	Divergence	Diameter	Pulse width, PRF	Spot diameter
Nd:YAG @ 1064nm	1.5mrad	4mm	10ns, 20Hz	60μm
He-Ne @632.8nm	1mrad	2mm	CW	40μm

Constant DC level was observed in the oscilloscope corresponding to the He-Ne signal initially when pump beam was kept off. After turning ON the pump beam, with low initial pulse energy, the oscilloscope reading was stable. Energy of pump laser was increased in incremental steps of 1A using laser power supply after 10 shots. With continous increments in pulse energy, He Ne signal was kept under obeservation. A sudden drop in signal was obeserved when the sample gets damaged due to high energy pump pulses. The moment, sample was damaged, energy of the pump pulse was measured and subsequently the LIDT of AR coated sample at 1064nm.

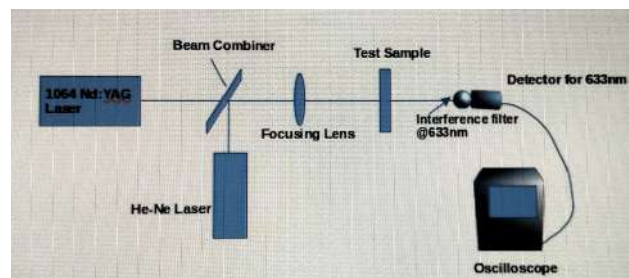
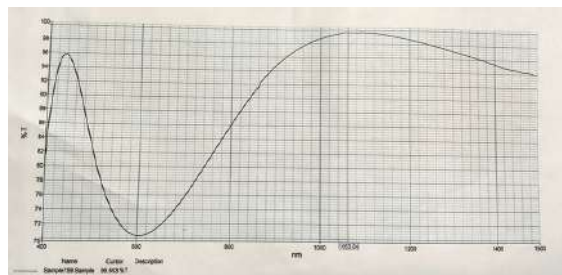


Figure: a) Transmission characteristics of AR coated FS sample, b) Schematic of experimental set-up for LIDT

Results and Discussion-

High Efficiency anti-reflection coating at 1064nm over fused silica optics has been developed. Transmission was measured using Perkin- Elmer spectrophotometer (Lambda-1050) and achieved 99.65% transmission at 1064nm. The sample was characterized for LIDT measurement at 1064nm using pump-probe technique and estimated laser damage was found to be 38J/cm² for 10ns, 20 Hz Nd:YAG source. The reported optical coating is environmentally stable as per MIL-48497. real-time correction methods in high-precision applications.

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Angle-Resolved Optical Properties of Self-Assembled Colloidal Monolayers: Grating Diffraction and Thin Film Interference

A. Anand Eswara Rao^{1,2}, P. Viswanath^{1,2}

1. Centre for Nano and Soft Matter Sciences (CeNS), Shivanapura, Bengaluru 562 162, India

2. Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201 002, India

Structural colors have attracted significant attention in various research fields in recent years due to their origin in complex interaction between light and periodic structures at the nano scale; often found in natural systems like butterfly wings, beetles, or peacock feathers. Unlike pigments and dyes, where color arises from light absorption and chemical composition, structural colors result from purely physical mechanisms such as interference, diffraction, scattering, and photonic bandgap effects. Structural colors have become a central focus in developing modern photonic materials, with growing relevance in bioinspired optics, functional coatings, and optical sensing fields [1]. In this work, we study the structural coloration in self-assembled monolayers of polystyrene (PS) colloidal spheres formed at the air-water interface [2]. These particles spontaneously organize into large-area, hexagonally close-packed monolayers, which are transferred onto solid substrates like silicon. We perform detailed angle-resolved reflectance spectroscopy to investigate the origin of their structural colors.

In an asymmetric geometry (fixed incident angle, varying detection angle), the spectra exhibit a single peak that shifts from blue to red with increasing angle. This behaviour agrees with diffraction phase matching condition ($m\lambda = d \cdot n_{\text{air}} \cdot (\sin\theta_m - \sin\theta_{\text{inc}})$, where $m = 1$). In contrast, symmetric geometry (equal incidence and detection angles, $m = 0$) reveals interference peaks that fit well with a thin-film interference model ($m\lambda_{\text{max}} = 2d_f \sqrt{n_{\text{eff}}^2 - \sin^2\theta_{\text{inc}}}$), assuming an effective refractive index ($n_{\text{eff}} = \phi n_{\text{PS}} + (1 - \phi)n_{\text{air}}$) derived from the PS-air volume fraction (ϕ) and a thickness equivalent to the particle diameter (d_f) [3].

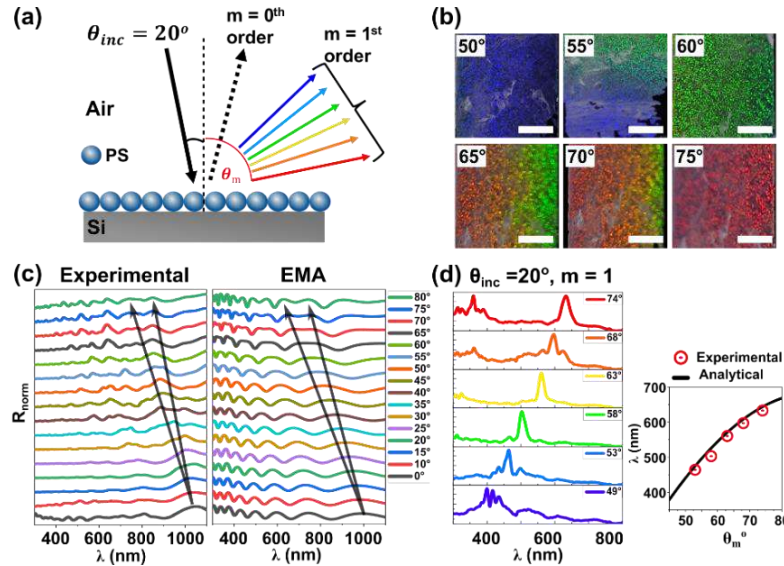


Fig. 1 (a) Schematic of the angle-resolved reflectance geometry setup to study interference (symmetric, dotted) and diffraction (asymmetric) of the monolayer. (b) Structural colors of the monolayers arose due to diffraction for a fixed illumination angle, at 20° , scale bar – 0.5 cm (c) Normalised reflectance variation with wavelength at different incident angles in symmetry geometry. (d) Diffraction intensity variation with wavelength at fixed angle of incidence (20°) for varying diffracted angles (left), diffraction peak position with detection angles (right).

Our findings reveal that a monolayer of colloidal PS spheres can support both diffraction and thin-film interference effects. Further, we identified that the origin of the structural colors is due to diffraction. This coexistence of distinct optical phenomena with clear signatures offers a versatile platform for investigating angle-dependent light-matter interactions. It enables the design of large-area photonic structures with potential applications in structural color engineering, low-cost meta surface fabrication, and optical sensing.

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Experimental measurement of complex coherence from a single pixel

Tanushree Karmakar¹, Rakesh Kumar Singh¹

1. Laboratory of Information photonics & optical metrology, Department of Physics, Indian Institute of Technology (Banaras Hindu University), Varanasi, Uttar Pradesh 221005, India.

2. Faculty of Engineering and Nano Technology Center, Bar-Ilan University, Ramat Gan

Abstract: This work presents a non-interferometric technique to measure two-dimensional complex coherence with the help of structured light projection and single-pixel detection. Some experimental results are presented to highlight the performance of the proposed technique.

Measurement of complex coherence is essential in various applications such as imaging through a scattering medium, quantitative imaging, biomedical imaging, etc. Several techniques have been reported to measure the complex coherence function, i.e., two-point correlation. Most of the existing methods are based on a first-order interferometer, which is vulnerable to noise and external disturbances [1]. Therefore, techniques based on intensity correlation have been explored for measuring the complex coherence by adopting an interferometric approach with a separate reference field [2].

In this paper, we present a non-interferometric technique utilizing single-pixel analysis of intensity correlation for measuring the complex coherence function. This technique employs Fourier-based structured pattern illumination and single-pixel intensity correlation. Single-pixel detection is a novel technique that reconstructs an object with a single-pixel detector (SPD) without the need for a camera with millions of pixels. In our work, we applied a strategy of digital bucket detection of intensity correlation via a spatial averaging approach to avoid the huge measurements required for temporal samplings in the intensity correlation scheme. Figure 1. (a) represents the experimental configuration. A laser beam is directed towards a spatial light modulator (SLM) through a beam splitter (BS). SLM encodes structured patterns $\sqrt{P_\phi}$ having spatial frequency $k \equiv k_x, k_y$, where $P_\phi = a + b \cos(xk_x + yk_y + \phi)$; a , b and ϕ being the DC term, contrast, and initial phase, respectively. Structured patterns fall onto the incoherent source, albeit in the context of a spatial statistical approach. A detector records speckle intensities $I(u, k, \phi)$ corresponding to each spatial frequency of the structured pattern; u being the coordinate at the detector plane. To execute the spatial averaging approach, each $I(u, k, \phi)$ is divided into small patches $I_{\phi,i}$.

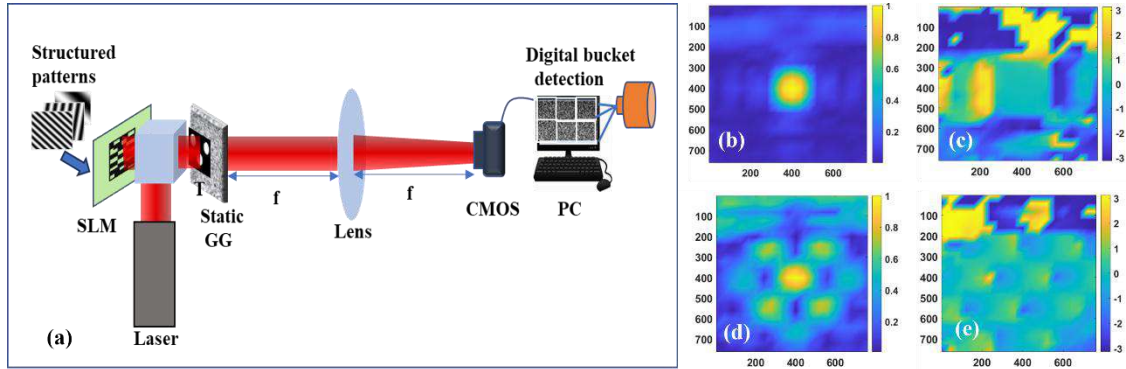


Fig. 1 (a) Schematic diagram of experimental configuration. Experimental results: (b) amplitude and (c) phase of Fourier spectra of a centre square; (d) amplitude and (e) phase of Fourier spectra of a three-pinhole aperture.

For every patch, cross-covariance is calculated and digitally summed as $C_\phi(k) = |W(\Delta u, k, \phi)|^2 = |\int I(u, k, \phi) d^2u|^2$; $W(\Delta u, k, \phi)$ being the complex coherence function. The process is referred to as digital bucket detection. To extract the complex Fourier spectra, a three-step phase shift is applied as follows $F(k_x, k_y) = \left[2C_0(k) - C_{\frac{2\pi}{3}}(k) - C_{\frac{4\pi}{3}}(k) \right] + i\sqrt{3} \left[C_{\frac{2\pi}{3}}(k) - C_{\frac{4\pi}{3}}(k) \right]$ [3]. The complex Fourier spectra correspond to the desired complex coherence functions of the object. To verify our proposed technique, we computed the complex coherence functions of two objects, namely a rectangular aperture and three-pinhole apertures arranged in a triangular geometry. Fig. 1(b) and (c) show the amplitude and phase of the experimentally recovered complex coherence, respectively. Fig. 1(d) and (e) present the coherence for three pinhole apertures, respectively. In conclusion, we present a reference-free technique based on single-pixel intensity correlation to measure the complex coherence function. The proposed method serves as a highly stable coherence measurement technique against external disturbances.

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Propagation Dynamics of Optical Vortex Constellation

Niladri Modak¹, Rafael Barros^{1,2}, Marco Ornigotti¹, Robert Fickler¹

1. Tampere University, Photonics Laboratory, Physics Unit, Tampere, FI-33014, Finland

2. Instituto de Física, Universidade de São Paulo, São Paulo, Brazil

An optical vortex is a point in the electric field of light where the field is undefined. A popular example is a phase vortex that appears for light with a transverse helical phase structure, i.e., a twisted phase front $e^{i\ell\phi}$ resulting in an undefined phase singularity along the optical axis. Here ϕ labels the azimuthal angle and ℓ is called the topological charge or order of the vortex. Such optical vortex beams with different topological charges have attracted a lot of attention in addressing different fundamental optics questions, and have found diverse applications in microscopy, imaging, communications and photonic quantum information processing [1].

However, generating light fields with perfect higher-order vortices is impossible due to experimental limitations such as finite resolutions of devices or imperfect optics, implying in practice, higher-order vortex splits into a constellation of unit charge vortices concentrated around the beam's centre (see Fig. 1(a)) [2]. Therefore, to fully benefit from light with higher-order optical vortices, understanding the behaviour and propagation dynamics of these constellations is essential. In this study, we formulate a mathematical framework for optical vortex constellations based on the elementary symmetric polynomials (ESPs) of the constellation coordinates which further enables us to experimentally explore the free-space propagation of such constellation.

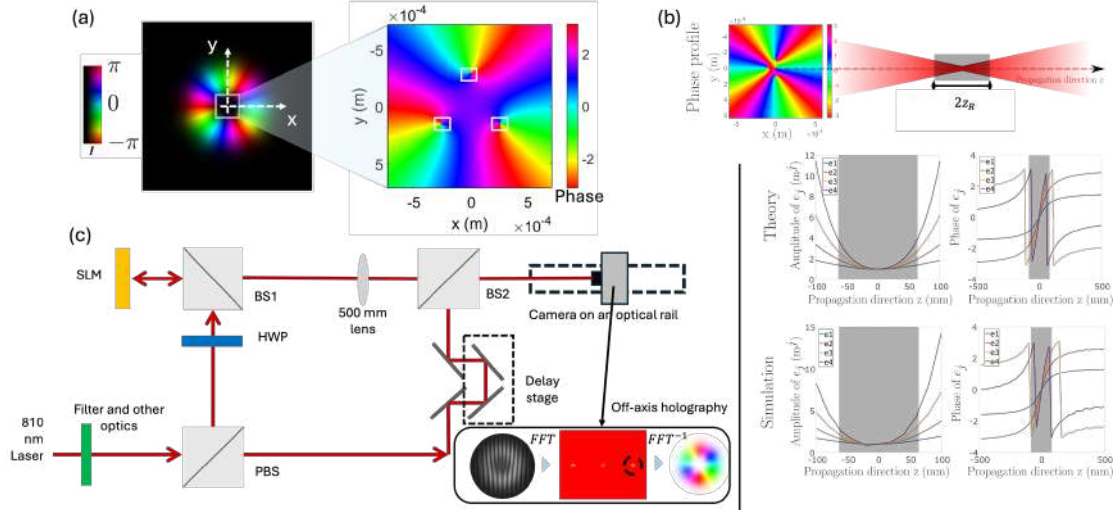


Fig. 1 Propagation of an optical vortex constellation in a Gaussian beam [1]. (a) Amplitude and phase profile of a constellation present in high-order vortex beam. (b) Theoretically and numerically simulated propagation of the complex ESPs e_j/e_0 ($j = 1,2,3,4$) of constellation coordinates for a constellation of four vortices given in the phase profile. Grey-shaded region marks the twice of Rayleigh range z_R . (c) Experimental setup to study the propagation.

The electric field representing an optical vortex constellation corresponding to a ℓ_m -charged vortex beam can be written as $\sum_{\ell=0}^{\ell_m} C_\ell \xi^\ell$ where $\xi = \frac{1}{\sqrt{2}}(x + iy)$; x, y being the Cartesian spatial coordinates (see Fig. 1(a)). The coefficients C_ℓ govern the feature of the background field and importantly, are connected to the ESPs of the set of complex roots of the electric field, which in turn are the spatial coordinates of the unit charge vortices in the constellation [2]. The ESP e_j evolves with propagation of the constellation as $e_j(z) = e_j(0) \left(\frac{z_R}{z_R - iz} \right)^{-j}$ where z is the propagation distance and z_R is the Rayleigh range of the beam [3]. Next, in the simulated propagation of a constellation of 4 vortices embedded in a Gaussian beam through a lens of focal length 500 mm (see Fig. 1(b)), the propagation of the constellation is elegantly captured by complex ESPs. Importantly, ESPs can be directly calculated from the singularity positions providing an efficient metric for describing real-world evolutions of higher-order vortex beam.

Building on this theoretical framework, we go on to experimentally demonstrate the propagation of vortex constellations using the ESPs. The constellation interferes with a reference beam and the interferogram is used for subsequent off-axis holography to retrieve the vortex coordinates and to calculate ESPs (see Fig. 1(c)). Apart from the fundamental importance of understanding the complex behaviour of higher-order vortex beam, the higher-order ESPs provide metrological advantage being more prone to beam propagation (see Fig. 1(b)).

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Design and Realization of Strong Exciton-Photon Coupling in a DBR-Metal Hybrid Microcavity

Yadav Rohit Umashankar, Parinda Vasa

Department of Physics, Indian Institute of Technology Bombay, Mumbai (400076) Maharashtra, India

Corresponding author: parinda@iitb.ac.in

Abstract: Strong light–matter coupling between organic molecular excitons and optical cavities has been extensively studied in recent years [1–3]. Such hybrid states, known as polaritons, are promising for applications in low-threshold lasers, room-temperature condensates, optical logic, and energy harvesting [4–6]. TDBC J-aggregates, with their sharp excitonic transitions and large oscillator strength, serve as an excellent platform for realizing strong coupling under ambient conditions. In this work, COMSOL simulations were used to design $\text{TiO}_2/\text{SiO}_2$ distributed Bragg reflector (DBR) stacks, with results validated against transfer matrix calculations (TMM). Optimized DBRs were then fabricated and integrated with a thin Ag layer to form a Fabry–Pérot microcavity containing TDBC J-aggregates. Angle-resolved reflection revealed strong exciton–photon coupling with a Rabi splitting of ~ 135 meV, while normal-incidence photoluminescence at 550 nm showed well-defined upper and lower polariton branches. These experimental results were further supported by COMSOL simulations using a Lorentz oscillator model for TDBC.

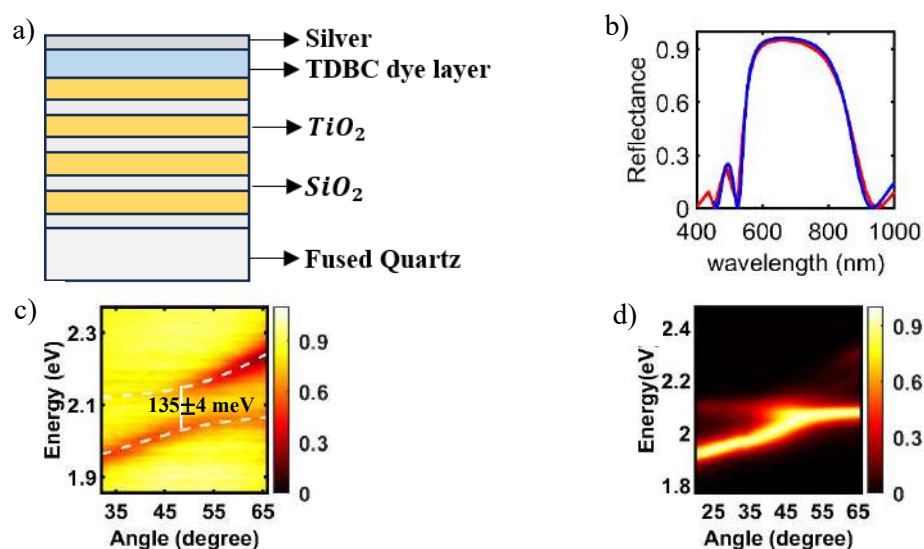


Fig. 1 a) Schematic diagram of the DBR-Metal cavity b) Simulated (red curve) and TMM (blue curve) at 5-degree incidence angle c) Experimentally obtained contour plot of the coupled system d) Strongly outcoupled PL spectrum

This integrated workflow establishes a reliable route for designing and realizing strongly coupled organic–photonic microcavities. The observed polariton dispersion and large Rabi splitting underscore their potential for tunable polaritonic and exciton-based photonic devices.

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Optimizing Spectral Purity and Noise Performance in Cascaded Random Raman Fiber Lasers with Conventional Pumping

Shantanu Dambare, V. Meher, V. Balaswamy

Department of ECE, Indian Institute of Science, Bengaluru, Karnataka, India

CRRFLs—cascaded Raman fiber lasers using random distributed Rayleigh backscattering—are simple, power-scalable, and wavelength-agile systems with diverse applications [1,2]. Key performance metrics like RIN and spectral purity (percentage of output power in desired Stokes band) critically impact narrow-linewidth Raman amplifier design at wavelengths unreachable by rare-earth doped fiber lasers. Stokes RIN strongly depends on pump RIN. ASE-based and phase-modulated single-frequency fiber amplifiers [3–5] offer low RIN and high purity, but their architectures are complex and struggle to maintain high spectral purity across considerable operating power range for all the Stokes orders.

To achieve ~98% spectral purity in CRRFL outputs, we apply band-pass filters (BPFs) targeting specific Stokes orders. We characterize RIN up to the 7th Stokes order using conventional pump lasers (Fig. 1(a)), supplying 55 W at 1064 nm to 680 m OFS Raman fiber post wavelength division multiplexers (WDMs) [5]. WDMs spatially isolate Stokes orders and induce ~4% Fresnel reflection via flat cleaves, forming a half-open cavity. RIN is measured using 50 nm bulk BPFs, 30 GHz photodetectors (800–1700 nm), and an 8.6 GHz radio frequency (RF) spectrum analyser. Spectrum data is collected with an optical spectrum analyser, enabling detailed noise analysis across multiple orders.

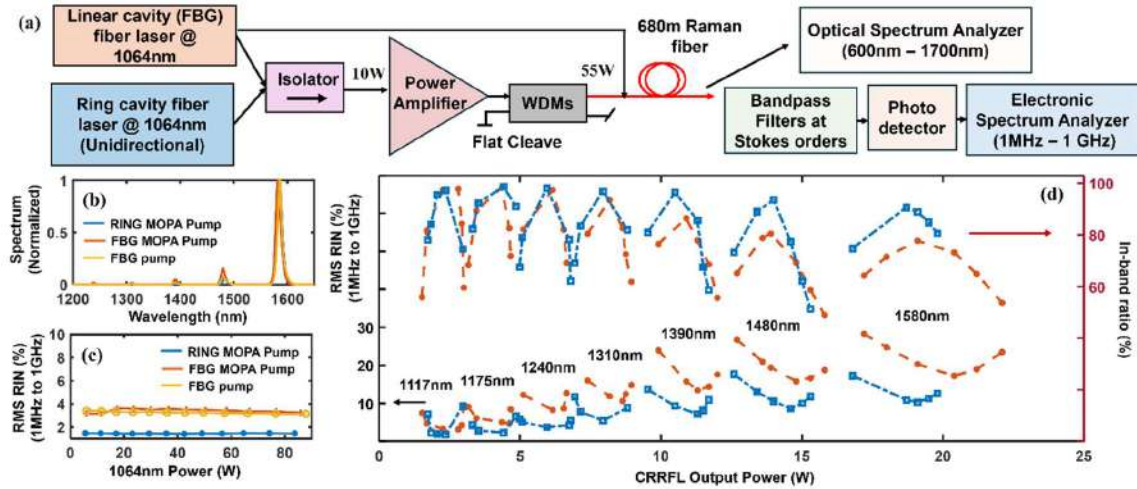


Fig. 1(a). Experimental setup of CRRFL systems, **1(b).** 1580nm normalized power spectral density plots at minimum RIN values for specified CRRFLs, **1(c).** RMS RIN evolution of various pump sources, **1(d).** RMS RIN and unfiltered in-band power ratio evolution of forward FBG MOPA (orange curve) and forward ring MOPA CRRFL (blue curve)

Fig. 1(b) presents the 1580 nm Stokes spectrum at minimum RIN for CRRFLs under various pump schemes, with the unidirectional RING MOPA exhibiting superior noise performance. Fig. 1(c) shows RMS RIN (%) across pump sources integrated over 1 MHz–1 GHz, where RING MOPA achieves a 60% RIN reduction. Fig. 1(d) illustrates how RMS RIN and unfiltered in-band power evolve across Stokes orders with output power; a U-shaped RIN trend appears universally. Crucially, minimum RIN occurs only at maximum in-band power, with RIN nearly doubling from small power shifts, demonstrating high sensitivity. Averaged across Stokes orders, RING MOPA CRRFLs show a ~48% RIN drop versus alternatives. Additionally, in-band power ratios exceed 90% at minimum RIN points, compared to ~77% in other systems. These results indicate that unidirectional RING MOPA pumped CRRFLs are promising for cost-effective, narrow-linewidth, low-noise, high-power Raman amplification.

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Controlling Photon-Magnon Coupling Using Another Magnon

Fizaan Khan, Sachin Verma, Biswanath Bhoi, and Rajeev Singh

Nano-Magnetism and Quantum Technology Lab, Indian Institute of Technology (BHU), Varanasi, Uttar Pradesh - 221005, India

Hybrid magnon–photon systems are promising platforms for coherent information processing and scalable quantum technologies[1, 2]. In this work, we demonstrate photon-mediated coupling between two spatially separated magnonic films—Yttrium Iron Garnet (YIG) and permalloy—placed on a planar hexagonal ring resonator.

Despite no direct dipolar interaction between the films, we observe enhanced permalloy–resonator coupling when the YIG film thickness is increased. This indicates a nonlocal interaction pathway via the shared photonic mode. Notably, the permalloy film parameters are held constant, yet its coupling strength (g_1) increases linearly with the YIG–resonator coupling (g_2). This effect is confirmed via both full-wave simulations and a three-oscillator quantum model based on input–output theory[3, 4].

This indirect magnon–magnon coupling, tunable by adjusting only the YIG thickness, provides experimental evidence for geometric control over coupling in hybrid systems. It highlights the need to reconsider conventional approaches to isolation and crosstalk, especially in compact magnonic circuits. The planar, room-temperature architecture makes the system a scalable and low-cost testbed for hybrid quantum technologies.

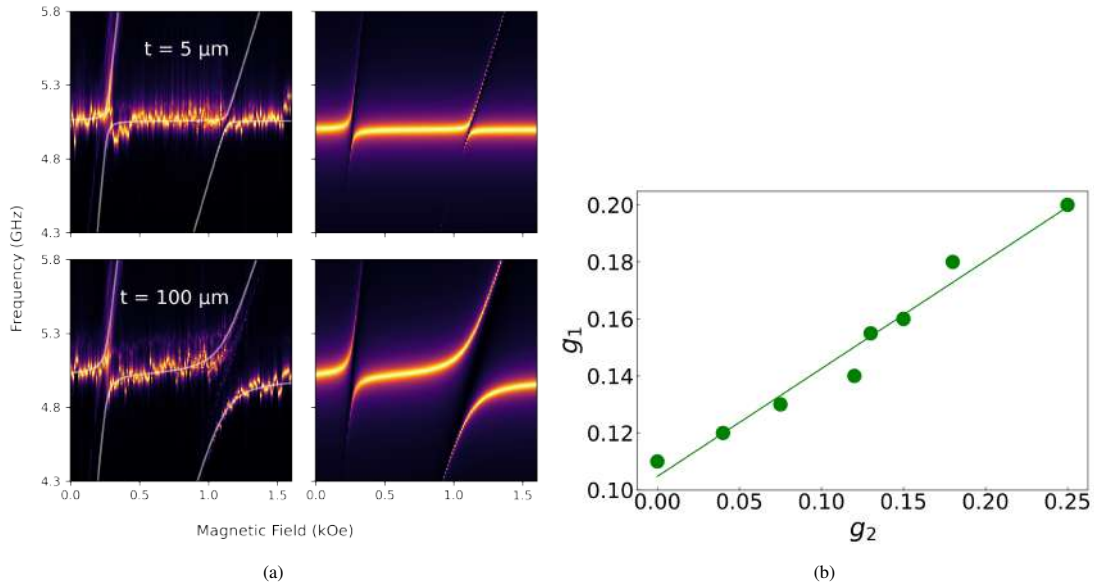


Figure 1. (a) Observed (left column) and simulated (right column) S_{21} spectra for varying YIG thicknesses are seen. Increased splitting near the permalloy mode with YIG thickness confirms indirect coupling. (b) Linear relationship between permalloy–resonator coupling g_1 and YIG–resonator coupling g_2 .

This work provides verification of geometric control over one magnonic mode via another, in a system explicitly designed to avoid direct dipolar interaction. Our results underscore the need to re-evaluate assumptions about isolation and crosstalk in hybrid magnonic devices. At the same time, the simplicity and scalability of the planar architecture suggest a low-cost testbed for exploring more sophisticated magnon–photon–magnon interactions and indirect quantum links.

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Coincidence detection of correlated photon pairs

Krishna Yadav, Milenia Basumatary, Prem B Bisht

Department of Physics, Indian Institute of Technology Madras, Chennai, Tamil Nadu 600036, India

The spontaneous parametric down conversion (SPDC) technique is used to generate entangled photon pairs. Coincidence detection of photon pairs is an essential requirement in quantum optics experiments such as Hong Ou Mandel (HOM) interference, ghost imaging etc. We have fabricated a coincidence counting circuit [1] by using four D-type flip-flops (74ACT74) as shown in Fig.1. When two input pulses with maximum time difference 250 ns arrive at inputs A_{IN} and B_{IN} the circuit yields coincidence pulses at output CC. We have tested our circuit with two inputs from function generator and coincidence counts observed in oscilloscope. The improvement and implementation of the circuit in the experiments will be discussed.

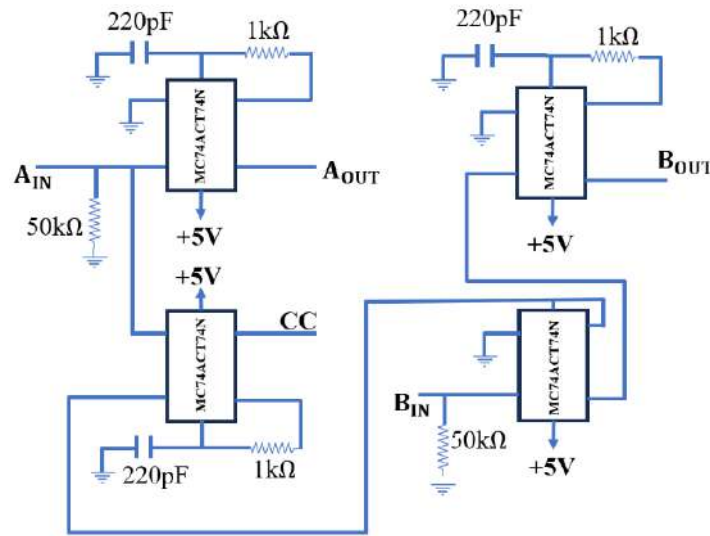


Fig. 1: Schematic diagram of coincidence count circuit made by four D-type flip-flops.

Acknowledgement

We thank Dr. Mayukh Lahiri for fruitful discussions

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SCOPOSIS 2025

Excitation of white light whispering gallery modes of single optical microspheres using a dark-field microscope in transmission mode

Sibanisankar Sahoo, and Venkata Ramanaiah Dantham*

Department of Physics, Indian Institute of Technology Patna, Bihar, India, 801103,

*Corresponding author: dantham@iitp.ac.in

Optical microspheres are nothing but transparent dielectric microspheres that support optical resonances or optical modes due to the total internal reflection of light near their surface [1]. These optical modes are known as surface modes and whispering gallery modes (WGMs) [2]. The important characteristic parameters of these WGMs are the quality factor (Q), wavelength location, and free spectral range [3, 4]. These WGMs are also called morphology-dependent resonances because their wavelength locations are extremely sensitive to the size, shape, and relative refractive index of the microsphere. In recent years, the WGMs have garnered significant attention due to their implications for sensing, lasing, nonlinear optics, and cavity quantum electrodynamics [5]. The WGMs of bare optical microspheres can be observed as sharp dips in their transmission spectra and peaks in the scattering spectra [2]. However, capturing the scattering spectra of optical microspheres is relatively easy.

It is worth mentioning here that, so far, the WGMs of single optical microspheres have been excited using narrowband or monochromatic light sources, and the narrowband scattering spectra of single optical microspheres have been reported in the literature [6]. However, in the present study, we used the white light source to excite the WGMs efficiently and record the broadband scattering spectra with the help of a dark-field microscope in transmission mode. The experimentally observed white light WGMs are well characterized using the Lorenz-Mie scattering theory. Moreover, the role of irradiation time and polarization of light on the white light WGMs is studied systematically. Based on our experimental results, it is found that the white light WGMs in the scattering spectra will be useful for studying the dispersion characteristics of various optical materials by simply monitoring the shift in the wavelength locations of the WGMs upon adsorbing them on single optical microspheres.

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Characterization and Comparison of Single and Colliding Femtosecond Laser-Produced Filaments in Air

Irene Rose¹, Anu Avarachan², Shilpa S², Riju C Issac², Pramod Gopinath^{1*}

1. International School of Photonics, Cochin University of Science and Technology, Cochin, Kerala 682022, India

2. Department of Physics, Cochin University of Science and Technology, Cochin, Kerala 682022, India

*Email: pramod@cusat.ac.in

When high power femtosecond laser pulse propagates through media, they can generate self-guided filaments that persists over longer distances. The formation of these filaments occurs due to the dynamic equilibrium between laser self-focusing due to non-linear Kerr effect and defocusing as a result of ionization processes [1,2]. These filaments have diverse applications in the fields of remote sensing of chemical/biological agents, white light generation, lightning control, Terahertz generation, generation of higher harmonics, pulse compression etc. [3].

A Ti-Sapphire femtosecond laser beam of 800 nm central wavelength, 35fs pulse duration, 7mJ energy and 1kHz repetition rate was used to generate the air filaments. The beam was separated into pump and probe beams where the pump beam generates the filaments, and a transverse probe beam is used to obtain its shadowgraph with picosecond time resolution. The pump beam was again separated into two equal intensity beams to generate two air filaments which collide as they propagate. The characteristics during picosecond time evolution of single air filament [4] and colliding filaments were compared. Typical emission spectra of single and colliding air filaments are shown in figures 1(a) & 1(b) respectively. The images showed an enhanced emission intensity for the colliding filaments than the single filaments. Analysis of shadowgram data and detailed analysis of the plasma evolution will be discussed.

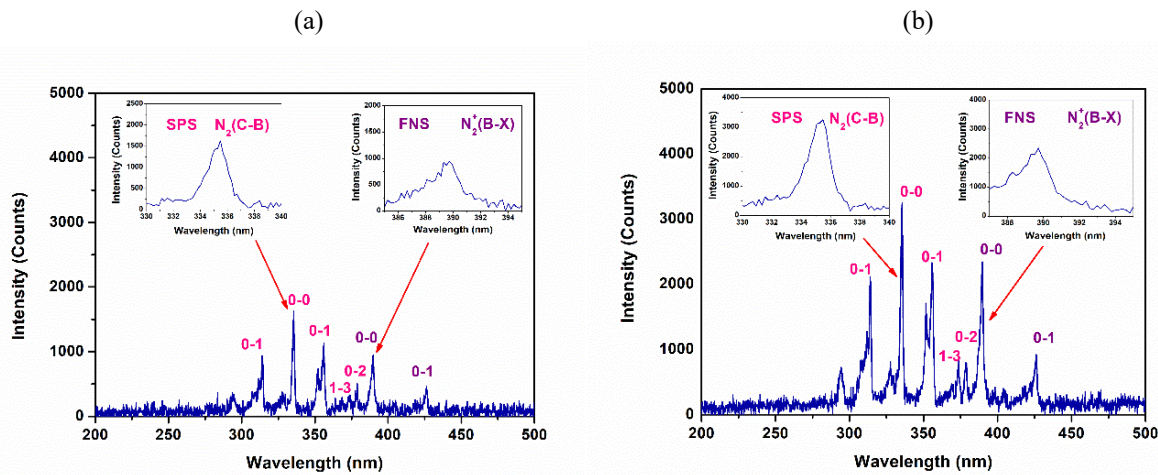


Fig. 1. Molecular emission of nitrogen from (a) single air filament (b) colliding air filaments

SPS : Second Positive System of N_2 , FNS : First Negative System of N_2^+

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Optical design and analysis of a compact catadioptric system for space based optical observation of space debris

Totan Chand¹, S. Sriram¹

1. Indian Institute of Astrophysics, Koramangala, Bangalore 560034, India

The exponential increase in number of space debris is now a concrete threat for safety of space orbit as well as space environment. Thus monitoring and mitigation of such space junks is essential to ensure the overall performance of spacecraft and space resources. The detection of space debris mainly used passive ground based or space based instruments. The ground based techniques equipped with either radar or by means of photoelectric telescope. The detection capability of radar makes it suitable for lower earth orbit space debris detection, as it's detection range varies inversely fourth power of distance. The detection of high altitude space debris largely done by means of ground based optical telescope as its detection capability varies with inversely second power of distance. However, adverse weather and atmospheric condition limits the effective use of ground based detection systems. Thus the space based space debris detection systems are getting an important alternative option throughout the globe. These space based detection systems which generally mounted with spacecraft are work mainly by means of optical. The main goal of space based space debris detection system is to detect space debris of 1 to 10cm in size or even smaller in geo stationery or lower earth orbit. In passive space based space detection system, the reflected light from the space debris which is illuminated by sunlit is captured. On the other hand, in active system the reflected light from the space debris is captured which got illuminated through a laser equipped with detection system, thus it's make no depend on sunlit. The stringent optical design requirements of such system such as compactness, lightweight, high encircled energy and contrast with low distortion makes them challenging to the designer.

In this paper we are proposing a catadioptric system for space based space debris detection in the wavelength range of $0.45\mu\text{m}$ - $0.9\mu\text{m}$ which is lightweight and compact, can be fitted with a CubeSat size spacecraft. The baseline of the optical design is a RC type cassegrain telescope system with a primary mirror size of 100 and f-number of 1.5. The secondary mirror occultation of the system is about 36 percent. This optical design is target to detect a 10th order magnitude space debris with a circular field of view of 1.5 degree. Three spherical lens element is added to correct the overall residual aberration. The focal length of the system is 420mm and a CMOS detector of size 11mm with a pixel size of $5.5\mu\text{m}$ is considered to design the system. The optical design gives a diffraction limited performance over the full field of view and full wavelength range($0.45\mu\text{m}$ - $0.9\mu\text{m}$). The optical design layout and spot performance plot is shown in figure1.



Fig. 1 Optical layout(left) and spot performance plot(right)

The chromatic focal shift of the design system is about $22\mu\text{m}$ which is half of the diffraction limited range. The overall distortion of the designed optical system is less than 0.6% and the field curvature is less than $50\mu\text{m}$. The encircled energy is more than 95% in less than two-pixel size. The MTF of the system appears over 0.4 more than 140line/mm.

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Thin Film Lithium Niobate (TFLN) Waveguide-Based Photon Pair Sources for Quantum Applications

Muskan Arora, Jyoti Arya, Pranav Chokkara, Jasleen Lugani

Centre of Sensors, Instrumentation and Cyber Physical System Engineering (SeNSE),
Indian Institute of Technology Delhi, Hauz Khas, New Delhi, 110016, India

We report on a singly poled TFLN waveguide design that enables two very different type-II SPDC processes with wavelengths in telecom O- and C-bands with distinct spectral properties. Benefitting from unique properties of TFLN, waveguides fabricated in this platform serve as useful elements for generating and manipulating quantum states of light[1]. These states are generated through a second-order non-linear optical process known as spontaneous parametric down conversion (SPDC) in which photons from an input laser (pump) get down converted to two daughter photons (signal and idler) when the conditions of energy and momentum conservation are satisfied[1,2]. Material dispersion makes momentum conservation challenging, and typically periodic poling for quasi-phase matching (QPM) is often employed as one of the approaches to compensate for this phase mismatch[1,2]. The relationship between phase mismatch (Δk) and the poling period (Λ) of an SPDC process[2] can be written in terms of the effective refractive indices ($n_p, n_{r=\{s,i\}}$), and wavelengths ($\lambda_{p,s,i}$) of the interacting modes as

$$\Delta k = 2\pi \sum_{r=s,i} \frac{n_p - n_r}{\lambda_r} = \frac{2\pi}{\Lambda} \dots (1)$$

To explore the possibility of enabling multiple and very distinct SPDC processes using a single poling period, we study and compare three different waveguide platforms (PPLN ridge, PPKTP, and TFLN)[2], with different cross-sections and refractive index contrast, and study their dispersion (variation of effective index n_{eff} with wavelength) as shown in Fig. 1. The plot shows the strongest dispersion in case of TFLN owing to its small cross-section and large refractive index contrast. This strong dispersion means that even small changes in wavelength result in significant changes in the effective indices. This allows the numerator term ($n_p - n_r$) given in Eq.(1) to compensate for wavelength changes between different SPDC processes, such that different useful SPDC processes across telecom band region can be enabled by same poling period (Λ)—something that is not feasible with weakly dispersive platforms[1]. This study has been confirmed by considering and comparing poling periods of different SPDC processes across telecom bands for the considered waveguide platforms.

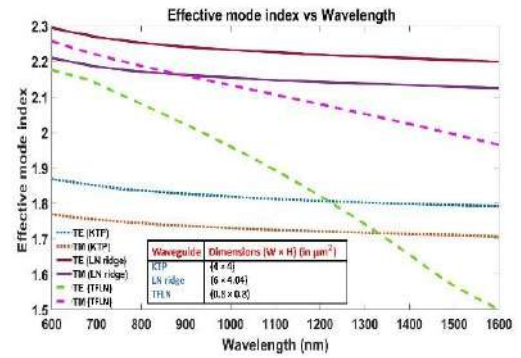


Fig.1 Variation of n_{eff} vs λ for different waveguides

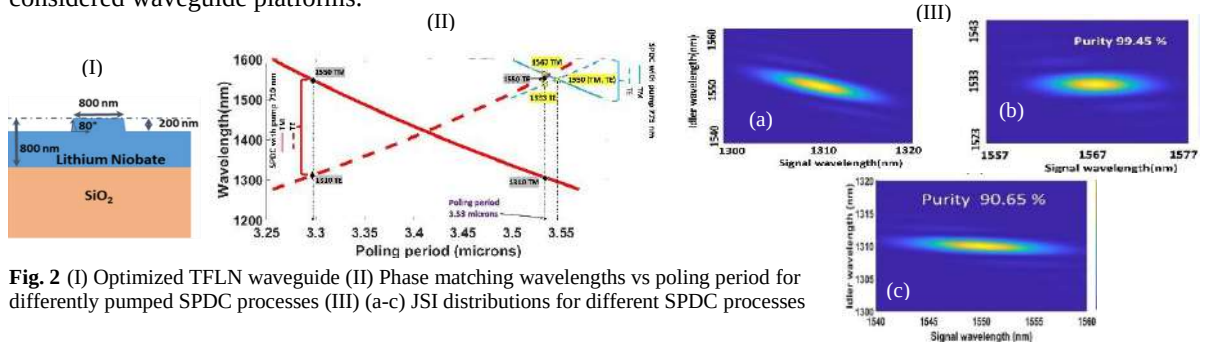


Fig. 2 (I) Optimized TFLN waveguide (II) Phase matching wavelengths vs poling period for differently pumped SPDC processes (III) (a-c) JSI distributions for different SPDC processes

Fig. 2(I) shows our optimized TFLN waveguide design, while in Fig. 2(II) we plot the variation of phase-matched signal-idler wavelengths as a function of poling period (Λ) for two different type-II SPDC processes one pumped at 710 nm and the other at 775 nm. From the plot, we can see that at $\Lambda \sim 3.53 \mu m$, both processes generate photon pairs in desired telecom O- and C-bands: pump at 710 nm pump results in signal-idler photons at 1310 nm (TM) and 1550 nm (TE) respectively. While pump at 775 nm give rise to signal-idler photons at 1567 nm (TM) and 1533 nm (TE), respectively. Joint spectral intensity (JSI) analysis (Fig. 2(III(a-b))) shows that the SPDC process pumped at 710 nm produces spectrally correlated pairs (Fig. 2(III(a))), while the SPDC corresponding to 775 nm pump yields uncorrelated pairs with 99.45% purity (Fig. 2(III(b))). Apart from that, the same waveguide design with a slightly different poling period of $3.29 \mu m$ (Fig. 2(II)) can also be used to generate orthogonally polarized spectrally uncorrelated photons at 1310 nm (TE) and 1550 nm (TM) with spectral purity of 90 % as confirmed by JSI fig. 2 (IIIc).

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Exploration of promising electronic, vibrational and NLO properties of stilbene and its derivatives: a TD-DFT/DFT approach

Paven Kuruvilla^{1,2*}, Mohamed Ashfaaq^{1,2}, Alisha K^{1,2}, M. R. Kannan¹, S. Manvizhi¹, and T. Vijayakumar^{1*}

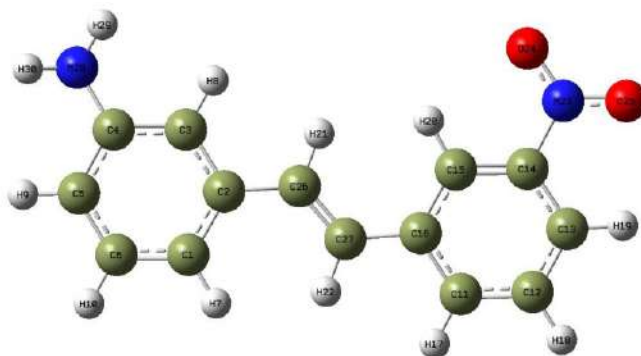
¹ Futuristic Materials Research Centre for Planetary Exploration, Department of Physics and Nanotechnology, College of Engineering and Technology, Faculty of Engineering and Technology, SRM Institute of Science and Technology, Kattankulathur - 603 203, Chengalpeta, Tamil Nadu, India

² Department of Electronics and Communication Engineering, College of Engineering and Technology, Faculty of Engineering and Technology, SRM Institute of Science and Technology, Kattankulathur - 603 203, Chengalpeta, Tamil Nadu, India

Corresponding authors: pk1974@srmist.edu.in and vijayakt1@srmist.edu.in

Abstract

In recent years, Intramolecular Charge Transfer (ICT) has gained attention in the development of advanced nonlinear optical (NLO) materials. ICT systems have evolved with the integration of strong donor-acceptor architectures, enabling enhanced second and third-order NLO properties. This study demonstrates the D- π -A configured stilbene-based chromophores (P1-P10) were designed to study their nonlinear optical (NLO) properties. The molecular structures of the designed derivatives were optimized at B3LYP/6-311++G(d,p) functional. Comprehensive theoretical analysis such as frontier molecular orbitals (FMOs), density of states (DOS), UV-Visible (UV-Vis), Natural bond orbitals (NBOs) and nonlinear optical (NLO) properties were carried out at same functional mentioned above. The FMO analysis revealed that all the derivatives exhibit lesser band gap values than the reference stilbene(P0), with P9 demonstrating that least band gap among all the derivatives manifesting highest reactivity and NLO properties. NBO calculations demonstrated strong stabilization and extensive delocalization in the chromophores that contribute to their structural stability. The DOS calculations confirmed efficient charge transfer from HOMO to LUMO, showing high charge transmission. In the NLO analyses, all the designed derivatives demonstrated with dipole moment (μ), polarizability (α), and first order hyperpolarizability (β) leads to higher NLO performance. The intramolecular charge transfer can be significantly improved by the incorporation of various acceptors into stilbene molecule, thereby increasing the NLO activity. These properties, together with good stability and exhibits higher NLO property, suggest the potential use of the new chromophores as advanced material devices.



SCOPOSIS 2025

Real-time Detection of Protein Biomarkers Using High-Quality Factor Whispering Gallery Mode Photonic Microresonators

Arya Kumar Siddharth[†], Shubham Kumar Mahanta^{†*}, and Venkata Ramanaiah Dantham

Department of Physics, Indian Institute of Technology Patna, Bihar 801103, India

[†]Authors contributed equally

**Presenting author: shubham_2421ph15@iitp.ac.in*

Recently, whispering gallery mode (WGM) photonic microresonators have been found useful for real-time detection of pathogens such as viruses and protein markers of dangerous diseases [1]. The WGM biosensors have unparalleled sensitivity and ultra-high resolution. The detection of pathogens has been demonstrated by monitoring the shift in the wavelength locations of the WGM upon adsorbing pathogens on the surface of the microresonators [2,3]. Along with the detection, the crucial information of pathogens, such as size and mass/molecular weight, can be easily extracted from the experimental wavelength shift of the WGM with the help of the reactive sensing principle [4,5]. This can be considered the unique feature of the WGM biosensors.

Herein, we report the real-time detection of thyroglobulin and myoglobin protein biomarkers using high-quality factor WGM microresonators. Thyroglobulin is a protein biomarker for thyroid disorders, including thyroid cancer and autoimmune conditions, and myoglobin is an important biomarker for the early diagnosis and assessment of myocardial infarction (heart attack) [6]. The microresonators are fabricated using a nanosecond CO₂ laser, and the high-quality factor WGMs are achieved by the phase-matching excitation using the tapered optical fibers, which are fabricated using a propane-gas flame melting apparatus. The experiments are performed by immersing the fabricated microresonators in the buffer solution encapsulated by a microfluidic channel. The fabrication details of the microresonators and tapered fibers, experimental results, and analysis of the experimental results will be presented at the SCOPOSIS 2025.

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Unveiling the intramolecular charge transfer kinetics via vibrational, terahertz, structural and optical properties of calmagite for NLO applications

M. R. Kannan^{1*}, S. Manvizhi¹, Ajinkiya Punjal², Raturaj Puranik², Utkarsh Pandey², S. S. Prabhu², Naini Bajaj³, Amartya Sengupta³, T. C. Sabari Girish⁴ and T. Vijayakumar^{1*}

¹*Futuristic Materials Research Centre for Planetary Exploration, Department of Physics and Nanotechnology, College of Engineering and Technology, Faculty of Engineering and Technology, SRM Institute of Science and Technology, Kattankulathur - 603 203, Chengalpet, Tamil Nadu, India*

²*Department of Condensed Matter Physics and Materials Science, Tata Institute of Fundamental Research, Mumbai, Maharashtra 400005, India*

³*Department of Physics, Indian Institute of Technology Delhi, New Delhi 110016, India*

⁴*Nanophotonics Laboratory, Department of Physics, Bharathidasan University, Tiruchirapalli 620024, India*

*Corresponding Author Email id: km5890@srmist.edu.in and vijayakt1@srmist.edu.in

Abstract

Azo dyes have been used extensively in a variety of industries, including food, cosmetics, biological applications, and textile dye baths. In recent years, experimental and theoretical analysis of azo dyes have been conducted because of the significance of molecular structure [1,2]. In the present work, the potential compound of calmagite was investigated using FT-IR, FT-Raman, UV-Visible spectra, and quantum chemical computations. The vibrational contribution of each normal mode is calculated using the vibrational energy distribution analysis (VEDA 4) programme. The electronic stability of the compound arising from hyper conjugative interactions and charge delocalization is investigated using natural bond orbital analysis. The third order nonlinear optical parameters were analyzed by Z-scan technique. The second harmonic generation was validated by using powder method. The intramolecular charge transfer was analysed by the Terahertz time domain and Terahertz Raman spectroscopy.

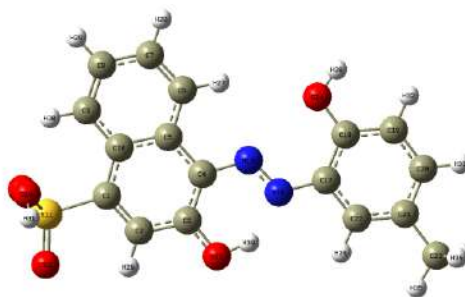


Fig.1. Optimized Structure of Calmagite

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Identifying Optimal Magnetic Field Configurations for Decoherence Mitigation of Boron Vacancies in Hexagonal Boron Nitride

Basanta Mistri¹, Saksham Mahajan², Felix Donaldson³, Rama K. Kamineni⁴, Siddharth Dhomkar¹

¹*Department of Physics, Indian Institute of Technology Madras, Chennai 600036, India*

²*Department of Electrical and Electronic Engineering, University College London, London WC1E7JE, UK*

³*London Centre for Nanotechnology, UCL, London WC1H0AH, UK*

⁴*SIAS, Krea University, Sri City 517646, India*

The negatively charged boron vacancy (VB^-) center in two-dimensional hexagonal boron nitride (hBN) has recently emerged as an excellent candidate for quantum sensing applications due to its ability to host spin-1 electronic states with robust optical readout at room temperature. However, its quantum sensing performance is fundamentally limited by rapid spin decoherence, originating from a dense bath of hyperfine-coupled nuclear spins in the hBN environment.

In this work, we systematically investigate how external static magnetic field strength and orientation can be tuned to identify subspaces of the VB^- defect's Hamiltonian that are optimally protected against decoherence. By detailed numerical diagonalization of the composite spin Hamiltonian encompassing both electron and nuclear spin degrees of freedom, we map transition energies, their gradients, and curvatures across a broad range of field amplitudes and directions. Figures 1 illustrates the energy gradient of a spin transition with the highest possible transition probability at the specific field strengths.

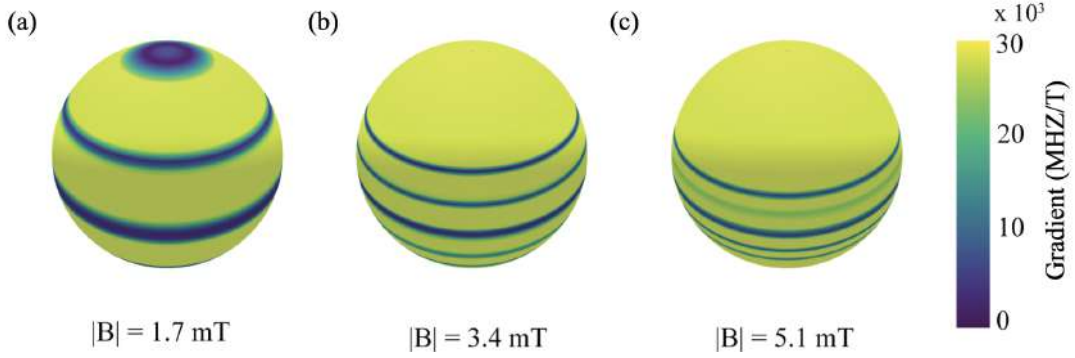


Figure 1: The energy gradient of a spin transition with the highest possible transition probability at the specific field strengths.

We discover that specific magnetic field strengths and orientations, particularly near level anti-crossings and for Zeeman–hyperfine matching conditions, lead to a sharp reduction in energy gradients, yielding “decoherence-free subspaces.” This minimization condition is described analytically as $B_z = -\frac{m_I A_{zz}}{\gamma_e}$ allowing generalization to other spin-1 defects coupled to nuclear environments. We further show that transverse magnetic fields provide a broad regime of reduced magnetic sensitivity.

To quantify the practical impact, we estimate the coherence times (T_2) achievable in these optimal regimes using a perturbative model incorporating both gradient and curvature contributions to the energy broadening induced by magnetic noise. Our results indicate that coherence lifetimes can be substantially enhanced—by up to an order of magnitude—at targeted field configurations.

This approach provides a widely applicable framework for decoherence mitigation in solid-state quantum systems where isotopic purification is not possible and dynamical decoupling may be impractical. The developed methodology and identified field configurations offer valuable insights for experimental decoherence suppression and advanced quantum sensing protocols in 2D materials.

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Study of Bloch Surface Wave Properties in a Truncated Cylindrical One-Dimensional Binary Photonic Crystal

Gaurav Singh¹, Vivek Singh¹

1. Department of Physics, Banaras Hindu University, Varanasi, Uttar Pradesh 221005, India

This work presents a theoretical analysis of Bloch surface waves (BSWs) in a truncated one-dimensional binary photonic crystal (1D-BPC), a structure that has not been extensively studied before[1]. Comprising alternating high- and low-refractive-index dielectric layers arranged radially around a solid core, the model focuses on transverse magnetic (TM) polarised waves[2,3]. Using the transfer matrix method (TMM) in cylindrical coordinates, we investigate the field distribution, confinement, and decay length. The results reveal strong surface mode confinement within the photonic band gap (PBG), with the thickness of the truncation layer playing a critical role in localisation and decay characteristics[4]. The effect of variation of thickness of truncated layer structure has been studied where it is found that the surface truncation give rise to surface mode which are confined within the photonic band gap.

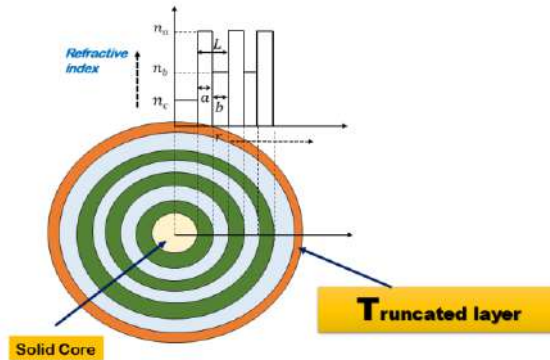


Fig: Schematic diagram of a one-dimensional cylindrical binary photonic structure in the radial direction with a solid core.

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Exploring The Förster Resonance Energy Transfer Between Ligand-Protected Copper and Gold Nanoclusters for Enhanced Photoluminescent Applications

Shubhankar Narayan Bandekar and Sudhir Cherukulappurath,

School of Physical and Applied Sciences, Goa University, Taleigao Plateau, Goa 403206

Metal nanoclusters are isolated particles less than 2 nm in size with several to a hundred atoms. Due to their discrete energy levels and strong quantum confinement, they exhibit molecule-like optical and electronic properties such as strong photoluminescence [1]. We report a systematic investigation of the Förster Resonance Energy Transfer (FRET) mechanism between ligand-stabilized copper nanoclusters (Cu NCs) and gold nanoclusters (Au NCs) in aqueous media. FRET is a non-radiative energy transfer process between two light-sensitive molecules - a donor and an acceptor, based on dipole-dipole interactions. The Cu NCs, synthesized using ascorbic acid and PVP as reducing and stabilizing agents, exhibit strong blue photoluminescence while Au NCs present red emission when excited with lower wavelength light. [2-4]

Upon coupling Cu NCs with BSA-stabilized Au NCs, we observe a dynamic interplay of donor-acceptor interactions that are characteristic of FRET mechanism. Such a configuration supports efficient non-radiative energy transfer pathways, making these hybrid assemblies highly promising for photonic and biosensing applications. Further we have used silica coated gold nanoparticles to study the Metal Enhanced Fluorescence (MEF) in the FRET between Cu NCs and Au NCs. This enhancement arises from the interaction between the fluorophores and the localized surface plasmon resonance (LSPR) of the metal, which boosts both the excitation and emission processes.[5]

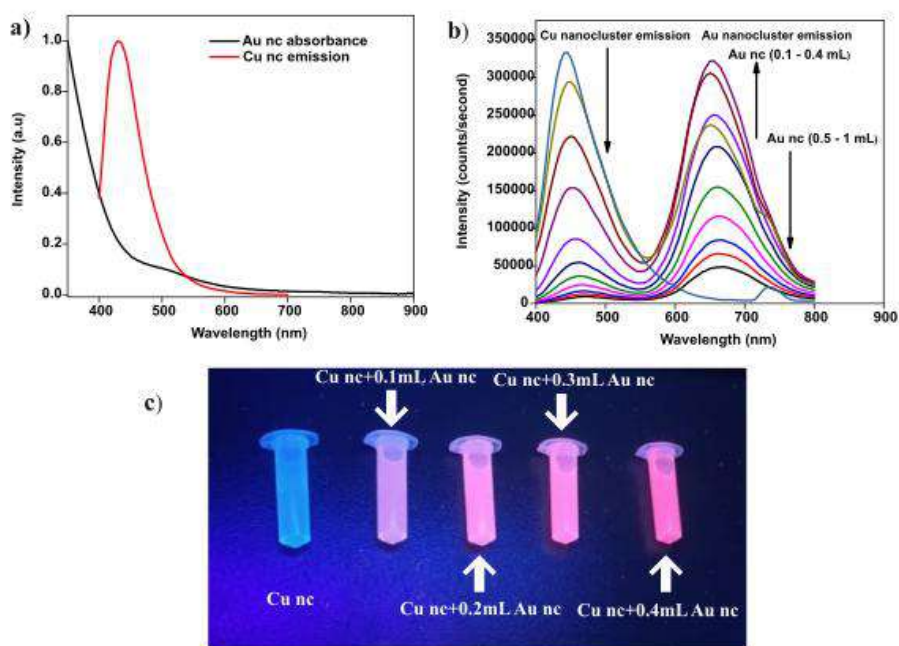


Fig. 1 a) Spectral overlap between Cu nanocluster emission and Au nanocluster absorption, b) FRET plot between Cu nanoclusters and Au nanoclusters and c) Cu nanoclusters (Left) with increasing volume of Au nanoclusters viewed under UV light.

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Polarization entangled photon pairs from spatial multiplexing of SPDC in a Type-0 single-pass geometry

Milan Jana^{1,2}, Swagata Sarkar^{1,2}, Ayan Kumar Nai^{1,2}, and G. K. Samanta¹

¹ Photonic Sciences Laboratory, Physical Research Laboratory, Navrangpura, Ahmedabad 380009, India

² Department of Physics, Indian Institute of Technology Gandhinagar, Palaj, Gandhinagar 382355, India

Generation of a bright entangled photon source (EPS) with high interference visibility has been one of the key research topics in the field of experimental quantum optics, and the spontaneous parametric down conversion (SPDC) process has been used extensively for this purpose. Using the highly correlated pair photons generated randomly in time and momentum distribution, the two main criteria of local realism (local randomness and distant correlation) can be violated to establish entanglement in various degrees of freedom. For polarization-based entanglement, the local randomness has been established through various post-processing techniques in the literature, including the use of a beam-splitter (BS) [1], a Sagnac interferometer geometry [2] with Type-0/Type-I phase phase-matched SPDC, and a single delay Type-II phase-matched SPDC setup [3]. However, all these techniques have their own limitations in terms of the unavailability of an ideal BS and the stringent requirement of symmetric position of the nonlinear crystal in the Sagnac loop to avoid a relative phase between the photons generated in both directions. To overcome these limitations, we employ (see Fig. 1(a)) a single-pass, non-collinear, type-0 phase-matched (PP-KTP crystal), degenerate SPDC process to generate photon pairs exhibiting strong temporal and spatial quantum correlations at diametrically opposite points on an annular emission ring, with inherent quantum-mechanical randomness. By spatially sectioning the ring into two halves (blue and pink colour), transforming in orthogonal polarizations, superposing them by a PBS after introducing controlled relative delay (delay to pink colour half), and subsequently partitioning the resultant superposed half ring into two quarters by a D-shaped mirror, we detect the correlated photon pairs to realize a high-fidelity Bell state:

$$|\psi^-\rangle = \frac{1}{\sqrt{2}}(|H_A V_B\rangle - |V_A H_B\rangle) \quad (1)$$

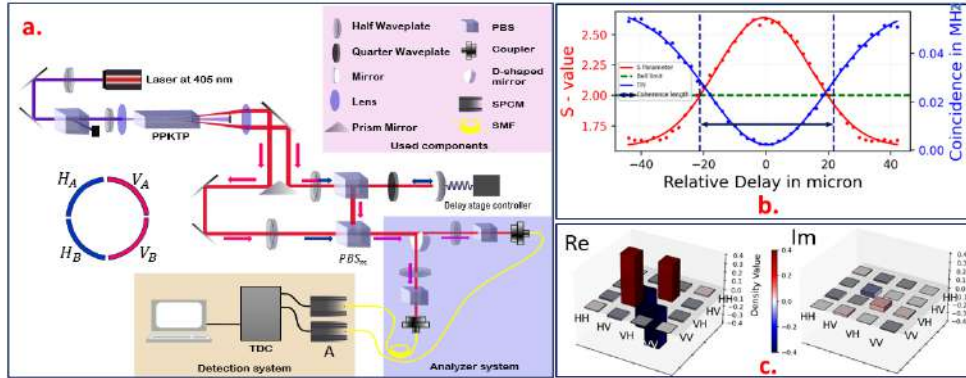


Fig. 1: **a** Schematic experimental set-up. CW, single-frequency laser at 405 nm acts as a pump. **b** Variation of S value and coincidence counts with the path delay between the pair photons. **c** Real and imaginary parts of the reconstructed density matrix of the generated state.

Although the photon pairs generated on the emission ring are inherently probabilistic and indistinguishable, differences in propagation paths, polarization transformations to orthogonal states, and subsequent combination at the PBS in the current experiment render them distinguishable. We erased it by transforming both photons into diagonal polarization and employing a translation stage to precisely control the relative optical delay. Experimentally, we scan the path delay and measure two-photon interference via coincidence counts and the Bell parameter S , as shown in Fig. 2(b). The maximum violation of the Bell inequality, $S = 2.62 \pm 0.017$, coincides with the minimum coincidence rate at zero relative delay, confirming the generation of a high-quality entangled state. The source exhibits a brightness of 0.23 MHz/mW, a fiber coupling efficiency of 11.5%, and a spectral bandwidth of 10 nm. Quantum state tomography, shown in Fig. 1(c), reveals real and imaginary components of the reconstructed density matrix consistent with the Bell state ψ^- , yielding a fidelity of 0.95 and a concurrence of 0.83. In conclusion, we have demonstrated a broadband high-brightness entangled-photon source in a single-pass SPDC geometry. Further results will be presented in future work.

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Structured Laser Beams for Robust Vertical Free-Space Optical Communication Links: A Numerical Study Using Scintillation Index Estimations

Lekshmi S R¹

¹ Space Physics Laboratory, Vikram Sarabhai Space Centre, ISRO, Thiruvananthapuram, India, 695022.

Atmospheric turbulence remains as a significant challenge to the free-space optical communication (FSOC) systems, as the random fluctuations in the refractive index cause wave-front distortions. These distortions are primarily observed as intensity fluctuations. The corresponding normalized intensity variance is called the scintillation index and it serves as a major parameter that quantifies the atmospheric distortion. Larger values of scintillation index correspond to severe wave-front distortions and vice versa [1].

In this current study, scintillation indices of three classes of beams of distinct spatial diversity (fundamental Gaussian, Hermite–Gaussian (HG) of first order, and Laguerre–Gaussian (LG) of first order) are estimated when passed through an identical vertical communication channel [2]. These results give clear insights on the comparative robustness of individual beams to the impact of atmospheric turbulence. This high-confidence, multi-beam comparison paves a new direction for structured-beam design in vertical FSOC channels.

To investigate the effect of a vertical communication link, a turbulent channel of 20km altitude which resembles to a ground to satellite communication system is simulated. Throughout the vertical link, the refractive index structure constant (C_n^2) varies as a function of altitude which is given by the Hufnagel-Valley (H-V) model with a ground level turbulence of $C_n^2 = 10^{-15} \text{m}^{-2/3}$ and wind speed of 21m/s [1]. The corresponding Fried parameters are calculated and multiple phase screens following Kolmogorov turbulence statistics are generated at an interval of 100m throughout the link length [3]. Three distinct beams (Gaussian, HG and LG) are then propagated through the resulting turbulent medium. By analyzing the scintillation index values over 500 independent realizations of phase screens, resilience of each beam shape to the turbulence impact is compared and robust candidates for vertical FSOC systems is identified. The following figure shows the vertical C_n^2 profile estimated using the H-V model and the scintillation index calculated for different classes of incident beams.

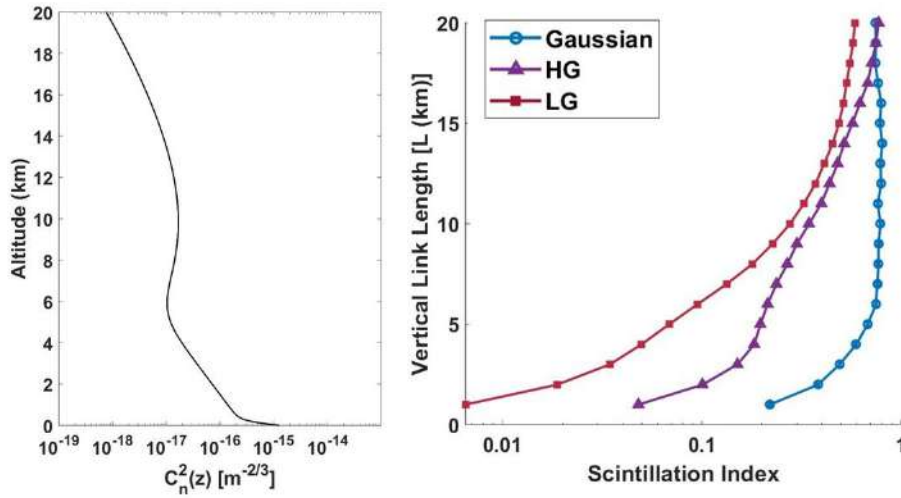


Fig. 1 (a) Shows the refractive index structure constant profile C_n^2 as a function of altitude and (b) Shows the scintillation indices corresponding to Gaussian, Hermite-Gaussian (HG) and Laguerre-Gaussian (LG) beams for vertical links 0-20km.

From the above figure one can infer that the fundamental Gaussian beam exhibits the largest value of scintillation index while LG and HG beams show considerably lower values. This advantage is most pronounced over link lengths below 12 km and beyond that point, all beam types mostly converge to a common plateau since the cumulative effect of decreasing C_n^2 also approaches a constant value. From scintillation index estimations, it can be concluded that deploying certain structured beams, especially for shorter link lengths and weaker turbulence, can substantially improve the quality for ground-to-satellite communications without additional hardware. Out of the three classes of beams, LG beams gives the smallest value up to around 12km which makes it a preferred candidate for such vertical FSOC system. However, beam generation complexity, receiver coupling, and pointing stability must also be taken into account before choosing an input beam.

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Classification of Phase Objects from their In-line Holograms

Chhavi¹, Ritish Kamboj¹, Kedar Khare², Satish Kumar Dubey¹

¹. SeNSE, Indian Institute of Technology Delhi, New Delhi 110016, India

². Optics and Photonics centre (OPC), Indian Institute of Technology Delhi, New Delhi 110016, India

Digital lens-less in-line holographic microscopy (DLIHM)[1], [2] is an advanced quantitative phase imaging [3] technique that records the intensity hologram encoding complex optical field (both amplitude and phase) information directly on the sensor without any imaging optics. This enables compact, cost-effective, label-free imaging over a wide field of view, making it suitable for high-throughput biological analysis and field-portable diagnostics. Hologram recorded by DLIHM is a Fresnel diffraction pattern that captures the spatial map of optical-path-length variations within the transparent biological specimen, embedding quantitative morphological and biophysical features: thickness, area, volume, diameter, refractive index variations etc. Hologram is typically reconstructed numerically to convert the coded information to a visually understandable phase and intensity maps. It is computationally intensive and time-consuming step, limiting practical utility of DLIHM in real-time and in resource limit settings. Numerical reconstruction is not necessary when objective is only classification rather than imaging [4], [5], as the raw diffraction pattern inherently contains all the optical information required for automated decision-making. However, the structure and the spatial frequency content present in the hologram depends on object to detector distance (z), as diffraction increases with z (Fig. 1a), the information bandwidth changes, directly affecting classification accuracy. Here, we demonstrate a reconstruction free machine learning approach for object classification directly from the diffraction data and find an optimal z range. Holograms are simulated across a broad z range, expressed in units of the effective depth of focus[6] : $z/\text{DoF}_{\text{eff}} = [0.25, 0.5, 1, 2, 5, 10, 15, 20, 50]$. Where $\text{DoF}_{\text{eff}} = \lambda/(NA_{\text{eff}})^2$ and NA_{eff} is the effective numerical aperture enclosing 95% of the object's spectral energy and λ is wavelength of incident plane wave. In-line holograms of the MNIST phase object dataset (60,000 training and 10,000 test images of 28×28 handwritten digits) are simulated using $\lambda = 0.5\mu\text{m}$ and detector pixel size of $2\mu\text{m}$. For each $z/\text{DoF}_{\text{eff}}$, holograms are generated via angular

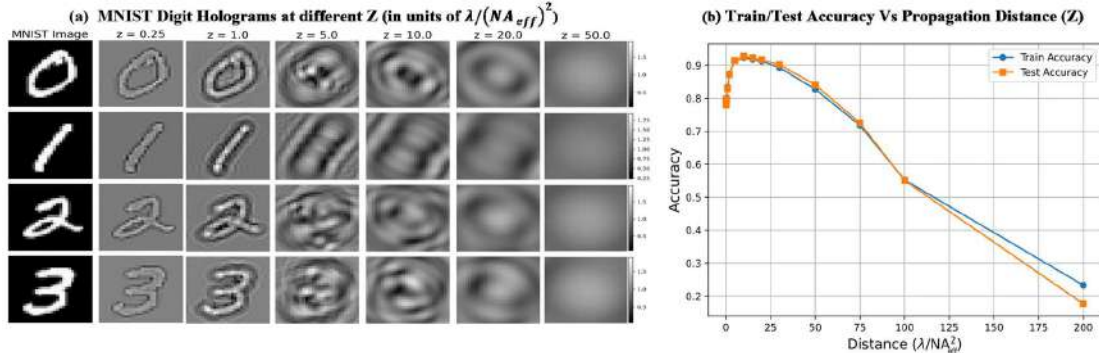


Fig 1. (a) In-line holograms of MNIST digits at propagation distances $Z = [0.25, 1, 5, 10, 20, 50] \lambda/(NA_{\text{eff}})^2$ as shown left to right. (b) Training and test accuracy as a function of propagation distance (Z).

spectrum propagation and a logistic regression model[7] (100 iterations, batch size = 32, learning rate = 0.1) is trained independently at each z to evaluate classification performance. Classification accuracy increases with z due to improved diffraction contrast, peaking at $z = 10 \times \text{DoF}_{\text{eff}} \approx 720\mu\text{m}$ with 92.5% test accuracy which is nearly identical to the original MNIST dataset (92.4%) and then declines at higher z due to the loss of high-frequency information in the holograms (Fig 1b). This proof-of-concept lays the groundwork for label-free, real-time classification of biological samples directly from raw in-line holograms without reconstruction using the DLIHM configuration.

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Surface Plasmon Enhanced Giant Goos–Hänchen and Imbert–Fedorov Beam Shifts on a Corrugated Metal Surface

Arani Maiti¹, Abhi Mondal¹, Souvik Roy¹, Ayan Banerjee¹, Nirmalya Ghosh¹, Subhasish Dutta Gupta^{1,2}

1. Indian Institute of Science Education and Research Kolkata, Department of Physical Science, Mohanpur, India

2. Tata Centre for Interdisciplinary Sciences, TIFRH, Hyderabad 500107, India

E.mail-am23ip014@iiserkol.ac.in

The longitudinal Goos–Hänchen (GH) and the transverse Imbert–Fedorov (IF) beam shifts from optical interfaces have played an important role in enriching our understanding of various non-trivial optical phenomena and for applications in metrology and sensing. Mechanisms for enhancing these two variants of the beam shifts are important in the context of their practical applications. In this regard, while surface plasmon resonance-mediated enhancement of GH shift in reflection from metal-dielectric interfaces are well studied, there are only limited investigations on the corresponding Imbert–Fedorov or Spin Hall shifts mediated by spin orbit interaction of light in plasmonic interfaces. Moreover, most of the studies on beam shifts from plasmonic interfaces are conducted using fundamental Gaussian beams, and the use of structured light or vortex beams in this scenario has not been explored. Here, we have investigated both the GH and the IF shifts of fundamental Gaussian and higher order Laguerre-Gaussian beams from a corrugated silver (Ag) interface using a generalized angular spectrum method. The surface plasmon-mediated enhancement of the different variants of the beam shifts and their dependence on the pre and post selection of polarization states and input orbital angular momentum states (of vortex beams) of light are systematically investigated for obtaining the recipe for optimal enhancement. In agreement with previous reports, strong enhancement of GH shift around the surface plasmon resonance (SPR) window are observed, which are known to originate due to a sharp angular variation of the reflection coefficient r_p (for incident p-polarized waves) and $\partial \theta_i / \partial \theta_i$ r_p . We have also observed SPR-induced

strong enhancement of spatial spin Hall effect with proper choice of the incident and projected polarization states of the beam, a phenomena which has not been noticed before. We have also extended our investigation to include the influence of vortex beams (light beams carrying orbital angular momentum) within the SPR regime. The angular deviations associated with the GH and IF effects become intertwined with the complex vortex structure of the beam, resulting in additional shifts that are influenced by both the polarization state and the vortex charge of the beam. Furthermore, we have also investigated these shifts in the conical diffraction geometry by incorporating the conversion between the p and the s -polarization states of light, allowing us to capture the complete behavior of light in this complex reflection regime. The details of these results will be presented.

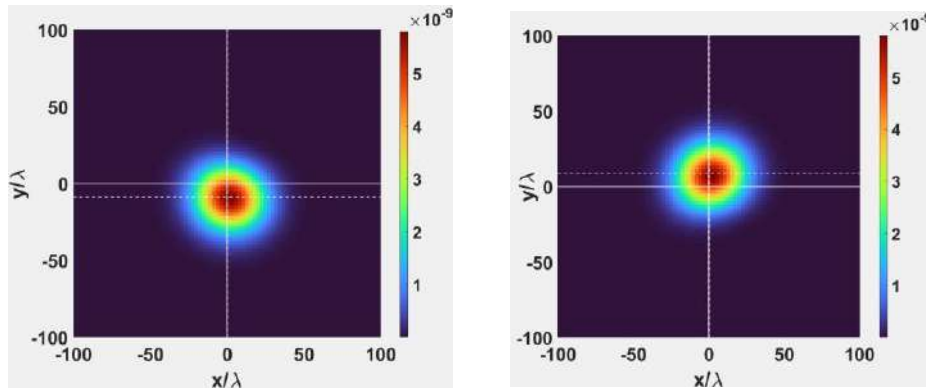


Fig. 1 Surface plasmon induced enhancement of spatial IF (spin Hall) shift. Input p-polarized state projected to its near orthogonal state with offset $\pm\epsilon = \pm 0.01$ where the incident angle was 40° .

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Spectrum Slicing and Bidirectional Transmission of WDM Signals

Amal Jani¹ and Shivaleela E S²

¹International School of Photonics, CUSAT, Kochi, India

²Department of ECE, Indian Institute of Science, Bangalore, India
amaljani14@ug.cusat.ac.in, lila@iisc.ac.in

We explore bidirectional transmission of wavelength division multiplexed (WDM) signals in the low-loss region of optical fiber, using spectrally-sliced wavelengths of broadband sources using fiber Bragg gratings (FBGs). Two broadband sources (BBS1 and BBS2) of 1530-1565 nm, are sliced, using two distinct FBG series networks to obtain five distinct optical carriers in each direction. These carriers are transmitted over 40 km single-mode fiber, in opposite directions, using circulators at both ends as in Fig 1(a). The spectrum at various points in the network are measured (refer table 1) using an Optical Spectrum Analyzer (OSA) as in Fig 1(b), with optical powers from the BBS1 measured at point x5 followed on by measuring at port 3 of C1 at x4 and finally port 4 of c2 at x1. These set of OSA readings are related to the first FBG series network, similarly reading were taken at x6, x3 and x2 for the second FBG series network.

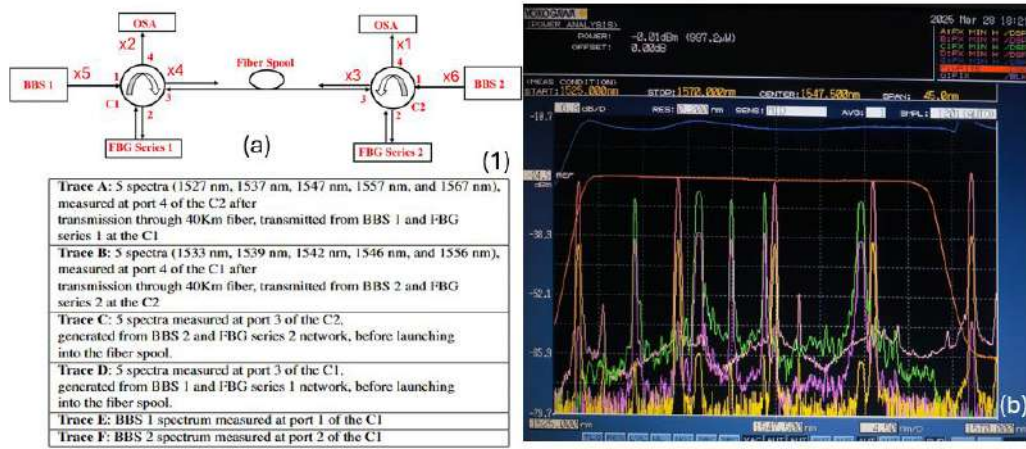


Fig. 1. (a) Spectrum slicing and 5 distinct Bragg wavelengths generated on each side and transmitted over 40 km single mode fiber spool (b) Traces taken at different points in the optical network using an OSA. Trace details are listed in table 1.

The power at various points throughout the system in regards to losses due to the path of $x5 \rightarrow x1$ can be obtained by examining the optical power at BBS1 (x5) as -11 dBm, port 3 of C1 (x4) as -25 dBm and OSA at port 4 of C2 (x1) as -40 dBm. In this, we see an overall loss of around 30 dB which is due to the two circulators, the reflectivity of the series network as well as the 40 km fiber path. Similarly, for the $x6 \rightarrow x2$, BBS2 (x6) -24.5 dBm, port 3 of C2 (x3) -29 dBm and port 4 C1 (x2) as -39 dBm. Here, we see an overall loss of around 15 dB. The difference in the loss between the 2 paths is due to the varying FBG reflectivity's. The findings in these papers help to underscore the importance of the precise wavelength selection and optimized component integration to minimize losses and interference, which are crucial when it comes to the advancement of a bi-directional fiber optic communication networks.

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Single-shot optical retardance imaging with polarization holography microscope

Mohit Rathor*, Sourav Chandra, Rakesh Kumar Singh

Laboratory of Information Photonics and Optical Metrology, Department of Physics, Indian Institute of Technology (BHU), Varanasi, Uttar Pradesh, 221005, India

*Email: rathormohit357@gmail.com

Abstract: Optical retardance measurement is vital for material characterization and biological imaging. Here, we present a retardance imaging microscope to capture the birefringence features of the sample using a polarization-resolved holographic system with a single-shot, common-path geometry.

Optical retardance is an intrinsic property of all materials and biological samples. Liquid crystals (LS) are most commonly used in research and industry and have high optical birefringence [1]. Measuring the birefringent parameters is crucial to quantifying and validating the LC-based device [2]. Besides material, retardance measurement of the biological cells is critical for identifying diseased cells and early disease detection. Retardance measurement is feasible by measuring the change in polarization state after interaction with the sample because the polarization describes the oscillation direction of the vector field.

Recently, several quantitative polarization imaging techniques have been developed. By replacing the polarization compensators with LC-based variable in conventional Pol-scopes, Oldenbourg and coworkers quantify the 2D distribution of birefringent parameters [3]. However, the need to acquire multiple images at different retarder orientations has limited the applicability of current systems to measure fast dynamical events. Several single-shot techniques enable rapid polarization dynamics measurement. Mu et al. used a Wollaston prism array for complete Stokes matrix retrieval but lacked microscopic validation [4]. Ortega-Quijano et al. measured linear dichroism at a single point, requiring 2D scanning for mapping [5]. We recently developed and published a polarization microscope system based on a modified Mach-Zehnder interferometer, enabling single-shot acquisition of spatially resolved polarization information from complex objects [6-7].

To rapidly image retardance distribution, we propose integrating polarization measurement with quantitative phase microscopy (QPM). QPM enables precise retardance estimation, offering structural and functional insights into the sample. Our single-shot, common-path method is fast and ideal for dynamic samples, but is limited to phase-only objects, such as microplastics and biological cells.

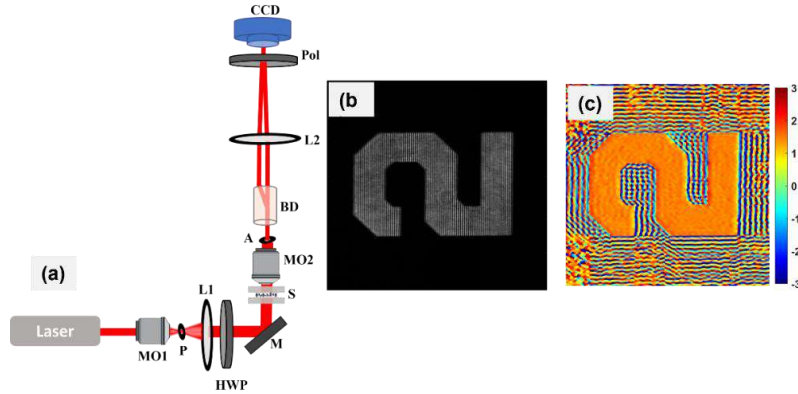


Fig. 1 (a) Schematic experimental design of the system; MO1 & MO2 are microscopic objectives, L1 & L2 are lenses, M: mirror, P: pinhole, A: aperture, S: sample, BD: beam displacer, Pol: polarizer. (b) experimental recorded polarization hologram; (c) experimentally reconstruct the retardance from the hologram.

We validated our proposed approach using a standard test object comprising a quarter-wave plate (QWP) and a resolution chart. Figure 1 shows the experimental setup, while Figures (b) and (c) display the recorded hologram and corresponding retardance map, respectively. The QWP was aligned at 0° to the horizontal, resulting in a theoretical retardance of 1.57 that closely matched the experimental measurement, thereby confirming the accuracy and reliability of our system. This performance indicates that it is beneficial for diagnostic applications in pathology.

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Non-invasive measurement of intraosseous blood flow in the knee-joint using Diffuse Correlation Spectroscopy

Susweta Das¹, Kavita Sharma¹, Hari M Varma²

¹. Department of Biosciences and Bioengineering, IIT Bombay, Mumbai, Maharashtra 400076, India

In this work, we used Diffuse Correlation Spectroscopy (DCS) to investigate the intraosseous blood supply in the knee targeting the patella and the meniscus region for the first time. DCS is a non-invasive optical technique for measuring microvascular blood flow and has been applied in various clinical contexts, including stroke, traumatic brain injury, and other functional studies. Recently, we used DCS to measure cerebral blood flow changes in the Anterior Cerebral Artery, a major artery of anterior cerebral circulation [1].

Here, we extend the application of DCS to probe blood flow within the patella and the meniscus region. In cases of knee injury, where vascularization is compromised, monitoring perfusion in the patella and the meniscus for initial examination and surgical intervention is crucial. A recent study using NIRS showed that patellar measurements are influenced by venous occlusion of the thigh, but not by cutaneous blood flow changes, supporting the feasibility that optical techniques can be used for probing into patellar hemodynamics [2].

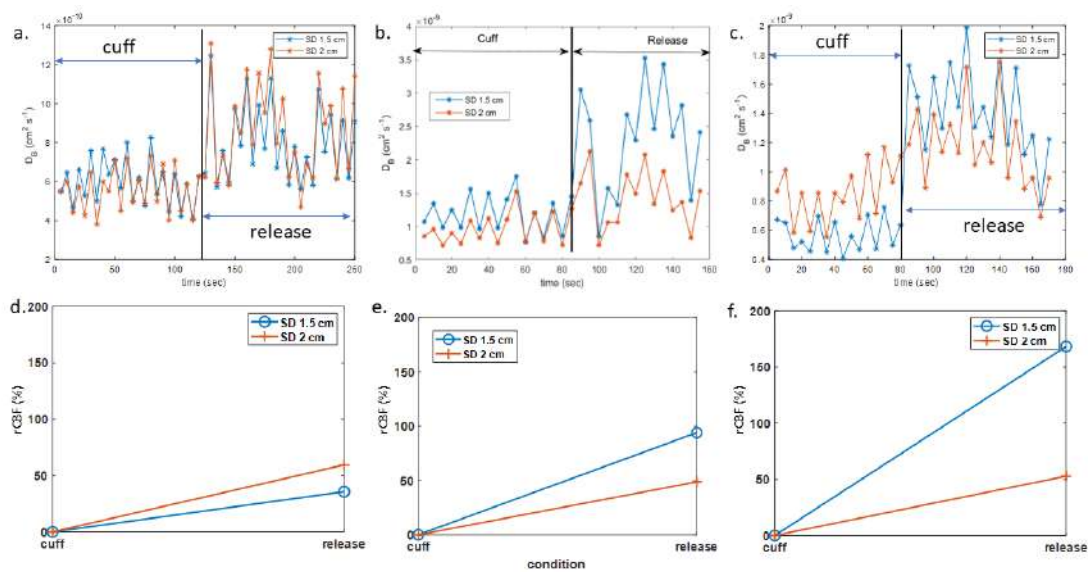


Fig. 1 Live blood flow plots during cuffed and release condition where the cutaneous blood flow is (a) lowered by icepack application (b) unperturbed (c) enhanced by local heating. The lower row is the mean blood flow changes w.r.t the cuffed condition where the cutaneous blood flow is (a) lowered by icepack application (b) unperturbed (c) enhanced by local heating.

In our study, blood flow was measured using our in-house developed DCS system [1] with two source-detector (SD) separations—1.5 cm and 2.0 cm—across three experimental trials on a healthy volunteer (protocol number – IITB- IEC/2024/10). Each trial followed an identical protocol: a thigh cuff was inflated for 1 minute prior to measurement, followed by 1–2 minutes of data collection during occlusion and 1–2 minutes post-release. In one trial, cutaneous blood flow was increased by applying heat to the patella; in another, it was decreased by applying an ice pack. As shown in Fig. 1, blood flow increased following cuff release in all trials and at both SD separations. However, relative cerebral blood flow (rCBF) at 1.5 cm showed variation with thermal manipulation (increasing from cold to warm), whereas the 2.0 cm data remained stable across all conditions. This suggests that the 2.0 cm separation has minimal contribution from cutaneous blood flow and may more accurately reflect blood flow within the patella. Future work will explore targeted functional tasks to perturb patellar or meniscus blood flow more specifically and validate this approach for quantitative intraosseous perfusion assessment.

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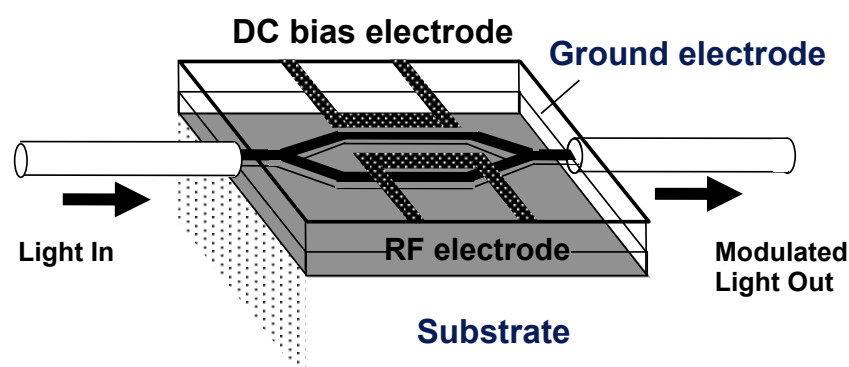
Indigenous Design and Fabrication of Polymeric Electro-Optic Modulator for Ultrafast Laser Communication Applications

T.Vijayakumar*, M.R,Kannan, S.Manvizhi, R.G.Tharun, M.Nagulan

Futuristic Materials Research Centre for Planetary Exploration, Department of Physics and Nanotechnology, College of Engineering and Technology, Faculty of Engineering and Technology, SRM Institute of Science and Technology, Kattankulathur - 603 203, Chengalpet, Chennai, Tamil Nadu, India

**Corresponding Author Email id: vijayakt1@srmist.edu.in*

Optical telecommunications have been the main application field driving the development of integrated optics devices. Devices of interest in this field include power splitters, switches, modulators, wavelength multiplexers/demultiplexer, optical cross-connects, dispersion compensators, gain equalizers, light sources and optical amplifier. Polymer waveguide technology has a great potential for economic mass production of complex planar photonic circuits that comply with the severe requirements imposed by applications in communication systems. The advances in space laser communications offer the communication system designer the flexibility to design very lightweight, high-bandwidth and low-cost communication payloads for satellites. In comparison to inorganic crystal-based modulators, organic polymer devices offer potential advantages of larger bandwidths and lower switching voltages, as organic polymers have low dielectric constants, which permit the optical and microwaves to propagate with nearly equal phase velocities. Moreover, organic polymers also offer exceptionally high electro-optic (EO) coefficients, which is a very important factor in reducing the switching voltage. In this paper, we discuss the indigenous fabrication of the polymer waveguide layers on a variety of substrates, by spin-coating, which enables integration of polymer waveguides with other components, and realization of conformable devices [1,2].



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Bridging Mid-Infrared and Telecom Bands for Free-Space Quantum Communication via Correlated Photon Pairs Generated in Silicon Waveguide

Abhishek Kumar Pandey¹, Deepak Jain¹, Catherine Baskiotis²

1. Indian Institute of Technology Delhi, New Delhi 110016, India
2. De Vinci Higher Education, De Vinci Research Center, Paris, France

Abstract: We propose spontaneous four-wave mixing in CMOS-compatible silicon waveguide design to generate quantum-correlated photon pairs bridging mid-infrared and telecom C-band. This tunable, scalable system enables efficient atmospheric quantum key distribution, advancing integrated quantum photonics applications.

Introduction: Sources of quantum-correlated photons spanning the mid-infrared (MIR) and telecom/visible bands are highly attractive for applications such as daylight atmospheric quantum key distribution (QKD), where MIR operation reduces Rayleigh scattering, mitigates solar background noise, and improves resilience to meteorological variations. Existing large-wavelength-separation sources typically use spontaneous parametric down-conversion (SPDC) in high χ^2 materials, which are costly, less versatile, and challenging to integrate on-chip. In contrast, silicon waveguide leverage a high χ^3 nonlinearity, low-cost CMOS-compatible fabrication, and scalability for practical quantum photonic systems. Here, we present a silicon photonic design achieving a record 2364 nm separation between signal and idler photons more than twice the previously reported value [1] linking the MIR atmospheric transmission window with the telecom C-band.

Theory and Method: We exploit the degenerate spontaneous four-wave mixing (SFWM) in the fundamental TE₀₀ mode of a silicon-on-insulator (SOI) waveguide. The process generates signal (ω_s) and idler (ω_i) photons from two pump photons (ω_p) when both the energy conservation condition ($2\omega_p = \omega_s + \omega_i$) and the phase-matching condition ($2\beta(\omega_p) - \beta(\omega_s) - \beta(\omega_i) = 0$) are satisfied, where $\beta(\omega)$ is the propagation constant. Phase-matching is governed by waveguide dispersion and dictates the achievable wavelength separation. The proposed SOI waveguide, illustrated in Fig. 1(a), consists of silicon core on a buried oxide (BOX) layer with SiO₂ cladding. We calculated the refractive indices of Silicon, SiO₂, and BOX using Sellmeier's equations, taking the BOX index equal to that of SiO₂. Using the Finite Element Method in COMSOL Multiphysics (Wave Optics Module), we computed the effective indices of the TE₀₀ mode across the target wavelength range to identify the phase-matching condition (cf. Fig. 1(b)). For a 2.210 μm pump, phase matching yields an idler at 1.541 μm in the telecom C-band and a signal at 3.905 μm in the MIR atmospheric window and targets the daylight QKD. The generated correlated photon pair wavelengths fall within silicon's transparency range, with propagation losses of 0.1 dB/cm (idler) and 0.002 dB/cm (signal). The MIR signal photon supports low-loss free-space links, while the telecom idler is compatible with standard single-photon detectors. Photon Pair-Generation probability per Pulse (PGP) was modeled following Barbier [2] under negligible-loss and narrow-bandwidth assumptions. For a 2 cm-long waveguide, 38.0 mW peak pump power, and 5 ps pulse duration, the maximum PGP reached ~ 0.05 (cf. Fig. 1(c)), consistent with prior experimental results[2], [3]. The PGP is tunable via pump power, and by varying waveguide dimensions, the design can target alternative MIR wavelengths for quantum photonics applications, including multi-waveguide arrays for species identification and precision sensing.

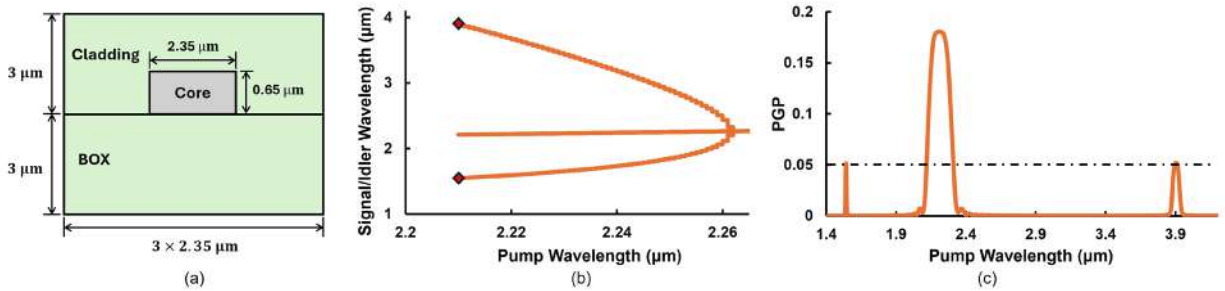


Figure 1(a) Cross sectional view of the waveguide. (b) Phase-matched signal and idler wavelength as a function of the pump wavelength. Phase-matched signal/idler wavelengths corresponding to selected pump wavelength is shown by red diamonds on the phase-matching curve. (c) Photon Pair-Generation probability per Pulse for the designed waveguide

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Synergistic Enhancement of Raman Signals Using a Novel Tri-hybrid Platform Combining Photonic Nanojet, SERS, and GERS Techniques

Anamika Sharma, Arya Kumar Siddharth, and Venkata Ramanaiah Dantham*

Department of Physics, Indian Institute of Technology Patna, Bihar 801103, India

*Corresponding author: dantham@iitp.ac.in

In this work, we introduce a novel tri-hybrid platform that combines Photonic Nanojet (PNJ), Surface-Enhanced Raman Scattering (SERS), and Graphene-Enhanced Raman Scattering (GERS) to significantly boost the giant enhancement in Raman signal intensity. To uncover the true potential of Raman spectroscopy, often hindered by low scattering cross-sections and fluorescence interferences, several advancements have been achieved. Researchers employ various advanced techniques, including PNJ-mediated Raman microscopy [1,2], SERS [3,4], and GERS [5-7], to amplify weak Raman signals from different materials. The enhancement of Raman signals in PNJ and SERS techniques is primarily driven by an electromagnetic mechanism, while GERS relies on a chemical mechanism. A synergistic approach that combines these techniques markedly improves Raman signal enhancements compared to using each technique individually.

Our results from this study, based on the integrated PNJ, GERS, and SERS techniques, demonstrate a significant improvement compared to the individual SERS or GERS methods. This combined effect not only improves the signal-to-noise ratio but also enhances spectral resolution, offering a cost-effective, simple, and robust strategy for the development of next-generation Raman spectroscopy platforms.

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Generation of arbitrary step waveforms using FBGs

Naveenkumar M^{1,2}, and Shivaleela E S¹

1. Electrical Communication Engineering, Indian Institute of Science, Bengaluru, Karnataka 560012, India

2. Department of Electronics and Telecommunication Engineering, Siddaganga Institute of Technology, Tumakuru, Karnataka 572103, India

We propose an optical arbitrary waveform generator capable of producing various staircase waveforms using a series Fiber Bragg Grating (FBG) network with distinct Bragg wavelengths in a reflection-based configuration. The system leverages existing optical transmitters and relies solely on passive, off-the-shelf fiber optic components, offering a simple, low-cost, and scalable solution for optical waveform synthesis.

Different methods have been reviewed [1] to generate optical arbitrary waveforms for high-energy laser systems and optical pulse waveforms [2] and [3]. In our experimental setup a broadband LED source is modulated by binary level electrical pulses, of width $1 \mu s$, is input at port 1 of a 3-port circulator. At port 2 of the circulator, cascade of five FBG series network of different Bragg wavelengths is connected. Fiber delay coils of length $d=10$ meters is placed in between each FBG to have a desired overlap between pulses reflected from each of them. The wavelengths corresponding to λ_1 , λ_2 , λ_3 , λ_4 , and λ_5 , are 1529.6 nm, 1533.3 nm, 1539.2 nm, 1542.87 nm, and 1546.3 nm respectively. All FBGs used in the experiment have uniform reflectivity.

The optical signal from port 3 of the circulator is detected by an optical receiver as shown in the Fig.1 (a), and then analyzed on the oscilloscope. The schematic is modified in such way that, the optical signal from port 3 of the circulator is passed through polarization controller (PC) and polarization beam splitter (PBS) as shown in the Fig.1 (b) to obtain two arbitrary waveforms. One of the polarized signal is delayed by $d_1=12$ meters length and combined with other polarized signal using polarization beam combiner (PBC) as in Fig.1 (c) and multi step waveform is obtained.

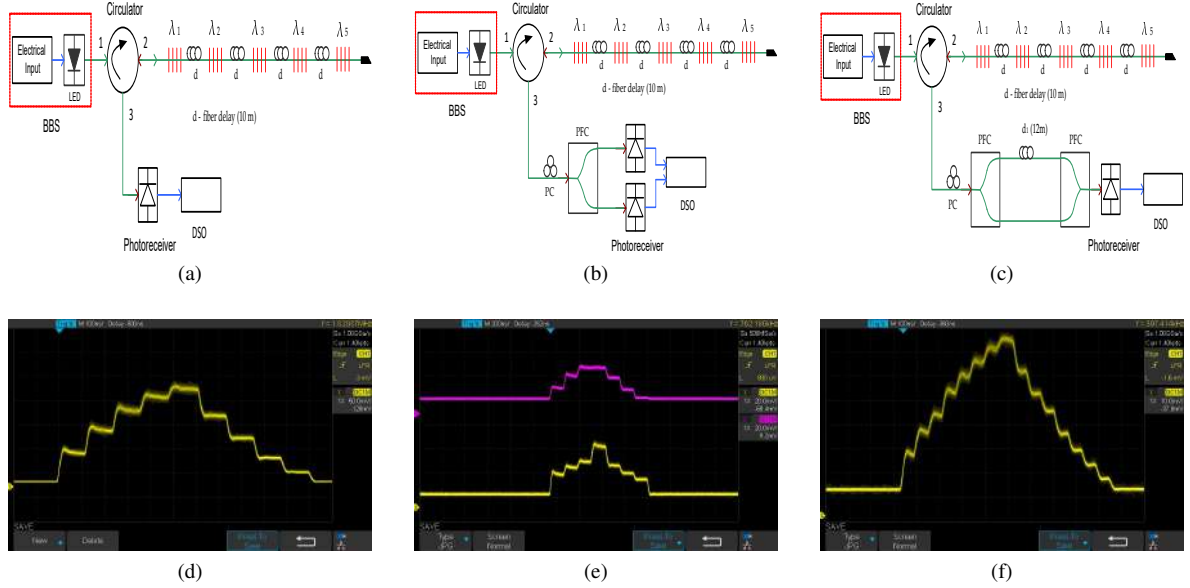


Fig. 1: Generation of arbitrary waveform with (a) five level signals (b) Ten level signals

For the three experimental setups, multiple arbitrary step waveforms obtained, for the schematic of Fig.1 (a), (b), and (c), are as shown in the Fig. (d), (e), and (f) respectively. This approach of generating optical arbitrary waveforms passively, is useful in applications requiring varied rise times and power levels.

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Probing mode-specific energy relaxation during polar solvation using broadband time-resolved impulsive stimulated Raman spectroscopy

Sakshi Chawla^{1,2}, Amit Kumar¹ and Arijit K. De¹

¹Condensed Phase Dynamics Group, Department of Chemical Sciences, Indian Institute of Science Education and Research Mohali, Knowledge City, Sector 81, SAS Nagar, Punjab 140306, India.

²Department of Chemistry, Indian Institute of Technology Gandhinagar, Gandhinagar, Gujarat 382355, India

Impulsive stimulated Raman spectroscopy (ISRS) is routinely used to monitor coherent vibrational dynamics in real-time. However, a couple of significant limitations of such two-pulse (Raman pump/probe) third-order (χ^3) measurements are that the timescales for population and coherence are inseparable, and the observation window of vibrational dynamics is limited by the dephasing time, which typically lasts for a few picoseconds only. To study vibrational dynamics in systems of varying complexities, circumventing these shortcomings, we developed three-pulse (actinic pump/Raman pump/probe) time-resolved ISRS (Fig. 1A), expanding upon the methodology of “broadband ISRS” [1-3], which enables mapping of vibrational amplitudes as islands in a contour plot of Raman shift to isolate individual vibrational modes (solute or solvent) from complex spectral regions that are otherwise challenging to observe using conventional Raman spectroscopy (Fig. 1B). We utilize this technique to study the polar solvation dynamics [4] using coumarin 153 in acetonitrile and show that the first/third-order ($\chi^1 + \chi^1$)/ χ^3 measurements offer unprecedented insights into energy flux from the probe solute to specific vibrational modes of the solvent [5] (Fig. 1B).

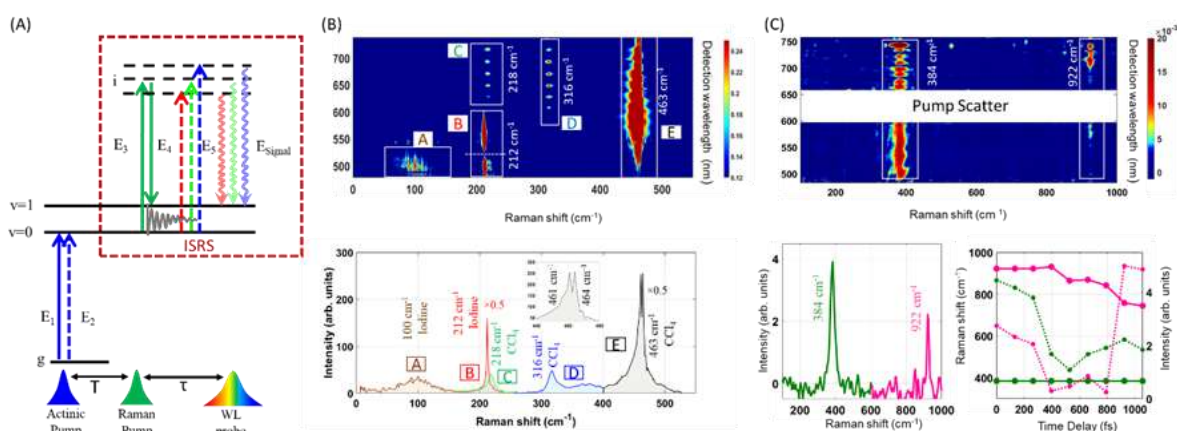


Fig. 1 (A) Schematic for broadband TR-ISRS, (B) contour plot for iodine in CCl₄ and Raman shift obtained by summing over different islands, and (C) contour plot for coumarin 153 in ACN, Raman shift obtained by summing over different islands, and variation of frequencies (solid) and amplitudes (dashed) of ACN modes at different actinic pump delays.

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High Bit rate Quantum Random Number Generator in Beam-splitter-free Architecture with Live Randomness Certification

Ayan Kumar Nai^{1,2*}, Vimlesh Kumar¹, M. Ebrahim-Zadeh^{3,4}, and G. K. Samanta¹

1. Photonic Sciences Lab., Physical Research Laboratory, Ahmedabad 380009, Gujarat, India

2. Indian Institute of Technology Gandhinagar, Palaj, Gandhinagar 382055, Gujarat, India

3. ICFO-Institut de Ciències Fòniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain

4. Institutio Catalana de Recerca i Estudis Avancats (ICREA), Passeig Lluís Companys 23, Barcelona 08010, Spain

Random numbers are crucial in diverse fields such as cryptography, secure communications, and scientific simulations [1]. While classical pseudo-random number generators (PRNGs) rely on deterministic algorithms and are vulnerable to predictability and tampering, quantum random number generators (QRNGs) harness intrinsic quantum randomness to produce truly random outcomes [2]. We demonstrate a beam-splitter-free, high-bit-rate, device-independent quantum random number generator (DI-QRNG) with real-time randomness certification via continuous Bell test measurements. By employing spontaneous parametric down-conversion (SPDC) in a polarization Sagnac interferometer, we generate degenerate, non-collinear entangled photon pairs at 810 nm in an annular distribution to use the temporal and spatial correlation of the photon pair. By dividing the ring into six sections and collecting photons from diametrically opposed sections, we create three entangled photon sources. Utilising two entangled photon sources, we generate a raw random bit sequence while the third source is simultaneously used to measure the Bell parameter for real-time quantumness certification without compromising bit generation. We achieved a post-processed bit rate of 1.8 Mbps with a minimum entropy of 97% from the raw bit stream, and continuous violation of Bell's inequality ($S > 2$) confirms the quantum origin of the randomness.

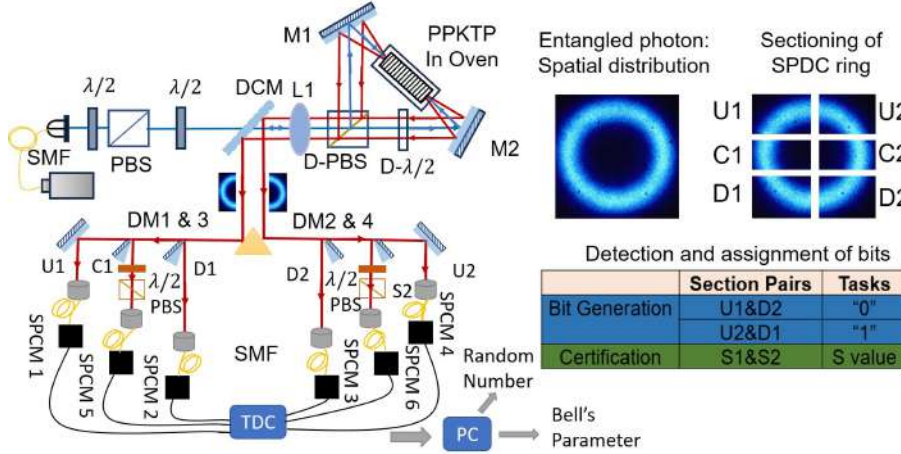


Fig. 1 The schematic representation of the experimental setup of the QRNG source. Inset: Spatial distribution of entangled photon source, the architecture of raw bit assignment, and quantumness certification.

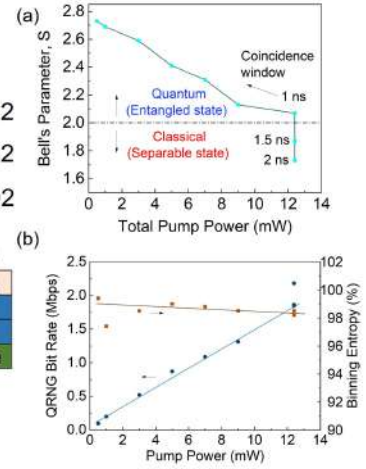


Fig. 2 (a) Quantumness certification of the QRNG process. (b) Characterization of the QRNG system.

We pumped a 20-mm-long, type-0 periodically-poled potassium titanyl phosphate (PPKTP) crystal kept in the oven inside a Sagnac interferometer to generate the SPDC ring. After filtering out the pump using a dichroic mirror (DCM), we cut the ring using a Prism-shaped gold-coated mirror (PM) and D-shaped mirrors (DM1-4) into six sections: U1-2, D1-2, and C1-2: Upper, lower, and side sections. Timing information of the entangled photon pairs is extracted using a coupler system, followed by a Single-mode fiber (SMF), single photon counting modules (SPCM1-6), a Time-to-digital converter (TDC), and a Computer. In Fig. 2, the Variation of (a) Bell parameter (S) and (b) the variation of the minimum entropy, $H_{\infty}(X)$ (red dots), and post-processed QRNG bit rate (blue dots) as a function of pump power and with coincidence windows are shown. The solid lines (red and blue) are linear lines fit to the experimental data. Additional results on randomness testing in the NIST and the TestU01 test suite, the autocorrelation coefficient estimation, and QRNG using non-maximally entangled states with a certification metric will be presented.

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Crystalline Ge₂Sb₂Te₅ Integrated on Silicon for Detection of Solar Spectrum

Bhavna Thakur^a, Anirban Mitra^a, Rajesh Kumar^{a*}

^aDepartment of Physics, Indian Institute of Technology Roorkee, Roorkee-247667, Uttarakhand, India

*rajesh.kumar@ph.iitr.ac.in

Phase change materials (PCMs) have long been the focus of extensive experimental and theoretical research, both for a wide range of application and to understand their fascinating and varied physical features. The development of novel materials for photonics applications is crucial for enhancing the efficiency and performance of the detectors. In this study, we explored the use of Ge₂Sb₂Te₅ (GST) and Si photodetector for the first time under solar illumination. The high thermal conductivity of the crystalline phase of GST [1], along with its high absorption coefficient ($10^5 - 10^6 \text{ cm}^{-1}$) [2], high thermal stability [3], strong photoconductive behavior [4], and favorable electronic properties, makes it a promising candidate for photodetection applications. Our work focuses on the electrical and optoelectronic response of the p-type crystalline GST on n-type Si under solar illumination. To the best of the authors' knowledge, there are no prior reports on the electrical and optoelectronic response of the p-type crystalline GST on n-Si photodetector under solar illumination. This study aimed to bridge this gap by investigating its performance and providing valuable insights into its potential application. Additionally, this study discussed the limitations of the device and focused on its future enhancement.

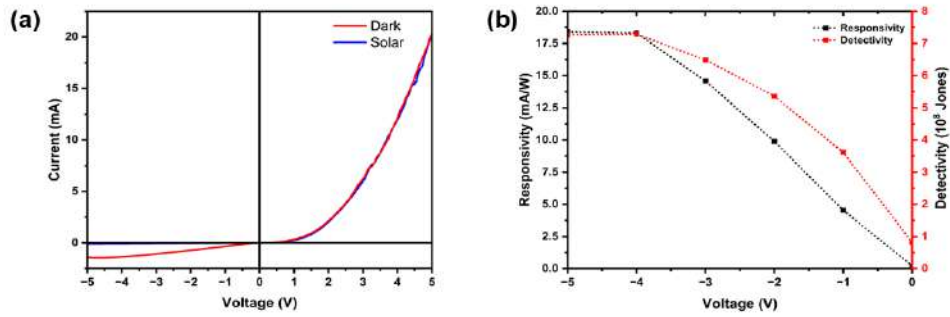


Fig. 1 (a) I-V characteristics (b) Responsivity and Detectivity.

Table 1: Characteristics performance obtained for the investigated photodetector.

I_0	η	R_s	R_{sh}	ϕ_B
3.26 nA	4.8	152 Ω	591.71 Ω	0.91 eV

The I-V characteristics of the photodetector is shown in the Fig 1 (a). Table I. summarized the characteristics performance parameters of the photodetector. The High sheet resistance (R_s) led to non-uniformity in the device, while low shunt resistance (R_{sh}) suggested higher leakage current and lower efficiency. Fig 1(b) illustrates the photoresponse and detectivity of the device, the photodetector was successfully tested under a solar simulator emitting a broad spectral range of 350–2700 nm, simulating the full solar spectrum from near-UV to short-wave infrared (SWIR). Under these conditions, the device exhibited a responsivity of 18.40 mA/W and a detectivity of 7.28×10^8 Jones, confirming its capability to effectively respond to a wide range of solar wavelengths. These results indicate that the photodetector can successfully detect and convert incident solar radiation across the visible and near-infrared spectrum. The calculated value of optoelectronic parameters, responsivity, and detectivity indicates the moderate performance of the device. Future research can focus on incorporating a buffer layer between GST and silicon or applying an anti-reflecting coating on the GST for better performance.

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Nanophotonic structures using bi-disperse scatterers for wide and tunable photonic band gaps

Kuldeep Singh, Mohd Aleem, and Rajesh V. Nair*

Laboratory for Nano-scale Optics and Meta-materials (LaNOM),
Department of Physics, Indian Institute of Technology Ropar, Rupnagar, Punjab 140001, India
*Email: rvnair@iitropar.ac.in

Light transport in disordered media is strongly influenced by the existence of spatial correlations among scatterers, which arise from their specific size and arrangement within the structure. The scattering properties of bi-disperse disordered (BDs) nanophotonic structures are promising due to its potential applications in coloration, wide photonic band gap, localizations and emission control. In this work, we have presented the detailed structural morphology along with optical properties of self-assembled BDs samples with different scatterers size (β) combinations. The structural correlations exhibit a linear dependence on β , whereas the strength of photonic band gap varies non-linearly. These findings led to define a minimum value of β which dictates the presence of broad photonic band gap for a given combination of scatterers. This minimum also decides a striking transition from monodisperse BDs to polydisperse BDs architecture, which demonstrates a novel approach to engineering light scattering. Observed polydisperse behaviour of BDs is compared with highly polydisperse TiO_2 sample through transport mean free path, which is supported by coherent backscattering measurements. Notably, by changing only single parameter β , the spectral position can simultaneously be tuned, coinciding with the strength of the photonic band gap, which is referred as dual tuning of these gaps. Experimental results demonstrate excellent validation with FDTD simulations, as corroborated by structure factor ($S(q)$) calculations.

Keywords: Multiple scattering, Wide band gap, Omnidirectional materials.

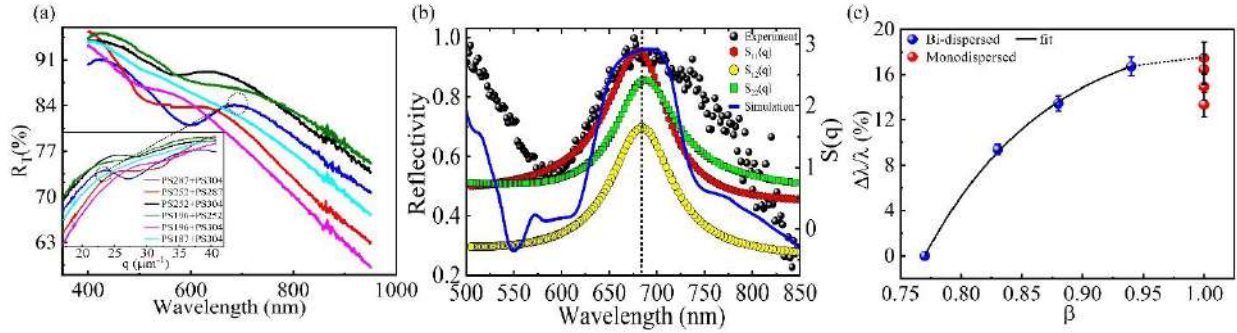


Figure (a) Experimentally measured total reflectivity profile R_T for all the samples, illustrating the presence and tuning of PBG. The inset shows R_T as a function of spatial frequency (q), signifying the wavevector dependence on optical features. (b) Experimental (black solid symbols) and simulated (blue solid line) reflectivity profile for S1, along with the numerically calculated structure factors $S_{11}(q)$ (red pentagons), $S_{12}(q)$ (yellow circles), and $S_{22}(q)$ (green squares), demonstrating the structural origin of PBG. (c) Variations of PBG strength ($\Delta\lambda/\lambda_g$) as function of size parameter (β) for bi-disperse samples (blue solid symbols), with nonlinear fitting (black solid line). The $\Delta\lambda/\lambda_g$ is compared systematically with the monodisperse samples (red solid symbol; PS287, PS304, PS252, in order of uppermost to lowermost), dotted line from blue to red solid symbol signifies the saturation of PBG effect.

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Design and Implementation of a Reflection and Transmission Mode LSCM System for Microvascular Blood Flow Analysis

Kavita Sharma¹, Hari M Varma¹

¹Department of Biosciences and bioengineering, IIT Bombay, Powai-400076, India

We report the design and fabrication of a Laser Speckle Correlation Microscopy (LSCM) system for real-time, non-invasive monitoring of blood flow dynamics in small veins. The developed setup operates effectively in both transmission and reflection modes, enabling versatile imaging across different sample geometries. Silica based polymer is used to fabricate tissue mimicking phantoms. Blood flow measurements were conducted under varying exposure times and controlled flow rates to assess the system's sensitivity and spatiotemporal resolution. The speckle contrast analysis demonstrates the ability of the system to capture subtle flow variations, offering valuable insights into microcirculatory function. This dual-mode LSCM system presents a compact and cost-effective solution for preclinical vascular imaging and dynamic flow studies.

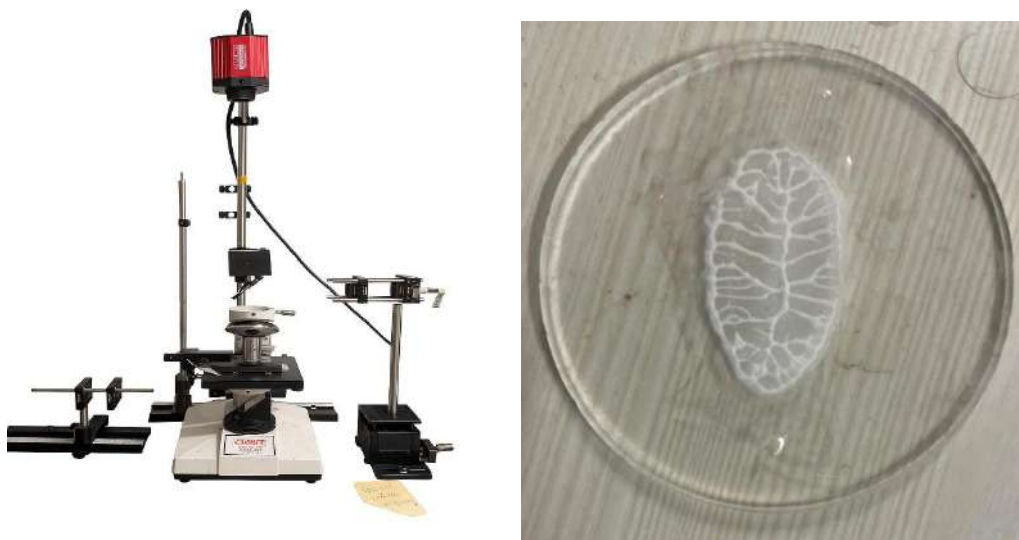


Figure 1: (a) Experimental setup for LSCM (b) Tissue mimicking flow phantom for blood flow monitoring

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Quantification of Singlet Oxygen Generation in Mice from BPD using a Single Photon Avalanche Diode

Vikas¹, Baozhu Lu², Weibing Yang², Brian C Wilson³, Timothy C Zhu², Robert H Hadfield¹

¹James Watt School of Engineering, University of Glasgow, Glasgow G128LT, UK,

²Department of Radiation Oncology, University of Pennsylvania, Philadelphia, PA, 19104, USA

³Department of Medical Biophysics, University Health Network/University of Toronto, Toronto, Canada

Photodynamic therapy (PDT) offers a targeted and minimally invasive approach to cancer treatment, leveraging light-activated photosensitizers to generate reactive oxygen species, primarily singlet oxygen ($^1\text{O}_2$), as the cytotoxic agent [1,2]. Accurate, real-time monitoring of singlet oxygen in vivo remains a critical challenge due to its transient nature and weak near-infrared luminescence. Monitoring $^1\text{O}_2$ luminescence (~ 1270 nm) during PDT using a photon-counting detector enables optimal treatment delivery to the tumor target with reduced off-target effects. A Time-resolved Singlet Oxygen Luminescence Detection (TSOLD) setup can be prepared by using single-photon detectors such as InGaAs-single-photon avalanche diode (SPAD) detectors and superconducting nanowire single-photon detectors (SNSPDs) has emerged as a powerful technique for real-time detection and quantification of $^1\text{O}_2$ during PDT [3]. In this study, we present a novel in vivo detection system employing a SPAD to sensitively measure $^1\text{O}_2$ luminescence at 1270 nm in tumour-bearing mice administered with benzoporphyrin derivative (BPD). A TSOLD system was prepared using a specifically designed pulsed 690 nm laser, which was coupled with fiber optics, optical filters, and mirrors, an ID230 SPAD detector, time-tagger electronics, and a separate bifurcated fiber bundle to excite BPD and detect the $^1\text{O}_2$ signal simultaneously. The TSOLD system successfully showed the detection of $^1\text{O}_2$ signals in C3H mice bearing RIF (Radiation Induced Fibrosis) tumors after they were injected with 2 mg/kg of BPD. Signal peaks were observed 15 minutes to 3 hours post-BPD administration, consistent with photosensitizer accumulation in tumor tissue. The results revealed a strong correlation between local BPD uptake and singlet oxygen generation up to 2 hours post-BPD administration; after that, the signal remains constant. Control measurements under oxygen-depleted and BPD-free conditions confirmed the specificity of the detected luminescence. This approach demonstrates the feasibility of using compact, high-sensitivity SPAD detectors for real-time monitoring of therapeutic events. The integration of this technique offers significant potential for improving PDT dosimetry, optimising treatment protocols, and advancing personalised cancer therapy.

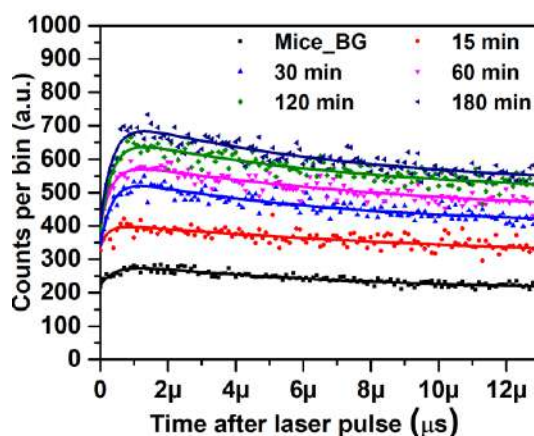


Figure. Measured and fitted histogram of the detected signal depended upon BPD uptake in mice. The histogram has been created with a bin width of 50 ns and an acquisition time of 5 min.

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Laser-Induced Microbubble-Driven Microfluidic Colorimetric Biosensor for Simultaneous Pathogen Detection

Ankita choudhary¹, Om Khare¹, Sandeep Yadav², Anand Dev Ranjan¹, Amirul Islam Mallick², Ayan Banerjee¹

1. *Department of Physical Sciences, Indian Institute of Science Education and Research Kolkata, Mohanpur, Nadia, West Bengal, 741246, India*

2. *Department of Biological Sciences, Indian Institute of Science Education and Research Kolkata, Mohanpur, Nadia, West Bengal, 741246, India*

Colorimetric biosensors have emerged as practical and accessible diagnostic tools, capable of detecting biomarkers through visible color changes. While conventional laboratory tests offer high sensitivity, they are time-consuming and require expensive equipment, limiting their suitability for on-site diagnostics. In contrast, colorimetric methods are rapid, user-friendly, and cost-effective, making them ideal for point-of-care and real-time monitoring. However, traditional platforms are often limited to single-analyte detection and require large amounts of sensing material, increasing production costs[1]. In this work, we present a transparent glass slide-based platform for simultaneous detection of multiple pathogens. It is fabricated using our lab's indigenously developed Micro-bubble Lithography (MBL) technique, where we used a 1064 nm laser to induce localized heating in a liquid medium, generating a microbubble that translates with the laser beam to enable precise and controllable pattern formation[2].

For proof-of-concept, we patterned model viral and bacterial targets, M2e (Influenza virus) and Hcp (Campylobacter jejuni) directly on a glass slide using MBL[1]. Detection was performed via an antigen-antibody-based colorimetric assay, the patterned targets were incubated with their respective primary and secondary antibodies, followed by the addition of a chromogenic substrate. A blue color indicated successful antigen – antibody binding, confirming the presence of the patterned bacterial or viral target. To halt the reaction and enhance visual readability, a stopping solution was introduced, producing a yellow color as the final end-point signal[3].

We have successfully demonstrated independent detection of both pathogens, and ongoing work focuses on integrating both detection systems into a single chip for true multiplexed capability. This platform offers a low-cost, scalable, and portable diagnostic solution, particularly suited for self-testing, point-of-care applications, and disease surveillance in low-resource settings. The integration of multiplexed detection into a single microfluidic chip represents a significant advancement toward accessible, real-time pathogen diagnostics.

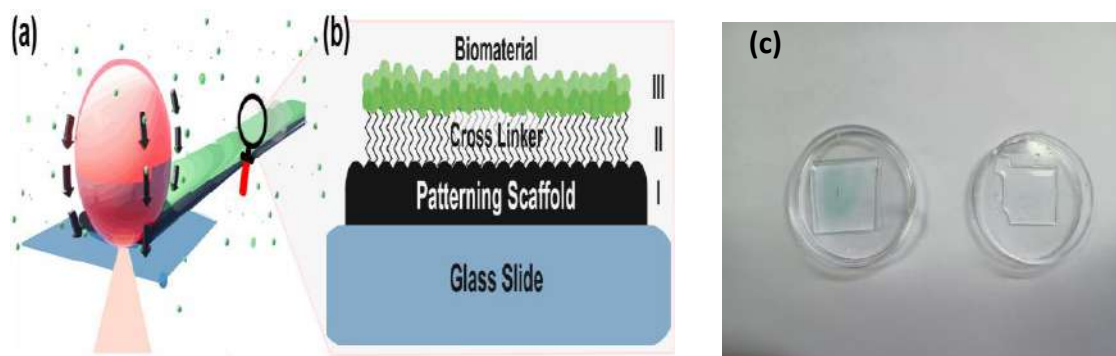


Fig.a.: Generation of a microbubble via localized laser-induced heating. Fig. b: Schematic representation of biomaterial patterning on a glass substrate. Fig. c: Blue colorimetric signal produced upon binding of *Hcp* bacteria with primary and secondary antibodies after substrate introduction.

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Polarization Independent Silicon Metasurface Supporting Mid-Infrared Quasi-BIC Resonance

Urmila Bag¹ and Varun Raghunathan¹

¹Department of Electrical Communication Engineering, Indian Institute of Science, Bengaluru, Karnataka 560012, India

We experimentally demonstrate a polarization-independent quasi-BIC resonance at 6.05 μm using silicon-based all-dielectric metasurface structure with Q-factor exceeding 3000, offering a promising platform for resonantly enhanced infrared sensing and efficient nonlinear optical frequency up-conversion.

All-dielectric resonant metasurfaces are gaining prominent interest in recent years due to their broad optical transparency, low optical absorption, high optical damage threshold, and the ability to engineer electric field, with promising applications in nonlinear optical wave mixing [1], quantum photonics [2], sensing [3], etc. Quasi-bound states in the continuum (BIC) resonance supported in such metasurfaces are particularly attractive due to the strong field enhancement achieved through the introduction of structural asymmetry [4]. However, unit cell incorporating such asymmetry are inherently polarization selective, which limits their resonant enhancements and device functionality to specific polarization states. Achieving polarization-independent, high Q-factor resonances is highly desirable. In this work, we design and experimentally demonstrate a high Q-factor, polarization-independent quasi-BIC resonance that maintains its performance for any incident polarizations.

Fig. 1(a) illustrates the schematic of the 2D periodic array of amorphous silicon (a-Si) tetramer unit cells on a MgF_2 substrate. The unit cells of the tetramer structure outlined by the dashed rectangle consist of four cylindrical resonators with optimized disk diameters, D1 and D2, arranged in an alternate fashion. The optimized structural parameters are: D1 = 3.1 μm , D2 = 2.5 μm , height, H = 0.2 μm , with a square pitch, P = 6.4 μm , which excites quasi-BIC resonance at $\sim 5.99 \mu\text{m}$ with Q-factor of 3450 for any incident light polarized. Here, unit-cell asymmetry is introduced by choosing the diameters of the alternating disks while maintaining symmetric spatial offset within the tetramer configuration, thereby ensuring polarization independence. The simulated transmission profile for varying incident polarization angles is shown as a contour plot as an inset in Fig. 1(a), clearly showing the position of quasi-BIC resonance. The normalized top-view electric field profile on resonance is also shown as an inset in Fig. 1(a), revealing ~ 20 -times field enhancement with inherent scattering due to magnetic quadrupolar nature.

The designed resonant metasurfaces are fabricated using standard CMOS-compatible fabrication techniques. Fig. 1(b) shows the scanning electron microscopy (SEM) image of the fabricated metasurface with the zoomed-in view of a single unit cell shown as an inset. The transmission spectra of the fabricated metasurface are measured using a pulsed quantum cascaded laser (QCL) as the excitation source and a mercury cadmium telluride (MCT) detector for the transmitted signal detection. Fig. 1(c) represents a comparison between the simulated and experimentally measured transmission spectra for two orthogonal incident polarizations. Very good agreement is observed between simulation and experiment, validating the polarization-insensitive nature and high Q-factor of the resonances (3100 and 2940 for X- and Y-polarizations, respectively). A small red shift in the resonance position is observed relative to the simulations, which is attributed to minor deviations in the unit-cell dimensions. Such polarization-independent resonant metasurfaces are a highly versatile platform for surface-enhanced spectroscopy, infrared up-conversion, and seamless heterogeneous integration of the layered 2D materials or organic molecules, eliminating the need for precise alignment between the active layer and metasurface.

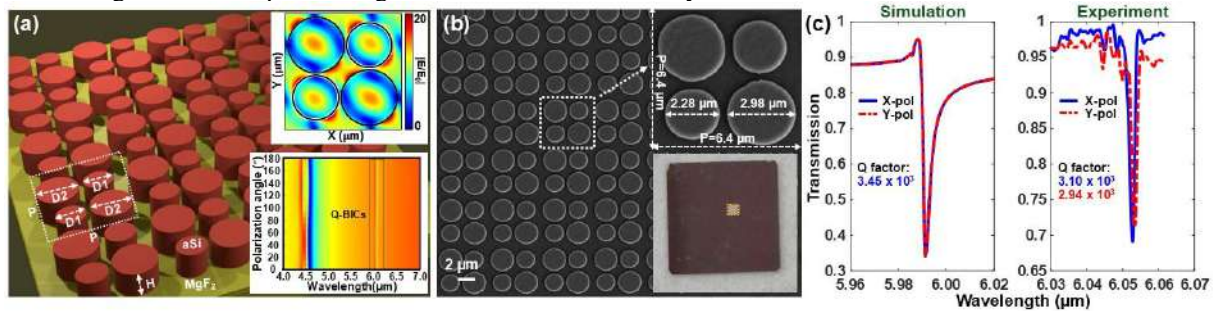


Fig. 1 Schematic of periodic array of the resonant metasurface: unit cell indicated in the dotted rectangle, top right inset shows the normalized electric field profile, bottom right inset shows the contour plot of the transmission profile under various polarization excitation; (b) SEM image of the fabricated metasurface with zoomed-in unit cell indicated (top-right inset) with fabricated dimensions, photograph of the fabricated sample with 1x1 mm² patterned area (bottom-right inset); (c) comparison of the simulated and experimentally measured transmission resonance spectra.

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Estimation of QBER and Key-rates using various Radiative Transfer code for quantum communication in arid regions

Vedant Dhawale¹, Prashant K Barnwal¹, V. Narayanan¹

1. Department of Physics, Indian Institute of Technology Jodhpur, Jodhpur, Rajasthan 342037, India

Quantum communication provides unparalleled security [1]. Satellite based communications are routinely used for long distance communication. In order to have secure long-distance communication, satellite-based quantum communications have been proposed and various researchers have attempted to implement the same. The atmospheric effects are pronounced in satellite-based communications. We investigate the effect of atmosphere in various quantum protocols via. quantum bit error rate (QBER) and secure key-rates. It is essential to estimate the effect of Quantum Bit Error Rates (QBER) and Key-rates for different QKD protocols such as BB84, B92, BBM92, E91 which can be employed to create ground to satellite based QKD links. For all the DV-QKD protocols, QBER depends on the transmittance, radiance and depolarisation. To calculate these parameters, we modelled and simulated the atmosphere using various radiative transfer (RT) codes. RT codes solve the radiative transfer equation (RTE) using various RTE solvers for the desired atmospheric conditions. The QBER (e) and Key rate (R) for BB84 protocol are given as [2],

$$e = \frac{cP_{\text{signal}} + \frac{1}{2}(P_{\text{dark}} + P_{\text{stray}})}{P_{\text{click}}}$$
$$R = \frac{1}{2}P_{\text{click}}[(1 - \tau') + f(e)[e \log_2(e) + (1 - e) \log_2(1 - e)]]$$

In our investigations, to simulate summer and winter weather conditions of Jodhpur we employ RTE code namely MODTRAN ® [3], thereby estimating the transmittance of signal within the spectral range of 0.4 – 2.0 μm through the atmosphere from ground station to a satellite. Due to extreme changes in temperatures from 9°C - 48°C at Jodhpur, the composition of the aerosol changes which changes the values of transmittance. These values of transmittance are further included in calculation to estimate the QBER and key rates. Additionally, we employ another RT code, namely LibRadtran [4] was used to simulate the sun's positions through its zenith tool and the QBER and secure key-rates are estimated using this code. Third RT code, namely VDISORT [5] solves the vectorized form of RTE equation, enabling us to study the effect of the atmosphere on the polarisation of signals. Different aerosol composition affects the polarisation of signal differently and causes the depolarisation of the signal. This depolarisation of signal affects the QBER and Key rates. Using VDISORT, we estimated the Mueller matrix of atmosphere in atmospheric conditions and calculated the depolarisation index which is taken in account to calculate QBER and Key rate.

We propose to estimate the effect of atmospheric background light using a fiber-coupled single photon avalanche diode (SPAD) and this set-up will help validate the scalar RT solver codes. In order to verify the polarisation effect of the atmosphere, we propose to construct a polarimeter to measure the degree and angle of polarisation (DOP & AOP) of the desired signal in the sky [6]. This setup consists of the fish eye lens, relay optics, 3- way beamsplitter, CCD camera and other optics. This DOP obtained experimentally can be compared by the depolarisation index obtained from VDISORT and it will be validated experimentally.

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Functional Photoacoustic Microscopy with Beamforming-Based Image Enhancement for Quantitative Ocular Chromophore Mapping

Aranya Sarkar, Deepayan Samanta and M Suheshkumar Singh*

Biomedical & nano-Bioscience Engineering (BnBEng) Laboratory, School of Physics (SoP),
Indian Institute of Science Education and Research, Thiruvananthapuram, Maruthamala P. O, Vithura, Kerala 695551, India.

This work demonstrates a multi-spectral functional photoacoustic microscopy (PAM) approach for the non-invasive, high-resolution imaging of tissue chromophores like Oxyhemoglobin (HbO₂), Deoxyhemoglobin (HbR) etc. in dissected whole goat eyes. We used our in-house built Acoustic Resolution Photoacoustic Microscopy setup, using a 30 MHz Olympus water-immersion ultrasound transducer with 15–45 MHz bandwidth, combined with a Nd: YAG broadband pulsed laser operating in the NIR region (700-900 nm) to acquire 3D volumetric data via 2D (x-y) raster scanning.

The dissected goat eye sample was prepared by washing in 5% glucose solution to restore corneal transparency, and then fixing on a petri-dish using 4% agar solution. The whole goat eye is imaged by immersing in a water tank in reflective mode to extract 3D high-resolution spatial distributions of tissue chromophores. We implemented a Linear Multi-spectral Unmixing Technique to estimate concentrations of HbO₂ and HbR based on their unique optical absorption spectra in NIR region. Laser fluence over the whole imaging area was estimated using Beer-Lambert's Law on boundary surface fluence measurement of the Laser Output. The 30MHz water-coupled ultrasonic transducer was set such that the sample, which is immersed in water, is at the focal plane of 19mm for the transducer. The coupling factors to convert measured signal to photoacoustic pressure was determined using impedance characterization of the transducer over its frequency bandwidth.

The results reveal spatially-resolved distributions of chromophores in ocular structures, including the retina-choroid and iris-ciliary body complexes. Total Hemoglobin (total-Hb) and oxygen saturation percentage (sO₂%) maps are derived from the estimated chromophore concentration maps, showing high oxygenation in retinal regions. The figure given below shows the 2D projection images of XY, XZ & YZ planes for the 3D spatial distribution of the chromophore concentrations. Functional image enhancement was done using Synthetic Aperture Focusing Technique (SAFT) along with Coherence Factor (CF) on the raw transducer data before spectral unmixing. The accuracy and resolution of our method was validated by comparing known anatomical landmarks from previous biological studies on mammalian and human eyes.

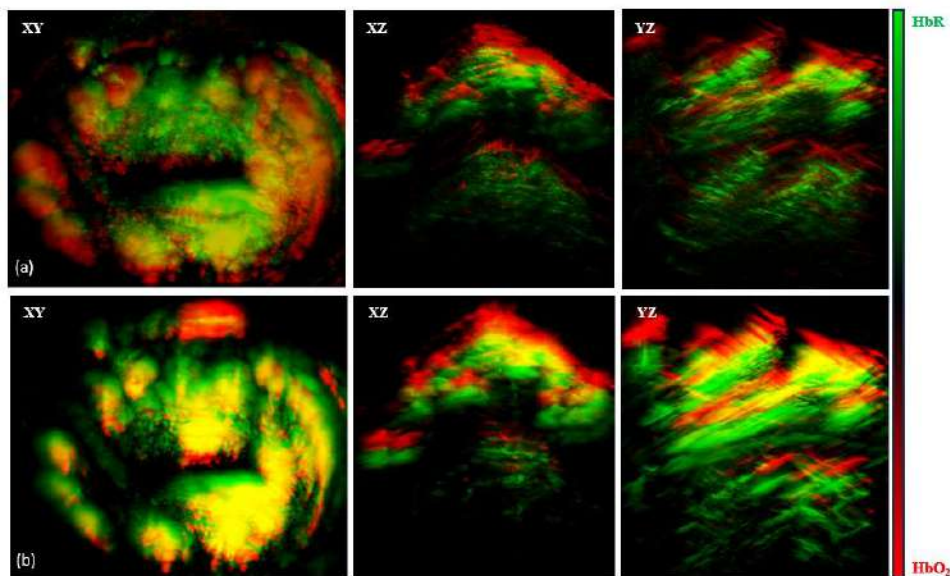


Figure: HbO₂ and HbR concentration maps overlayed to identify the regions of oxygenation in goat eyes for 2D projection planes (a) with raw sensor data in conventional algorithm (b) with beamformed data using SAFT-CF algorithm showing brighter and more precise chromophore concentrations

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Assessment of tissue damage caused by burn skin using Polarization Sensitive Optical Coherence Tomography

Richa Parihar¹, Nilesh J Vasa¹, Joy Mammen²

1. Department of Engineering Design, Indian Institute of Technology Madras, Chennai 600036, India

2. Department of Transfusion Medicine and Immuno Haematology, Christian Medical College, Vellore 632004, India

Detailed evaluation of burn injury in skin is imperative, accounting for the large number of skin injuries worldwide [1]. Estimation of the depth of burn wound is essential for identifying the course of treatment and recovery. Until now, in clinical practice, burn skin assessment is done superficially without depth characterisation. Optical Coherence Tomography proves to be effective for this type of characterisation. Here we are using the Polarisation Sensitive Low Coherence Interferometry (PS-LCI) technique for the characterization of burn skin.

A schematic of an in-house laboratory setup consisting of a free-space polarization-sensitive, low-coherence interferometry unit along with the polarization measurement in the transmission mode is illustrated in Fig.1 [2]. A broadband supercontinuum laser source (Leukos, Electro-250-IR) in the 800 – 2800 nm wavelength range was used. Two wavelengths, namely 1300 nm and 1060 nm, were selected using respective band-pass filters. An optical spectrum analyzer (Thorlabs, OSA 203C) was used to measure the spectral characteristics at the polarization-sensitive coherence interferometry output ends and the transmission end. Chicken's skin of thickness approximately 1.23 mm was burned for 5 seconds to get a second-degree burn. Chicken's burn skin was used for obtaining transmission characteristics.

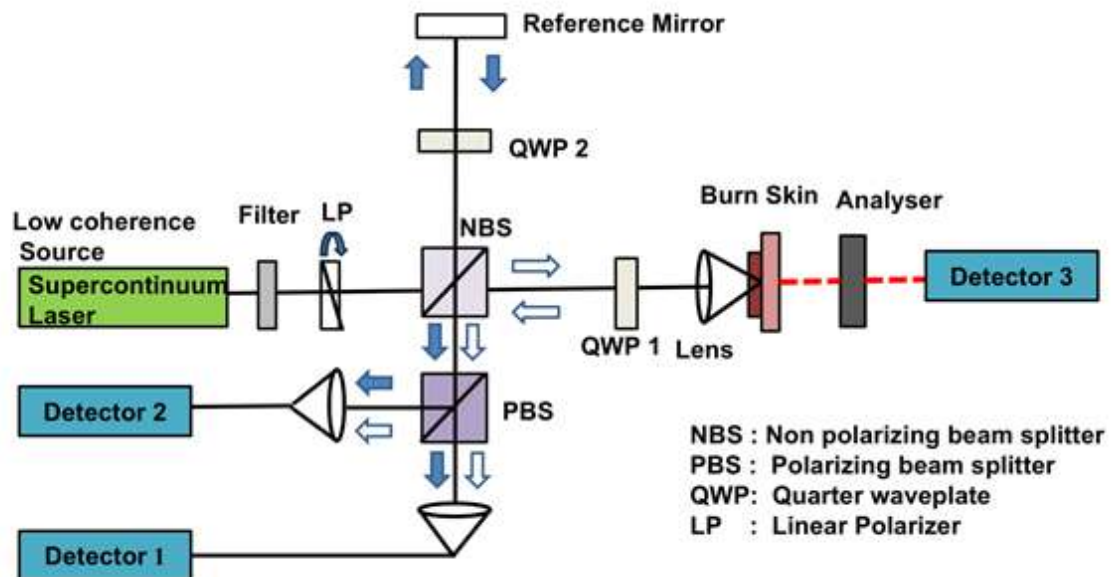


Fig. 1 Schematic of the polarization-sensitive low coherence interferometry setup with the transmission measurement in free space.

Birefringence characteristics were measured using a polarizer in the transmission end. Spectral measurements corresponding to horizontal and vertical polarization were measured using the polarization-sensitive low-coherence interferometry setup. Experiments on the normal skin and the burn skin were made for 1300 nm and 1060 nm. Based on the transmission experiments, it is observed that there is a change in the polarization for burn skin in comparison to that of normal skin. Similarly, birefringence values are also calculated for normal and burn skin at 1300nm and 1060nm.

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SU(2) gadget for higher-order polarization optics

Mohammad Umar^{*}, P. Senthilkumar^{*}

*Optics and Photonics Centre
Indian Institute of Technology Delhi
New Delhi 110016, INDIA*

Abstract

The well-known configuration of two quarter-wave plates and one half-wave plate, irrespective of their ordering, serves as a universal SU(2) gadget capable of implementing arbitrary SU(2) polarization transformations on the conventional Poincaré sphere. However, an equivalent system for implementing all SU(2) polarization transformations does not exist for the higher-order Poincaré sphere, a member of the higher topological index space. In this space, SU(2) transformations can be realized using q -plates that are themselves associated with the same topological index. This work shows that a configuration composed of two quarter-wave q -plates and one half-wave q -plate, regardless of their sequential arrangement, functions as a complete SU(2) gadget, capable of performing all polarization transformations on the higher-order Poincaré sphere.

The Poincaré sphere (PS), provides a geometric framework to represent the polarization of light, where all the polarization states are bijectively mapped to its surface through the Stokes parameters as Cartesian coordinates. Each point on the PS corresponds to a homogeneous state of polarization (SOP) distribution, with transformations between them described by elements of the three-parameter group called the SU(2) group. The SU(2) transformations between the SOPs are equivalent to rotations on PS, governed by the SO(3) group, reflecting the two-to-one homomorphism between SU(2) and SO(3) groups. Birefringent media, such as waveplates, serve as a practical example of SU(2) elements in this context. While waveplates facilitate SU(2) transformations, a single waveplate is insufficient for achieving all possible SU(2) transformations on the PS. It has been shown earlier that the combination of two quarter-wave plate (QWP) and one half-wave plate (HWP) arranged in any order coaxially is a suitable SU(2) gadget [1] to realize all transformations on PS.

Despite the well-celebrated geometric elegance of the PS, it proves inadequate for representing higher-order solutions of Maxwell's equations that admits the spatially inhomogeneous beams. These beams form connected regions on the PS rather than single points. To circumvent this, G. Milione et al. introduced the higher-order Poincaré sphere (HOPS), where inhomogeneous beams are represented as points on its surface [2]. HOPS is homomorphic to PS, while PS is a Bloch sphere with spin polarization states as its basis, HOPS extends this by incorporating both spin angular momentum (SAM) and orbital angular momentum (OAM), representing polarized singular beams with uniform ellipticity across their cross-section.

While the standard PS admits a universal SU(2) gadget, no such formulation has been established for the HOPS to date. In pursuit of an SU(2) gadget compatible with the HOPS, we explored various configurations of inhomogeneous waveplates, particularly q -plates, and obtained promising results. A q -plate is a structured birefringent element whose fast axis orientation varies azimuthally in a well-defined manner. Depending on its retardance, a q -plate functions as a half-wave q -plate (q^H -plate) when the retardance is π , or as a quarter-wave q -plate (q^Q -plate) when the retardance is $\pi/2$. Both the HOPS and the q -plate share a common topological feature as one of their defining parameter is azimuthally varying, which makes the q -plate a suitable SU(2) optical element for traversing the HOPS surface [3]. Leveraging this, we have shown that, by using the Euler angle parameterization of the SU(2) element, an SU(2) transformation can be expressed as the product of the Jones matrices of three q -plates (two q^Q -plates and one q^H -plate), regardless of their sequential arrangement. Therefore, this configuration enables the realization of all SU(2) transformations on the HOPS and thus serves as the SU(2) gadget for the HOPS.

✉ aliphysics110@gmail.com, opz238433@opc.iitd.ac.in

✉ psenthilk@yahoo.com, psenthil@opc.iitd.ac.in

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Single pixel holography with Hadamard illumination basis

Satish*, Tanushree Karmakar, Sarita, Rakesh Kumar Singh

Laboratory of Information Photonics and Optical Metrology, Department of Physics,
Indian Institute of Technology (Banaras Hindu University), Varanasi, India – 221005

*satish.rs.phy23@itbhu.ac.in

Abstract: We present a single-pixel holography using Hadamard basis for illumination. Reconstruction of a Fourier transform hologram (FTH) is demonstrated with lower frequency Walsh Hadamard patterns, and some experimental results are presented.

Digital holography usually relies on a coherent laser source for recording and reconstruction of the wavefront. Nevertheless, coherent source produces speckle noise, limiting their applications in noisy conditions. This issue can be resolved by reconstructing a hologram with incoherent light using a single-pixel detector (SPD). Such a scheme is comprised of a light projector to illuminate the hologram with structured patterns and a single photodetector (PD), which has no spatial resolution. The PD measures the intensity after interaction with the hologram [1,2]. In the SPD, the sampling is shifted from the camera to the light source. The technique is effective in low light conditions, imaging through scattering media, and in cost-effective imaging beyond the visible range, such as in infrared, X-ray, etc.

In this paper, we present a technique to recover the complex amplitude of the object encoded in the FTH by illuminating the hologram with an incoherent source and measuring intensity with an SPD. We demonstrate the reconstruction of a complex-valued object using only a few measurements with Hadamard structured patterns illumination. Such illumination patterns are binary, and they are easily projected with a spatial light modulator (SLM). In the experiment, we use the differential method for acquisition of Hadamard spectrum (HS), which is highly effective against noise. HS of the object is $H = D_{+1} - D_{-1}$, where D_{+1} represents measurements corresponding to positive patterns and D_{-1} represents measurements corresponding to negative Hadamard patterns [3]. The image of the hologram is recovered by applying the inverse Hadamard transform to the measured H .

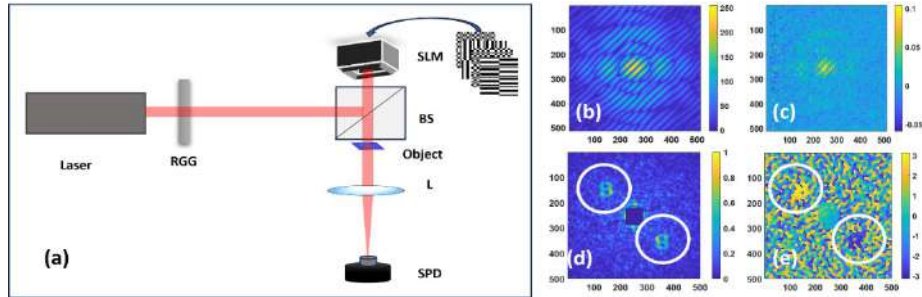


Fig. 1 (a) Experimental set up for the recovery of FTH (b) Original Hologram (c) Experimentally reconstructed image of hologram (d) Amplitude of the object (e) Phase of the object.

Fig. 1(a) represents the experimental lay-out of our technique. The setup consists of incoherent illumination achieved by passing a laser beam of wavelength 632 nm (Thorlabs, Model no: HNL150R) through a rotating ground glass (RGG), and then spatially modulated with the help of SLM (Holoeye: LC-R 720, 1280×768 -pixels, and $20 \mu\text{m}$ pixel pitch). Sequential projection of structured patterns from SLM illuminates the Fourier hologram. A lens (L) is used to collect light from hologram plane to PD (Thorlabs PD100A2). The PD records the intensity for each projected pattern, enabling computation of non-zero elements of HS. A total of 524288 patterns are required to fully sample the object of resolution 512×512 pixels on SLM, but only 8192 lower-order patterns are projected to reconstruct the image of the hologram. As shown in Fig. 1, the Fourier transform of the recovered image reveals the object 'B' encoded in the hologram. Fig. 1(b) shows the original hologram. Fig. 1(c) present experimentally recovered hologram. Fig. 1(d) and Fig. 1(e) are the reconstructed amplitude and phase of the object after applying Fourier transform digitally.

In conclusion, we have presented a new method for reconstruction of the FTH with an incoherent source and a single-pixel detector.

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Multiwave mixing and higher order nonlinear optical susceptibilities

Milenia Basumatary, Krishna Yadav, Balakrishnan Viswanathan, Prem B Bisht

Department of Physics, Indian Institute of Technology Madras, Chennai, Tamil Nadu 600036, India

Three-wave mixing is the lowest order multiwave mixing generally useful in ultrafast laser pulse measurement by the autocorrelation technique. Here, we have used four- and higher-wave mixing to investigate the nonlinear optical behaviour and obtain the values of higher-order nonlinear optical susceptibilities $\chi^{(3)}$, $\chi^{(5)}$ and $\chi^{(7)}$, respectively. We have employed the laser induced transient grating (LITG) technique by pumping the Kerr medium with second and third harmonic of Nd:YAG laser. As a result of multiwave mixing, we observe multiple diffraction orders. This phenomenon takes place in materials with high optical Kerr coefficient. The details and applications of the study will be presented. The schematic and corresponding 1st order diffracted spots resulting from $\chi^{(3)}$ are shown in fig.1.

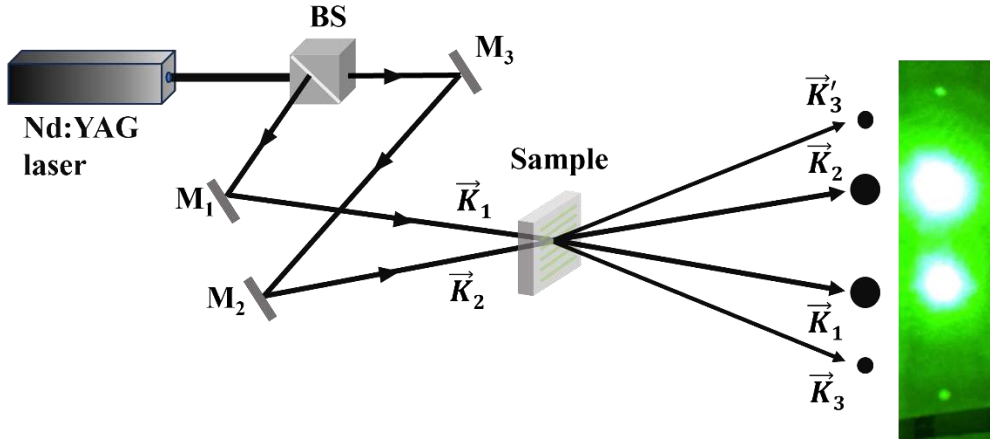


Fig. 1 Schematic of the laser induced transient grating (LITG) setup. BS: beam splitter; M₁, M₂, M₃ are mirrors. The 1st order diffracted spots are shown on the right.

Acknowledgements: We thank Dr.Mayukh Lahiri for fruitful discussions.

Plasmonic fiber optic humidity sensor for industrial applications

Debadrita Bhaduri¹, Nabarun Polley¹

¹. Fiber Optics and Photonics Division, Central Glass and Ceramic Research Institute, Kolkata-700032, West Bengal

Relative humidity, a key parameter in environmental, industrial and medical contexts, majorly relying on detecting the ratio of partial vapour pressure to the saturated vapour pressure at a specific temperature. Traditional electrical sensors remain economical but are vulnerable to interference and extreme conditions, while optical humidity sensors overcome these issues via light-based detection that enables high-resolution, distributed, and multiplexed sensing. We aim to explore the refractive index modulation induced by humidity changes using a gold nanostructure integrated onto an optical fibre tip, enabling a compact, flexible sensing platform with potential for multiplexed operation [1], [2].

In this study, we have investigated the performance of plasmonic fiber optic sensors under controlled humidity conditions based on a gold nanohole array (NHA) with a hydrophilic polymer layer, polyvinyl alcohol (PVA). Gold NHA was first fabricated on glass slides based on a self-assembly method, then it was introduced at the air-water interface and finally was incorporated into the optical fibre tip by pulling the fibre from inside out. PVA with a wt/vol% of 10% in water suspension was used to introduce a layer on top of NHA by dip-coating, resulting in a functional sensor.

An optical setup consisting of a broadband light source, a spectrograph, and a fiber bundle to carry the light to the sensor and back to the spectrograph was employed. To create a controlled environment, a climate chamber was used to generate different humidity conditions. The relative humidity was systematically varied from 20% to 99% to assess sensor performance under controlled environmental conditions at a constant temperature of 25 °C.

The optical response of the sensor is presented in Figure 1 (right) at 20%, 40%, 90%, and 99%. The reflectance minimum at around 740 nm corresponds to the extraordinary optical transmission (EOT) of the NHA. With increasing humidity, a consistent blue shift is clearly observed. This occurs because as humidity increases, the PVA layer swells, thereby decreasing the effective refractive index of the layer, which results in further blue shift of the minima. The spectral response with humidity shows an overall linear trend and is under consideration for calibration of the sensor. The evaluation of the sensor for industrial applications is currently in progress. We expect that this sensor will find relevance in applications of industrial significance, particularly in process monitoring, climate control, and storage environments where reliable humidity tracking is crucial.

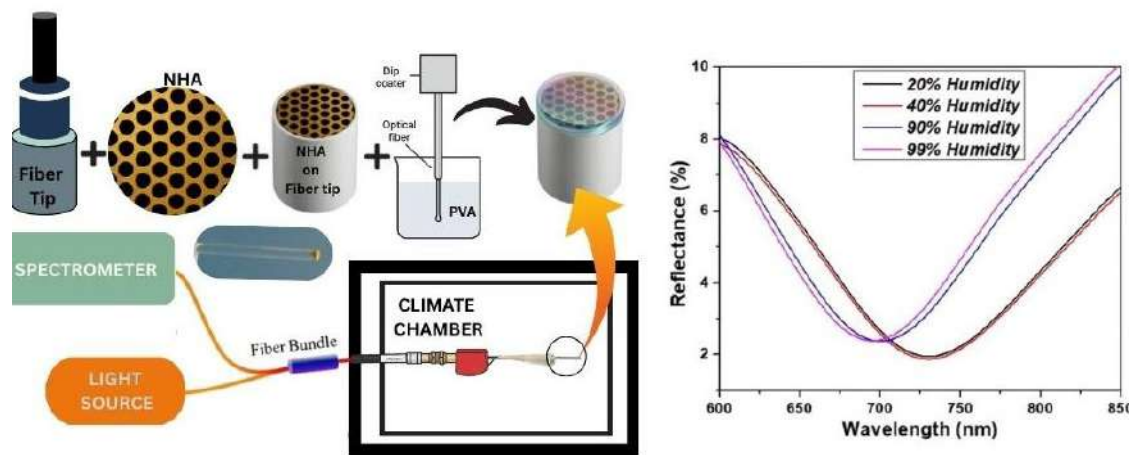


Fig. 1. Sensor Fabrication, Experimental setup and Response: (left) Fabrication of plasmonic optical fibre sensor based on a gold Nanohole array (NHA) is presented. Introduction of Polyvinyl alcohol as a humidity-sensing element by the dip coating method is also presented. The experimental setup utilised in this study is presented at the bottom. (right) The reflectance spectrum of the sensor under different relative humidity conditions is presented. The plasmonic minima are shifted towards blue with increasing relative humidity.

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Structural, Thermal and Optical Performance (STOP) Analysis for Predictive Performance Evaluation of a Medium Resolution, Wide Swath Electro-Optical Payload

Jenilkumar Changela, Jaimin Patel, Hardik Gediya, Chirag Diwan, Amiya Biswas
Optical Payloads Area, Advanced Engineering Group, Azista Industries Pvt. Ltd, Ahmedabad, Gujarat, India

Spaceborne earth observation systems undergo significant mechanical and thermal stresses throughout their operational lifecycle, necessitating a detailed analysis to predict the optical performance in these conditions. Optical systems with long focal lengths, wide fields of view (FOV), and broad spectral coverage are particularly sensitive to thermo-mechanical perturbations resulting in possible degradation in optical performance.

This work presents a Structural-Thermal-Optical Performance (STOP) analysis of a medium resolution wide swath optical payload for maritime surveillance from low earth orbit. The payload consists of two optical systems, each designed to obtain a better than 5-meter ground sampling distance with a swath of more than 150 kms. The optical system is based on Modified Double Gauss Derivative configuration consisting of 9 lens elements with an f-number of F/6.2. The optical system provides imaging in panchromatic and multiple multispectral bands in the spectral range of 400 – 900 nm using strip filters placed in front of an area array detector. The swath of 150 kms was obtained using two detectors, which were placed at the focal plane of the optical system using the technique of optical butting. The optical schematic of the system is shown in Fig. 1.

The STOP workflow integrates finite element analysis (FEA) results from ANSYS Mechanical with optical modeling in the STAR module of ZemaxOpticStudio, considering in-orbit thermal loads simulated using Siemens NX [1]. The thermal analysis observed a maximum temperature of 50 deg C for hot load case and a minimum temperature of -30 deg C for cold load case on the payload for a sun synchronous orbit. Specific thermal controls using heaters and radiators were designed for the purpose of maintaining the payload temperature between 22 ± 3 deg C. Thermally induced structural deformations in this temperature range were mapped onto the optical system through grid sag and surface tilt data to assess wavefront error and MTF degradation. The initial design showed a considerable drop in MTF due to the deformations.

Multiple optimization iterations were carried out to desensitize the optical design with respect to both fabrication and alignment errors and thermally induced perturbations. The maximum degradation in MTF was less than 0.5% in the finalized optical design for thermally deformed state in the given temperature range. This work shows that a STOP analysis is crucial to evaluate the optical performance of an optical payload in the presence of structural and thermal distortions. On non-satisfactory performance, a cycle of design optimization and STOP analysis was carried out until the stage where the optical system shows the required optical performance in the presence of given thermo-mechanical perturbations.

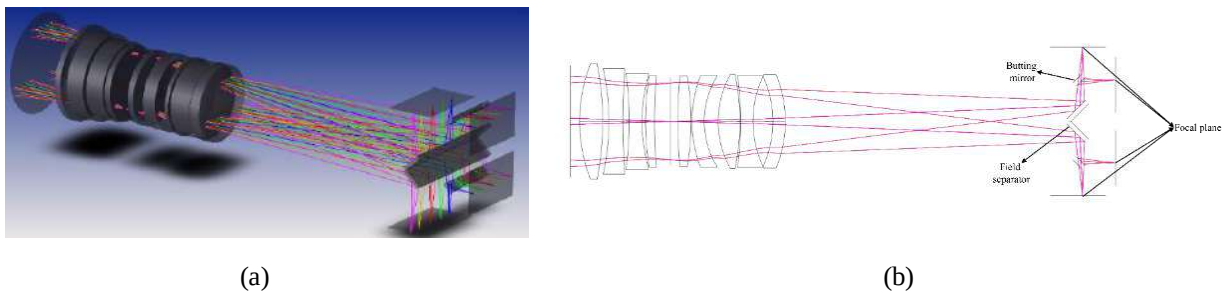


Fig. 1 Optical schematic in (a) 3D and (b) cross-section

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Asymmetric Composite Photonic Crystal Cavity on an Optical Nanocapillary for Cavity-QED

Srinu Gadde, Jelba John, and Ramachandrarao Yalla*

*School of Physics, University of Hyderabad, Hyderabad, Telangana, India-500046

In recent quantum technologies, single photons have been proven to be promising candidates for efficient information carriers. In this direction, sub-wavelength diameter optical nanofibers are emerging as promising candidates for efficient collection of single photons from a single quantum emitter and subsequent coupling with the single-mode fiber [1]. In this context, different cavity schemes have been proposed and experimentally demonstrated in the case of ONFs [2]. However, in these efforts, the maximum channeling efficiency (η) is limited to 65% through one-side of the guided modes of ONFs. [3]. To further enhance η -value, our group proposes a sub-wavelength inner and outer diameter optical nanocapillary fiber (NCF) and are filled with water and silica, respectively. The maximum η -value of 52% is obtained through the NCF-guided modes by placing a radially polarized QE at the center of the NCF inner diameter. To further enhance η -value, we design a symmetric composite photonic crystal cavity (PhC) on the optical NCF. The maximum η -value of 87% is obtained through NCF-guided modes by placing a QE at the cavity's anti-node [5].

In this paper, we report an asymmetric composite PhC cavity on NCF to channel the total spontaneous emission rate of single QE into one direction. The cavity is formed by combining the asymmetric grating-coupler (AGC) with the NCF-waist region, and a y-pol. QE is placed at the anti-node of the cavity, as shown in Fig. 1 (a). The maximum η -value of 80% is obtained through one-sided NCF-guided modes.

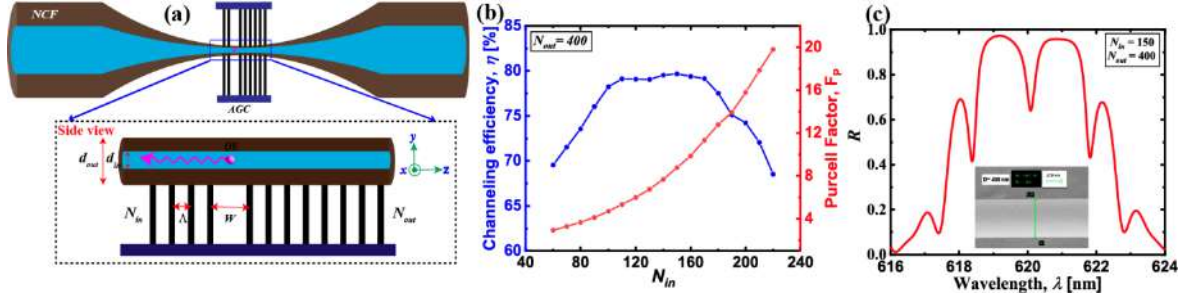


Fig. 1 (a) The schematic of the asymmetric composite cavity on a nanocapillary fiber (NCF). d_{in} (d_{out}), Λ , and W are the inner (outer) diameter of NCF, grating period, and a defect of width, respectively. (b) Channeling efficiency, η (blue circles), Purcell factor, F_P (red circles), dependence on the input slat number for the fixed output slat number. (c) The cavity's reflection spectrum at the optimum input and output slat numbers of 150 and 400, respectively. The inset shows the image of an optical nanofiber with a diameter of 500 ($\pm$ 20) nm.

We design an asymmetric composite cavity and systematically optimize the cavity's parameters for the unidirectional channeling of the total spontaneous emission rate of QE using the 3D-FDTD method. The optimum parameters for the symmetric composite PhC cavity are subwavelength $d_{in} = 125$ nm, $d_{out} = 515$ nm, $\Lambda = 244$ nm, $W = 1.5\Lambda$, and $N (=N_{in} + N_{out}) = 400$ [5]. The key point in this asymmetric cavity is an unequal slat number on either side of AGC to confine the total spontaneous emission rate of QE in one direction. First, we fixed the input slat number, $N_{in} = 200$, and optimized N_{out} of AGC while maximizing the η and F_P -values through the one-sided NCF-guided modes. The maximum η -value is obtained at $N_{out} = 400$. Next, we optimize the N_{in} -value while maximizing both η and F_P -values by keeping the $N_{out} = 400$ as shown in Fig.1 (b), and it shows that, η -value first increases and shows a saturation behavior and again decreases. Hence, the maximum unidirectional η -value of 80% is obtained at the optimum $N_{in} = 150$ and $N_{out} = 400$. Further, we investigate the reflection spectrum of the asymmetric cavity using y-pol. input mode source as shown in Fig.1 (c). It is clear that there is a strong reflection with a dip at the center of the stop band at the cavity's resonance wavelength of 620 nm. First, we fabricated ONF with a diameter of 500 ($\pm$ 20) nm using the heat and pull method as shown in the inset of Fig. 1 (c) [6].

In summary, we reported an asymmetric composite cavity on NCF for the unidirectional channeling of total spontaneous emission of single QE. The present cavity can be used as a deterministic single-photon source for cavity QED-based quantum applications.

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Achromatic Vector-Vortex Beam

Avula Harish Kumar* and Nirmal K. Viswanathan

School of Physics, University of Hyderabad, Hyderabad, Telangana, 500046, India

*Email: avulaharishkumar@gmail.com

More than three decades of extensive research activities of optical vortex (OV) beams and their angular momentum (AM) properties have resulted in a variety of methods of generating them and applications using them [1]. Most popular among the generation methods are the spiral phase plate and the spatial light modulator, both of which modify the phase structure of the incident Gaussian beam. An alternate method of using the spatial variation in the state of polarization (SoP) to generate OV beams, due to geometric Pancharatnam-Berry phase accumulation, was proposed by Bhandari [2] and demonstrated in the visible wavelength as the Q-plate [3]. This alternate approach led to the use of optical crystals to generate non-uniform or inhomogeneously polarized beam and from which an OV beam [4, 5]. However, much of such methods involve the use of crystals at tilted angles and focused incident beams to imprint the necessary optical phase variation in the beam cross-section and hence have not gained in popularity. This led us to explore the possibility to use standard but special optical component such as Soleil-Babinet compensator (SBC) as a possible alternate to generate OV beams from a paraxial incident Gaussian beam, directly from a laser. The geometric nature of the phase and the SoP variations in the beam cross-section allowed us to demonstrate the method to generate OV beam at different discrete wavelengths in the visible region from 632.8 nm to 457 nm.

We present our experimental results on using a small-divergence paraxial Gaussian beam from a laser, propagating through the SBC to first generate a vector-vortex (VV) beam and from which the OV beam. The wavevector ($\mathbf{k}$) at each point of the beam is oriented at different angle with the optic-axis of the SBC, leading to the non-uniform polarization and hence the $\mathbf{k}$ -dependent geometric phase accumulation in the beam cross-section. The resulting coupling between the spin and orbital angular momentum ensures the method as a part of spin-orbit interaction of light. A linearly polarized Gaussian beam (from He-Ne and Ar⁺ laser) is propagated through the SBC whose fast-axis is oriented at 45° to the incoming polarization (Fig. 1 (a)). The output non-uniformly polarized VV beam is characterised using Stokes parameter measurements to map the SoP variation in the beam cross-section (Fig. 1 (b)). Suitable polarization filtering of the output beam results in the OV beam for different input beam wavelengths (Fig. 1 (c), top row). The interferograms (Fig. 1(c) bottom row) show the characteristics forklet pattern, confirming the OV in the beam center.

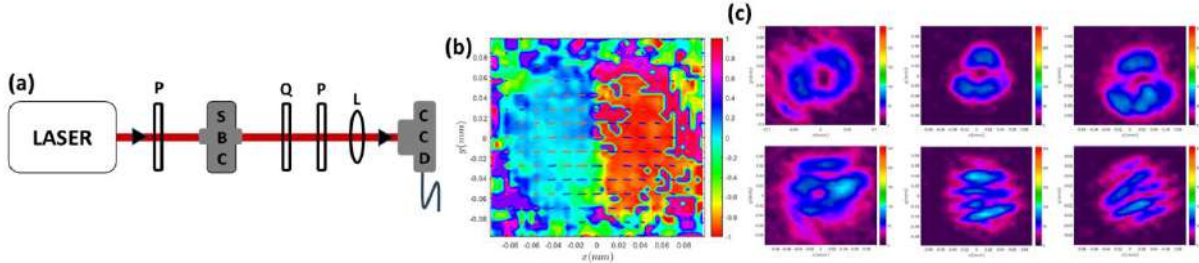


Fig. 1. (a) Schematic of the experimental setup. P - polarizer, SBC - Soliel-Babinet compensator, Q - quarter wave-plate, L - imaging lens and CCD - camera. (b) azimuthal phase variation overlapping the inhomogeneous polarization in the beam cross-section. (c) top row: OV beam generated for 632.8, 488 and 472 nm wavelengths and the corresponding forklet interferograms (bottom row).

The Jones matrix formalism is used for simulating the generation of OV beam using the SBC, with its fast-axis oriented 45° to the input polarization:

$$J_{45^\circ} = \begin{pmatrix} \exp(i\Delta) + \exp(-i\Delta) & \exp(i\Delta) - \exp(-i\Delta) \\ \exp(i\Delta) - \exp(-i\Delta) & \exp(i\Delta) + \exp(-i\Delta) \end{pmatrix} \dots (1); \quad E_f = J_{45^\circ} \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} \cos(\Delta) \\ i\sin(\Delta) \end{pmatrix} \dots (2)$$

Where, E_f is the Jones vector for generating the VV beam, $\Delta(x, y) = \Delta = \delta_0 - \delta_l + i\alpha x + \beta y$, where, $\delta_{0,l} = (2\pi/\lambda) (n_e - n_o) d_{0,l}$, is the retardance of the wedges (0) and of the fixed birefringent plate (l), λ is the wavelength of the incoming beam, $n_{e,o}$ are the extraordinary and ordinary refractive indices of the quartz crystal, $d_{0,l}$ are their thickness, α is the beam divergence angle, and c, β are constants, and x and y are the transverse coordinates of the beam. Using eqns. (1), (2) leads us to generate the VV beam in the output and by suitable polarization filtering the OV beam. More details of our results and analysis will be presented at the conference.

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Flexible Near-Infrared Plasmon-Polaritons in Epitaxial Scandium Nitride Enabled by van der Waals Heteroepitaxy

Debmalya Mukhopadhyay, Dheemahi Rao, Rahul Singh Rawat, Ashalatha Indiradevi Kamalasanan Pillai, Magnus Garbrecht, and Bivas Saha*



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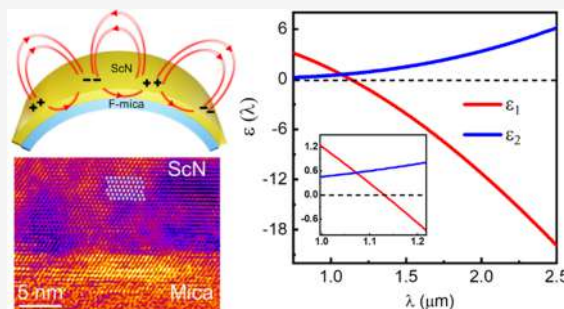
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Supporting Information

ABSTRACT: Van der Waals heteroepitaxy refers to the growth of strain- and misfit-dislocation-free epitaxial films on layered substrates or vice versa. Such heteroepitaxial technique can be utilized in developing flexible near-infrared transition metal nitride plasmonic materials to broaden their photonic and bioplasmonic applications, such as antifogging, smart windows, and bioimaging. Here, we show the first conclusive experimental demonstration of the van der Waals heteroepitaxy-enabled flexible semiconducting scandium nitride (ScN) thin films exhibiting near-infrared, low-loss epsilon-near-zero, and surface plasmon-polariton resonances. Deposited on fluorophlogopite-mica substrates with molecular beam epitaxy, polaritonic ScN heterostructures mark the first semiconducting nitride to exhibit plasmon resonance at the 1100–1250 nm spectral range, inside the biological transmission window. Interestingly, optical properties of such ScN exhibit remarkable stability even after bending more than 100 times. Creating low-cost and high-quality flexible yet refractory plasmonic ScN heterostructures for the near-infrared spectral range will advance flexible optics and bioplasmonic devices for practical applications.

KEYWORDS: Flexible plasmonics, van der Waals heteroepitaxy, near-infrared photonics, biological transmission window, scandium nitride, molecular beam epitaxy



Optical materials that are flexible, stretchable, bendable, wearable, and exhibit low-loss and high-quality plasmon resonances in the near-infrared (NIR) spectral range (750 nm–1400 nm) hold enormous potential for antifogging,¹ smart windows,² hyperspectral imaging,³ determining the quality of forages, grains, and grain-products in agriculture,⁴ and characterization of optical coatings for telecommunication industries.⁵ NIR plasmonics are also attractive for several medical uses, including the functional mapping of the human cortex, quantifying blood flow, blood volume, oxygen consumption, and photothermal therapy for noninvasive treatment of cancer cells within the biological transmission window (650 nm–1350 nm).^{6–9} However, despite these promising applications, the development of NIR plasmonic materials that are both flexible and maintain a low-loss, high-quality optical performance remains a challenge.

The main impediment in achieving epsilon-near-zero (ENZ) wavelength in the NIR originates from the difficulty in achieving a suitable carrier concentration in the $\sim(1-5) \times 10^{21} \text{ cm}^{-3}$ range.¹⁰ For example, noble metals such as gold, silver and transition metal nitrides (TMN) such as TiN, ZrN, HfN, etc., exhibit high electron concentrations ($>10^{22} \text{ cm}^{-3}$), leading to their ENZ wavelength in the near-UV and visible spectral range.^{11–13} However, reducing the carrier density of metals is not readily achievable. Similarly, doped-semiconductors and

transparent conducting oxides (TCO), e.g., tin-doped indium oxide, aluminum, or gallium-doped zinc oxide, and cadmium oxide exhibit a carrier concentration in the $\sim(1-5) \times 10^{20} \text{ cm}^{-3}$ range, resulting in their short-wavelength infrared (SWIR) and mid-infrared (MIR) ENZ resonances at wavelengths longer than 1400 nm.^{11,14} However, increasing the carrier concentration of TCOs to more than $1 \times 10^{21} \text{ cm}^{-3}$ while keeping a low optical loss is also not feasible due to the changes in band curvature. Therefore, the development of low-loss NIR plasmonic materials that are simultaneously flexible, stretchable, and bendable will make them attractive for a myriad of emerging device applications.

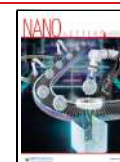
Scandium nitride (ScN), an emerging rocksalt refractory polar semiconducting TMN, exhibits low-loss ENZ resonance and surface plasmon polaritons in the SWIR 1800–2400 nm spectral range.^{15–17} The polar nature of atomic vibrations in ScN also leads to its far-infrared surface phonon-polaritons and Reststrahlen bands,¹⁷ which can be used for passive radiative

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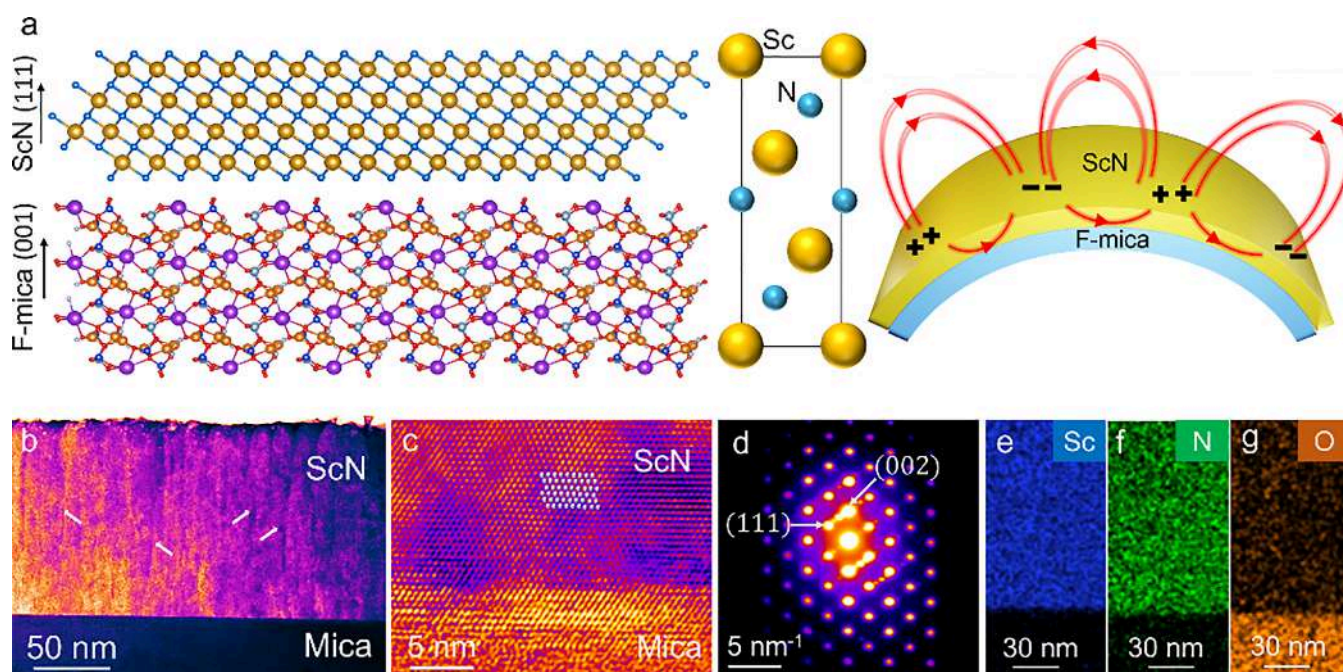


Figure 1. (a) Schematic of atomic arrangement in (111) oriented ScN deposited on the F-mica substrate for flexible plasmonic materials is shown in the left panel. ABC-ABC stacking of Sc atoms in ScN unit cell along the [111] direction is shown in the middle panel. The right panel shows the schematic of the surface plasmon resonance on a flexible ScN film deposited on the F-Mica substrate. The red curved lines exhibit the electric field distributions. Collective coherent oscillations of electrons on the metal surface or plasmon oscillations couple with the incident electromagnetic field and propagate at the boundary between the metal and dielectric (air). The plus and minus signs represent the polarization of the oscillating electron clouds on illumination of the incident electromagnetic field. (b) The HAADF-STEM image showing columnar ScN grain growth on the F-mica substrate. (c) Atomic resolution TEM micrograph showing coherent (111) lattice plane cross sections of ScN. The ABC-ABC stacking of Sc atoms along the [111] direction is marked with white balls. (d) An electron diffraction pattern (EDP) of ScN deposited on F-mica collected along the $[1\bar{1}0]$ ScN zone axis showing epitaxial crystalline growth. TEM-EDS mapping of (e) Sc, (f) N, and (g) O atoms exhibiting the homogeneous and uniform distribution of elements.

cooling,¹⁸ biomolecular fingerprinting,¹⁹ and diagnosis tools for cancer detection and dentistry applications.²⁰ However, unlike its wurtzite III-nitride counterparts, such as GaN and TCO,^{21,22} ScN possesses a unique property, such that incorporating oxygen as an *n*-type dopant on nitrogen sites in ScN does not introduce defect states within its bandgap.²³ As a result, the Fermi energy in ScN can move freely with oxygen incorporation, and the carrier concentration can be varied significantly by several orders of magnitude.²⁴ Previously, a maximum electron concentration of $1.6 \times 10^{21} \text{ cm}^{-3}$ was achieved in sputter-deposited ScN thin films, which resulted in the ENZ of $1.8 \mu\text{m}$, lying in the SWIR spectral range.¹⁷ Therefore, with increased oxygen concentrations, the carrier concentration of ScN could be increased to more than $2 \times 10^{21} \text{ cm}^{-3}$, leading to its low-loss and high-quality ENZ resonance in the NIR regions.

In addition, demonstration of flexible ScN epitaxial thin films has not been possible to date since most reports of ScN's interesting plasmonic¹⁷ and other physical properties such as thermoelectricity,²⁵ neuromorphic computing²⁶ employ epitaxial films deposited on mechanically hard inorganic substrates, such as MgO, Al_2O_3 , or GaN.^{15,25,27–30} van der Waals heteroepitaxy^{31,32} provides a transformative technique that allows the deposition of inorganic mechanically hard single-crystalline materials on two-dimensional substrates without requiring lattice-matched growth conditions. van der Waals heteroepitaxy typically produces materials with fewer defects and smoother surfaces, capable of being transferred onto different substrates.³³ However, the nucleation of

adatoms on 2D substrates often results in island growth, preventing the formation of large-area single crystals. While interfacial buffer layers and graphene templates have been used to address this issue,³³ the added complexity of buffer layers limits the process's overall practicality. Therefore, direct high-quality epitaxial growth of ScN on suitably chosen layered substrates would be a significant advancement in practical applications. Achieving NIR plasmonics in flexible ScN will also significantly advance bioplasmonic and photothermal research as ScN exhibits corrosion-resistant high mechanical hardness (24 GPa), radiation hardness, structural, mechanical, and chemical stability in most dilute acidic and base conditions and a high melting temperature of $\sim 2600^\circ\text{C}$.^{15,25,29,34,35} Moreover, the flexibility of ScN thin films can also be leveraged to many of its emerging functionalities, such as in thermoelectricity, neuromorphic computing, and Schottky barrier diode devices.

Therefore, motivated to develop a ScN-based flexible NIR plasmonic material, in this work, we have developed epitaxial ScN films on a F-mica substrate, showcasing their near-IR plasmon resonance within the biological transmission window (see Figure 1a). We leverage the excellent heat resistance and high-temperature stability of single crystalline two-dimensional (2D) layered fluorophlogopite-mica (F-mica [$\text{KMg}_3\text{Al}(\text{Si}_3\text{O}_{10})\text{F}_2$]) substrates³⁶ that also provide atomic-level surface flatness, transparency, excellent chemical stability, flexibility, and optical wave-penetrability, which are necessary for developing plasmonic devices for therapeutic applications.^{32,37–40} Further, epitaxial ScN thin films are thinned

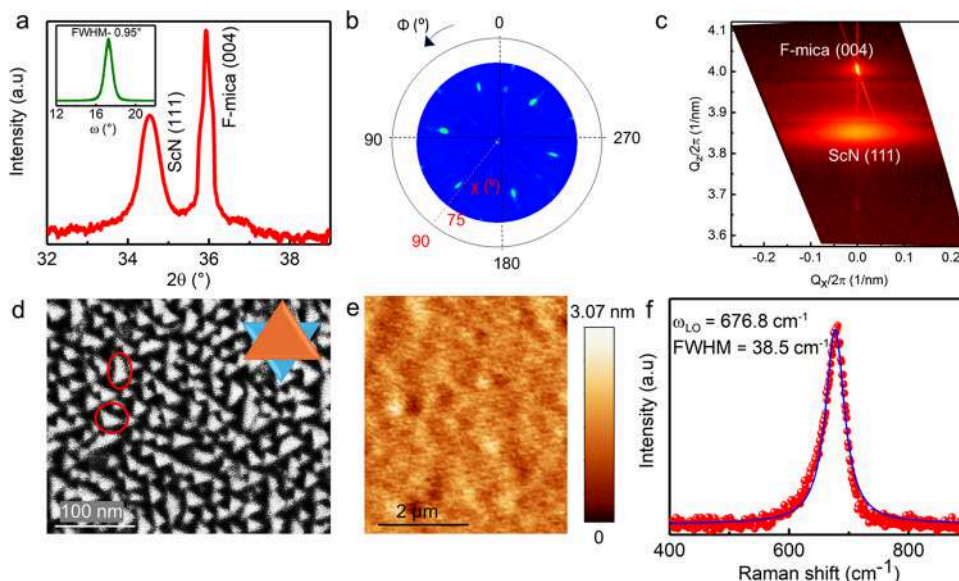


Figure 2. (a) Symmetric 2θ – ω HRXRD of ScN deposited on an F-mica (001) substrate. The film grows with (111) orientation with a small full-width-at-the-half-maxima of the rocking curve of 0.95° , which highlights its nominally single-crystalline nature. (b) Pole figure of ScN corresponding to the (002) plane showing twinned epitaxial growth highlighted by six equally spaced diffraction spots (c) Reciprocal space mapping (RSM) of ScN (111) and substrate (004) peaks. Spread in the (111) plane RSM map highlight mosaicity in the film. (d) Plan-view FESEM image confirms the pole figure measurements by highlighting two sets of pyramidal grains rotated 60° relative to one other. (e) AFM of ScN surface showing triangular grains with a rms. surface roughness of 0.63 nm. (d) Raman spectrum of ScN measured with a 532 nm laser source shows defect-induced LO phonon mode at 677 cm^{-1} .

through mechanical exfoliation of the F-mica in order to demonstrate optical robustness even after a large number of bending cycles.

Epitaxial ScN thin films are deposited in an ultrahigh vacuum molecular beam epitaxy (MBE) system with the base pressure of 1×10^{-10} Torr at 650°C substrate temperature. Details on the growth conditions and characterization techniques are elaborated in section 1 of the [Supporting Information](#) (SI). High-angle annular dark field scanning transmission electron microscopy (HAADF-STEM) imaging (see [Figure 1b](#)) shows (111) oriented columnar ScN grains with vertical grain boundaries. Most of the grains originate from the ScN/Mica interface and terminate at the surface having a lateral width of 15–20 nm. The grain boundaries are seen as dark lines as indicated using white arrows in [Figure 1b](#). The interface between the F-mica substrate and ScN appears sharp and distinct. High-resolution TEM images (see [Figure 1c](#)) at the interface show well-defined lattice fringes and coherent layer-by-layer epitaxial growth. The ABC-ABC stacking of Sc atoms along the $[111]$ direction is shown in [Figure 1c](#), by placing the white balls on the Sc atomic positions. The electron diffraction pattern (EDP) (see [Figure 1d](#)) collected along the $[1\bar{1}0]$ ScN zone axis reveals a single-crystalline pattern and epitaxial crystal growth. Few additional features in the EDP originate from the mica substrate (see section 2 in SI). From the HRSTEM imaging and EDP analysis, an epitaxial relationship of $[1\bar{1}0]$ (111) ScN $\parallel$ $[010]$ (001) F-mica is established for the flexible ScN film deposited on F-mica substrates. Further, STEM-energy dispersive X-ray spectroscopy (EDS) analysis reveals a uniform and coherent distribution of Sc and N atoms throughout the film ([Figure 1e](#) and [Figure 1f](#)). Importantly, the EDS mapping also reveals a uniform oxygen impurity distribution throughout the film ([Figure 1g](#)), which leads to n -type doping and high electron concentration, resulting in the NIR plasmonic behavior.

Symmetric 2θ – ω high-resolution X-ray diffraction (HRXRD) measurement (see [Figure 2a](#)) confirms the (111) oriented growth of ScN on the (001) F-mica substrate. From the 2θ -peak position, an out-of-plane lattice parameter of $4.49\text{ \AA}$ is determined for ScN, consistent with the previous literature reports.¹⁵ The out-of-plane lattice parameter of $9.99\text{ \AA}$ is also calculated from the (004) F-mica diffraction peak, which matches well with the literature values.^{36,39} The ω -scan (rocking curve) corresponding to the 111-peak of ScN presented in the inset of [Figure 2a](#) shows a full-width-at-the-half-maxima (fwhm) of 0.95° . Such a moderate value of fwhm is expected for single-crystalline epitaxial ScN deposited on a substrate with a small lattice-mismatch and at a slightly lower growth temperature as seen in previous reports.⁴¹ The epitaxial growth of ScN is further corroborated with pole figure measurement corresponding to the (002) plane (see [Figure 2b](#)), which shows six clear spots suggesting twinned growth of ScN triangular grains with 3-fold symmetry.^{42,43} Reciprocal space mapping (RSM) of the (111) plane shows pseudomorphic growth of ScN where the Q_x of both ScN and F-mica exhibit the same value (see [Figure 2c](#)). The ScN (111) diffraction spot in the RSM also exhibits a sizable broadening, highlighting the tilts in the vertical grains and revealing the mosaicity in the film.

The plan-view field-emission scanning electron microscopy (FESEM) image (see [Figure 2d](#)) shows pyramidal facets, consistent with the (111) ScN growth on (111) MgO, (0001) Al_2O_3 , and (0001) GaN substrates.^{27,28,44} Such pyramidal morphology and texture appear due to the reduced adatom mobility on the (111) surface of ScN compared to that on its (001) surface. Moreover, the sticking coefficient of adatoms on the (111) surface is expected to be much higher due to a greater concentration of dangling bonds, thus impacting the lateral mobility of adatoms.⁴¹ Interestingly, a closer look at the orientation of the triangular base of the pyramidal grains shows

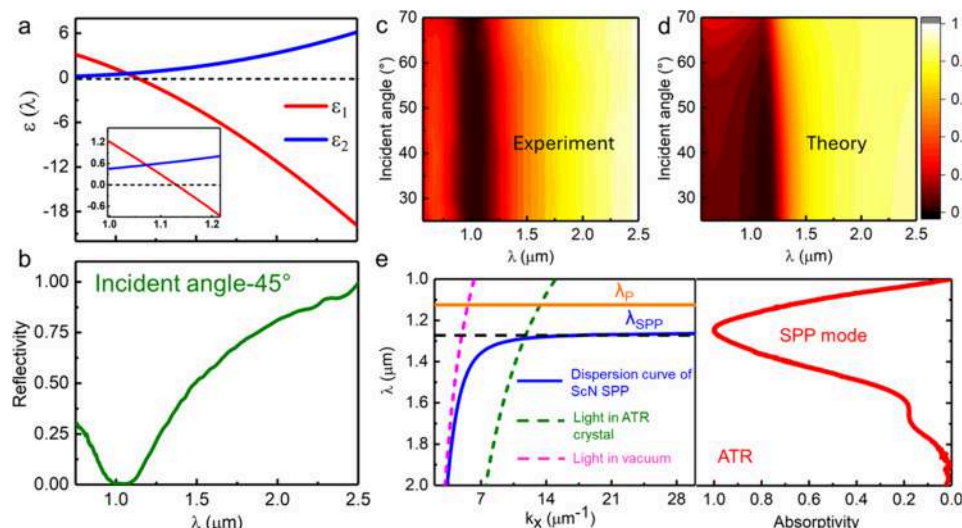


Figure 3. (a) Real (ϵ_1) and imaginary (ϵ_2) components of the dielectric constant of MBE-deposited ScN on F-mica. The epsilon-near-zero (ENZ) wavelength is $1.14 \mu\text{m}$ as clearly seen in the inset signifying the plasmonic nature of ScN. (b) The experimental reflectivity (normalized) of ScN at 45° incident angle shows plasmonic dip near to the ENZ wavelength. ScN films exhibit metallic nature after the ENZ wavelength. (c) Experimental angle-dependent reflectivity of ScN shows a dip near to the ENZ wavelength. (d) Calculated angle-dependent reflectivity from Fresnel's equation matches well with the experimental reflectivity (e) Theoretically calculated SPP dispersion curve (blue line) and the ATR-measured absorptivity curve exhibit the SPP excitation near $1.24 \mu\text{m}$. The yellow line shows the bulk plasma wavelength (λ_p).

two kinds of domains. These domains are a result of the structural twins that are rotated 60° to one another, as marked by the red circles in the SEM image. The observation of the twinning further confirms the HRXRD pole figure results.²⁷ Importantly, the plan-view SEM image clearly shows that the morphology, texture, and orientation of ScN films deposited on F-mica substrates exhibit similar trends compared with the results with film growth on inorganic mechanically hard substrates.

Atomic force microscopy (AFM) imaging of the surface (see Figure 2e) reveals a root-mean-square (rms) surface roughness of 0.63 nm , which matches well with the rms. roughness of ScN films deposited on (0001) GaN.²⁷ Such low surface roughness highlights near-complete wetting of the adatoms on the F-mica surface and coherent layer-by-layer growth without any island formation triggering Volmer–Weber growth.⁴⁵ Raman spectroscopy measurements (see Figure 2f) are further carried out with an incident laser wavelength of 532 nm , which shows distinctive ScN Raman mode at 677 cm^{-1} originating from the LO phonon vibration.⁴⁶ Note that although ScN exhibits a rocksalt crystal structure, where Raman modes should be symmetry forbidden, defects relax the q -selection rule and lead to first-order Raman mode, as also seen in other rocksalt TMNs.^{47,48} The fwhm of the Raman mode is 38.5 cm^{-1} , consistent with the ones obtained for ScN when deposited on ceramic substrates.⁴⁶ These detailed structural characterizations reveal that the growth of ScN on 2D F-mica substrates leads to flexible films with high crystalline quality and an epitaxial nature.

Plasmonic properties of the flexible ScN films, characterized with spectroscopic ellipsometry measurements, show that the dielectric constant's real (ϵ_1) component undergoes a positive-to-negative epsilon-near-zero (ENZ) transition at $1.14 \mu\text{m}$ (see Figure 3a). At the ENZ point (clearly shown in the inset of Figure 3a), the optical loss, represented by the imaginary component of the dielectric permittivity (ϵ_2) is 0.65 , comparable to the optical loss in TCOs at their respective ENZ wavelengths.^{11,14} After the ENZ crossover, the $|\epsilon_1|$

increases monotonically at longer wavelengths, highlighting the increasing metallicity of the film. Concomitantly, the optical loss also increases due to the free electron Drude absorption at lower energies. At higher energies, ϵ_1 exhibits a peak at $\sim 490 \text{ nm}$ corresponding to its direct bandgap (see section 5 in the SI), while the ϵ_2 also exhibits a peak due to direct band-to-band transition.⁴⁹ Note that the ENZ crossover of the ScN deposited on the F-mica substate is consistent with its high electron concentration of $2.4 \times 10^{21} \text{ cm}^{-3}$ originated due to the intentional exposure of Sc source material to oxygen, as discussed in section 6 of the SI. Despite the high carrier density, ScN on F-mica exhibits a moderate electron mobility of $9 \text{ cm}^2/(\text{V s})$ at room temperature (see Table 1 in section 6 of the SI), which is consistent with the mobilities achieved in (111)-oriented ScN films on inorganic substrates.²⁵

Reflectivity measurement (Figure 3b) further confirms the NIR ENZ response of the ScN film with a clear and well-defined dip near the ENZ point at the impedance matching condition. Away from the ENZ region, reflectivity increases monotonically highlighting metallic nature of the film in the SWIR and MIR spectral ranges. Ellipsometry data fitting further show an electron–electron scattering time of 2.3 fs in ScN, which is consistent with the electron scattering time in noble metals such as Au and Ag and transition metal nitrides such as TiN and HfN.¹² Angle-dependent reflectivity measurements (Figure 3c) highlight the reflection dip in the NIR spectral range for all incident angles of incidence. The angle-dependent reflectivity is further calculated using Fresnel's relation and the measured dielectric permittivity (see Figure 3d), which matches well with the experimental results. The apparent similarities between the calculated and measured reflectivity spectra further highlight the correctness of the measured optical constants.

Surface plasmon polariton (SPP) excitation of ScN in the NIR is further demonstrated with an attenuated total reflectance (ATR) measurement in absorption mode in a Fourier transform infrared (FTIR) spectrometer under the Kretschmann configuration (right panel of Figure 3e). The

FTIR machine is equipped with an mercury cadmium telluride (MCT) detector for capturing light in the NIR spectral region.¹⁷ The momentum of the incident light with a central position at 45° angle of incidence and a spread of $\pm 20^\circ$ is matched with the momentum of the SPP mode by passing it through a prism made of high refractive index material, diamond. Figure 3e shows a peak in the absorptivity spectrum of ScN at $\sim 1.24 \mu\text{m}$ in the ATR measurement, which indicates the coupling of light with the surface plasmon mode. The SPP dispersion is theoretically calculated between the ScN-air interface (left panel of Figure 3e) using the measured ϵ_1 .¹⁷ The intersection points of the SPP dispersion curve with the light cone inside the ATR crystal indicate the SPP excitation wavelength at the interface of ScN and the ATR crystal. The calculation matches closely with the experimentally measured absorptivity peak from the ATR data.

Having deposited the epitaxial ScN films on F-mica substrates and demonstrated its NIR plasmonic response, the flexibility and bending properties of ScN are demonstrated by mechanically exfoliating the film with $\sim 5 \mu\text{m}$ mica substrate underneath (see section 7 of the SI). Figure 4a shows the

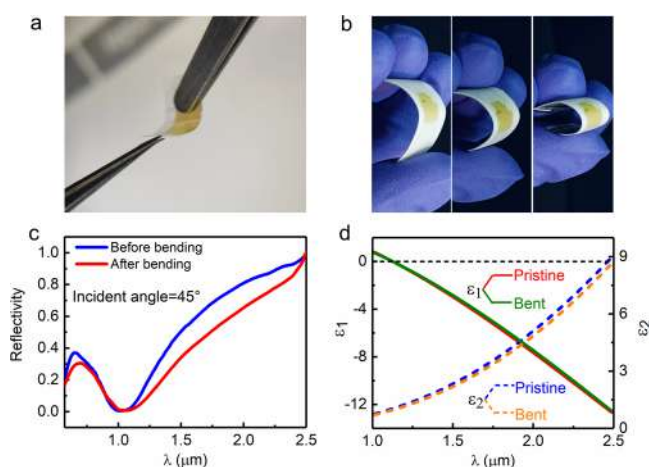


Figure 4. (a) Bending test of ScN/F-mica by a tweezer. (b) Bending of ScN/F-mica on top of a metal sheet in three different bending curvatures, which shows the flexibility of ScN on F-mica. (c) Reflectivity (normalized) of the ScN before bending and after 100 times bending shows almost similar plasmonic properties. (d) Unaltered dielectric constants of ScN before and after bending 100 times indicates that the optical properties of ScN/F-mica remain unchanged on bending.

bending test using a tweezer. The bending tests are further performed with three different bending curvatures (Figure 4b) by attaching the film to a thin metal sheet, demonstrating the mechanical robustness of this system. The reflectivity of ScN before and after 100 bending cycles is measured at an incident angle of 45°, and both the reflectivity plots appear similar, with the plasmonic dip in reflection at the same wavelength, ensuring the unaltered ENZ resonance of the ScN/F-mica film (see Figure 4c). The apparent decrease in the steepness of the reflection curve after bending (red line) appears due to a slightly higher electron relaxation time after bending. Figure 4d further shows the unchanged nature of ϵ_1 and ϵ_2 for the ScN/F-mica film before and after bending, which also verifies the robustness of the plasmonic nature of the films even after 100 bending cycles. The optical properties of ScN are also measured during the bending measurement and are presented

in section 7 of the SI, which shows practically no change in its properties. These measurements demonstrate the stability and flexibility of ScN on F-mica substrates, which is unique for its plasmonic device applications.

Finally, the plasmonic device performances, such as the surface plasmon polariton propagation length, confinement width, figure-of-merit (FOM) of the localized surface plasmon resonance, etc. of the flexible ScN films are compared with the previous reports of ScN deposited on inorganic substrates and other plasmonic materials in the SWIR and MIR spectral range.^{11,14,17,50} Figure 5a illustrates that the SPP propagation

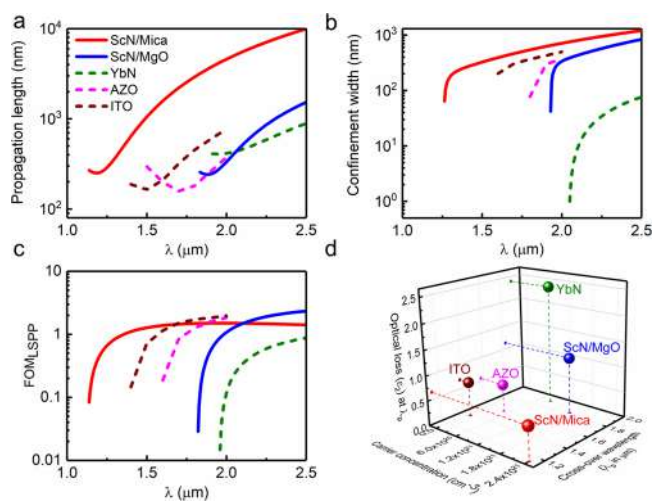


Figure 5. Comparison of the optical properties of ScN/F-mica with other established plasmonic near-infrared semiconductors. Comparison of (a) propagation length of SPP (b) confinement width of SPP, (c) figure of merit of localized surface plasmon polariton (LSPP), and (d) cross over wavelength, carrier concentration and optical loss at ENZ of ScN/F-mica with ScN/MgO, YbN, AZO, and ITO.

length in ScN/F-mica and air interface is ~ 250 – 300 nm at the ENZ wavelength and compare well with the ScN films deposited on MgO substrates as well as TCOs such as AZO and ITO at their respective ENZ wavelengths. Similarly, the SPP confinement width in ScN/F-mica was calculated to be $\sim 100 \text{ nm}$, which is comparable not only to the confinement widths in ScN/MgO but also with the TCOs (see Figure 5b). The figure-of-merit for localized surface plasmon polaritons (FOM_{LSP}) (see Figure 5c) shows a comparable FOM of ScN/F-mica compared to other materials. Figure 5d displays the ENZ wavelength, carrier concentration, and optical loss at the ENZ wavelength in a single plot, highlighting the plasmonic properties of flexible films.

In conclusion, we utilize van der Waals heteroepitaxy to deposit epitaxial and flexible ScN thin films that exhibit low-loss and high-quality NIR epsilon-near-zero and surface plasmon-polariton resonances in the ~ 1100 – 1250 nm spectral range. Deposited on heat resistance and high-temperature-stable single crystalline two-dimensional (2D) layered F-mica substrates with molecular beam epitaxy, the flexible ScN thin films exhibit layer-by-layer epitaxial growth with structural twinning and subnanometer surface roughness that highlight its excellent crystalline quality. The mechanically exfoliated ScN film with $\sim 5 \mu\text{m}$ F-mica substrate underneath is shown to be structurally stable even after bending more than 100 times, and its plasmonic properties remain unchanged. This work marks significant progress as it not only enables flexible ScN thin

films for the first time but will also help develop ScN's near-infrared plasmonic applications within the biological transmission window and beyond.

■ ASSOCIATED CONTENT

Data Availability Statement

The data that supports the findings of this study are available from the corresponding author upon reasonable request.

SI Supporting Information

The Supporting Information is available free of charge at <https://pubs.acs.org/doi/10.1021/acs.nanolett.4c04616>.

Details of thin film growth conditions, microscopy and structural characterization methods and details, ellipsometry and other optical characterization details, electrical and thermoelectric measurements, and detailed analysis of the results (PDF)

■ AUTHOR INFORMATION

Corresponding Author

Bivas Saha – Chemistry and Physics of Materials Unit, International Centre for Materials Science, and School of Advanced Materials (SAMat), Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 560064, India; orcid.org/0000-0002-0837-1506; Email: bsaha@jncasr.ac.in, bivas.mat@gmail.com

Authors

Debmalya Mukhopadhyay – Chemistry and Physics of Materials Unit and International Centre for Materials Science, Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 560064, India

Dheemahi Rao – Chemistry and Physics of Materials Unit and International Centre for Materials Science, Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 560064, India; orcid.org/0000-0002-1952-3210

Rahul Singh Rawat – Chemistry and Physics of Materials Unit and International Centre for Materials Science, Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 560064, India

Ashalatha Indiradevi Kamalasanan Pillai – Sydney Microscopy and Microanalysis, The University of Sydney, Camperdown, New South Wales 2006, Australia

Magnus Garbrecht – Sydney Microscopy and Microanalysis, The University of Sydney, Camperdown, New South Wales 2006, Australia

Complete contact information is available at:

<https://pubs.acs.org/doi/10.1021/acs.nanolett.4c04616>

Author Contributions

D.M. and B.S. conceived this project. D.M., D.R., and R.S.R. deposited the thin films, D.M. performed optical measurements and analysis, A.I.K.P. performed the HR(S)/TEM sample preparation, and M.G. performed HR(S)/TEM imaging and EDS mapping. D.M., D.R., M.G., and B.S. analyzed the results. All authors discussed and contributed to the preparation of the manuscript.

Notes

The authors declare no competing financial interest.

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Design and develop a tapered fiber-based platform for sensing applications

Amar Nayak, Shashank Suman, Mahesh Kumar Pani, and Ramachandrarao Yalla*

*School of Physics, University of Hyderabad, Hyderabad, Telangana, India 500046

Optical micro/nanofibers (OMNFs) are used for sensing due to their high sensitivity, compact size, fast response, and provide significant evanescent field (EF) accessibility, which is convenient in configuring for micro/nano-scale optical sensing [1]. Due to stronger confinement for guided light while offering low insertion loss, it facilitates strong interaction between the OMNF and its surroundings [2,3], which makes the OMNF a promising platform for optical sensing [4,5]. The traditional optical sensors based on OMNFs are designed using the waist region of tapered fibers [6]. However, the tapering region remains unexplored, which can be used for sensing applications. In this paper, we design and develop a tapered fiber-based platform for sensing applications by observing the scattered intensity counts in the tapered region for a broad range of wavelengths.

First, we numerically simulate scattering intensity using the finite difference time domain method (Ansys 3D-FDTD). We mount a test fiber (TF) on a probe fiber (PF) and measure the power coupled through the TF. The PF diameter is fixed at $10\text{ }\mu\text{m}$, while the diameter of TF is swept from $0.3\text{ }\mu\text{m}$ to $1.6\text{ }\mu\text{m}$. Similarly, the simulation is repeated for a PF of diameter $20\text{ }\mu\text{m}$. We have shown that the scattering loss profile for a PF of diameter $20\text{ }\mu\text{m}$ is higher than that of a PF of diameter $10\text{ }\mu\text{m}$, irrespective of wavelength [7]. The intensity of the evanescent field depends on the diameter of the TF. As the diameter of the TF decreases, the EF intensity increases. This increases the overlap between the EF and the PF, resulting in higher scattering loss. Similarly, we observe the same trend for longer wavelengths used to excite the modes in the TF and thicker PFs, as both increase the overlap between the EF and the PF. The scattering loss profile for a PF of diameter $10\text{ }\mu\text{m}$ is shown in Fig. 1 (b). We used this as leverage to design the experiment. A TF is fabricated using the chemical etching technique. First step, we take 40% of concentrated HF to remove the clad of the TF for 53 minutes and 24% HF to smooth and remove the extra coating of the fiber; here time varies according to the desired diameter of TF [8]. The schematic of the experimental setup is shown in Fig. 1(a), where a white light source is passed through the tapered single-mode fiber, and the transmitted spectrum is recorded using a spectrometer before and after the contact between the PF and TF is made at every $50\text{ }\mu\text{m}$ distance gap along the fiber axis. The inset shows the measured TF diameter in electron microscope.

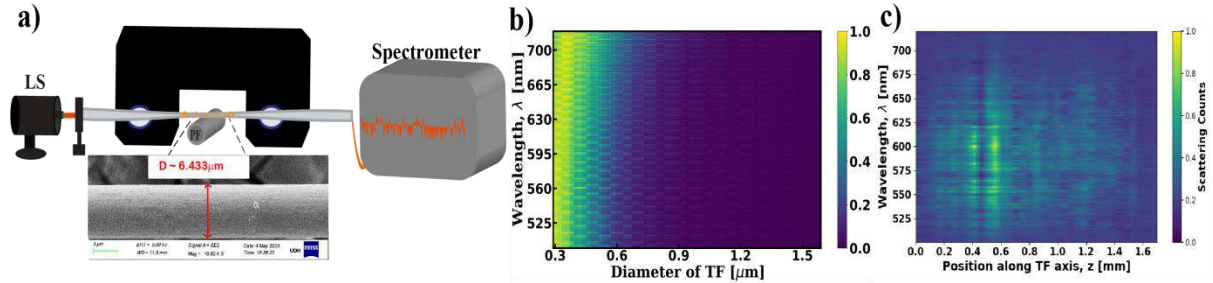


Fig. 1. (a) The schematic of the experimental setup. (b) Simulated scattering loss as a function of wavelength and diameter of the TF at a fixed PF. (c) The corresponding experimental results of scattering loss.

The summary of scattering intensity counts (SICs) along various TF positions is shown in Fig. 1 (c). The maximum SIC is observed at $0.5\text{ }\mu\text{m}$. As the PF moves along the TF axis from $0\text{ }\mu\text{m}$ to $1.7\text{ }\mu\text{m}$, SICs increase and decrease. This shows that the EF intensity also follows the same trend. The observed SICs in Fig. 1 (c) correspond well to simulation predictions in Fig. 1(b). The present method utilizes the wavelength dependence of scattering intensity counts using a white light source. The measured results show a qualitative correlation with the simulation results.

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Temperature resilient efficient source of polarization-entangled photons

Nilesh Tiwari¹, Omshankar¹, Vivek Venkataraman^{1,2} and Joyee Ghosh¹

¹Quantum Photonics Lab, Department of Physics, Indian Institute of Technology Delhi, New Delhi, 110016, India

²Department of Electrical Engineering, Indian Institute of Technology Delhi, New Delhi, 110016, India

¹Email: joyee@physics.iitd.ac.in

²Email: vivekv@ee.iitd.ac.in

Producing polarization-entangled photon pairs with high fidelity underpins key advancements in quantum technologies, particularly in long-distance QKD, free-space communication channels, and precision quantum sensing. Due to its inherent phase stability and compact architecture, the Sagnac-interferometer serves as an efficient platform for generating polarization-entangled photons, demonstrating strong immunity to environmental disturbances, including thermal drift and mechanical stress. [1][2]

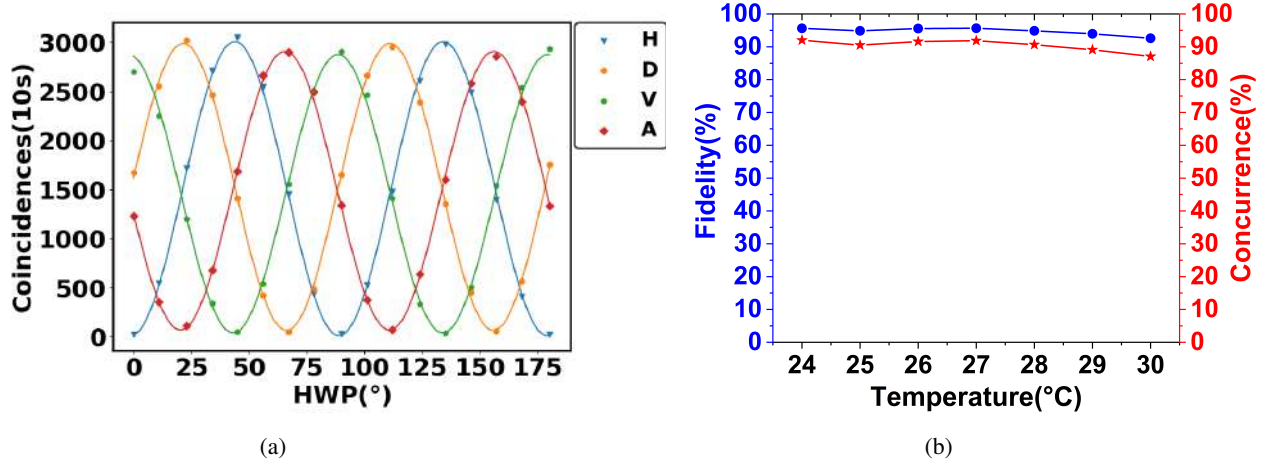


Figure 1: (a) Measured coincidence counts across different polarization bases are plotted as a function of the half-wave plate (HWP) angle. (b) Fidelity and concurrence, obtained from quantum state tomography (QST) measurements, are plotted as a function of temperature.

In the presented work, we demonstrate a robust and high-brightness source (2.76×10^7 pairs/s) of polarization-entangled photon pairs based on a Sagnac-interferometer incorporating a 30-mm long ppKTP crystal. The crystal is phase-matched at a wavelength of 400.22 nm and exhibits optimal performance at a temperature of 27°C. The entangled photon pairs exhibit high polarization visibilities of 98% in the H/V basis and 95% in the D/A basis. The coincidence curves for the D and A bases exhibit a clear phase shift of 22.5° relative to the H and V bases, respectively, which is a strong signature of the successful generation of the bell state $|\psi^+\rangle$ (Fig. [1a]). Importantly, the source maintains high entanglement quality over a temperature range of at least 6°C around the phase-matching temperature, as reflected in the stable fidelity and concurrence values shown in Fig. [1b].

In contrast to single-pass designs that are more susceptible to thermal drifts and require fine temperature tuning [3], our dual-pass Sagnac configurations offer enhanced robustness and efficiency, ensuring stable entanglement generation across varying conditions. The simplicity of the Sagnac architecture, combined with passive thermal robustness, makes this source highly promising for field-deployable quantum communication systems. Additionally, its compact footprint and stability reduce the need for active stabilization, enabling scalable integration into larger quantum networks.

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Optical Design of 20X MWIR Continuous Zoom Optics

Vikas Dua*, Manish Uniyal, V.K.Mishra, Ranabir Mandal

Instruments Research & Development Establishment, Dehradun - 248008

vikasdua.irde@gov.in

Abstract: In this paper, an optical design of MWIR continuous zoom optics with long focal length is presented. The f#4 continuous zoom optics is designed for a 1280 x 1024 array with 10 μm pitch cooled InSb detector having spectral response from 3 to 5 μm (MWIR). The designed optics has a zoom ratio of 20X and zoom range is 1200 mm to 60 mm.

1. Optical Design and Layout

The optical design has been carried out in a modular approach using CodeV® Optical Design software. First, the base zoom optics was designed for a zoom range of focal length 700 mm to 35 mm. Secondly, three lens range extender optics was designed with a magnification of $\sim 1.7X$. After this, both the designs were optimized in combination to achieve 20X zoom optics with a focal length range from 1200 mm to 60 mm. In this design, the system is aberration corrected for 09 zoom positions simultaneously and all optical and mechanical constraints are met. In the design process, enough care was taken to ensure that there are no deep curvatures or small thicknesses as these are difficult to manufacture. Deep curvatures result in very tight tolerances on the radius of curvature. Only spherical surfaces are used in the range extender optics. To reduce the spherical aberration and to balance other aberrations combination of spherical, aspheric and asphero- diffractive surfaces are used in the base zoom optics. Silicon and Germanium materials are used in the design. The number of elements in the range extender optics is three and in the base zoom optics is seven i.e there are total 10 lens elements. The aperture stop is placed at the cold window of detector in order to achieve 100% cold stop efficiency. The F-number is kept fixed at F/4.0 in order to match the detector numerical aperture at all zoom positions. Optical Layout of the designed system is shown in Fig. 1. The optical path is folded by two mirrors to achieve compact design. Lens number 5 and 6 are used for zooming. Lens number 7 is used for active athermalization and focusing. The designed system has been optimized to get a smooth CAM profile and good performance throughout the zoom range.

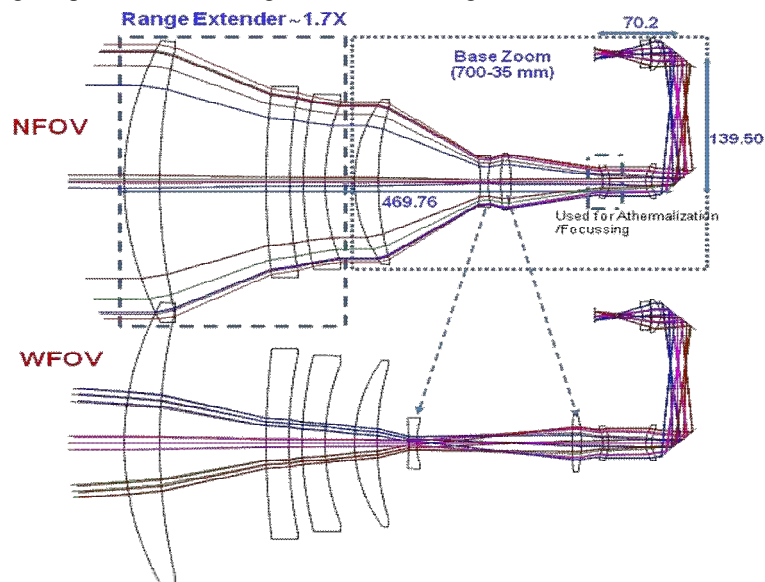


Fig. 1: Optical layout

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Coupling of nitrogen vacancy centers in a nanodiamond to an optical nano fiber tip for quantum technologies

Jelba John, Srinu Gadde, and Ramachandrarao Yalla

School of Physics, University of Hyderabad, Gachibowli, Telangana, 500046, India

The integration of single quantum emitters with nanophotonic elements is a key task in establishing scalable platforms for quantum technologies. The nitrogen vacancy (NV) centers in nano-diamonds are proven to be promising single quantum emitters due to their high photo-stability and sensitivity towards magnetic fields even at room temperatures. The nano-spatial dimension makes its integration into a variety of photonic platforms possible [1, 2]. Although different protocols exist, optical nano fiber tips (ONFTs) stand out as a promising platform as they have the automatic coupling to the single-mode fiber, which makes it easier to integrate into existing fiber networks [3-5]. In this paper, we experimentally demonstrate the coupling of fluorescence photons from the NV centers in nano-diamond to the guided modes of an ONFT.

The ONFTs are fabricated chemically using a two-step process employing hydrofluoric acid [4]. The fluorescent nanodiamonds of 40 nm average size, containing both NV^0 and NV^- , are diluted to 0.02% of the original concentration for isolating a few NVs. The prepared ND solution is filled in a micro litre vessel and fixed on top of the xy-stage. The ONFT was mounted on a high-precision motorized xyz-stage and approached the prepared ND solution. The ONFT is connected to a 532 nm laser to identify the tip and translated slowly towards the ND solution in sub-micron-sized steps. Once the tip touches the ND solution, a scattering is observed due to NDs at its tip [4]. The schematic of the experiment is shown in Fig. 1(a). The NDs on the ONFT are excited using a green laser through a 40X objective lens, and the fluorescence photons coupled to the guided modes of the ONFT are observed in the high-resolution spectrometer. A 600 nm wavelength cut-off filter (F) is used to filter out the laser light.

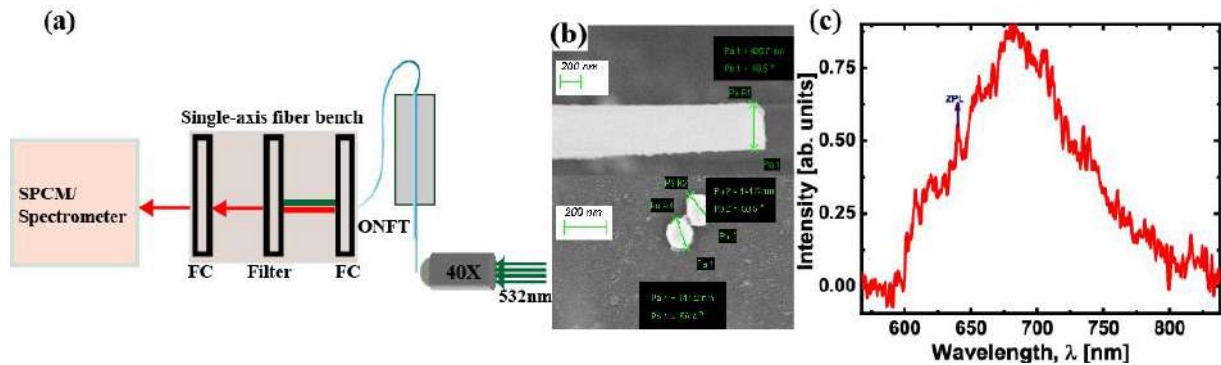


Fig. 1 (a) The experimental set-up for the deposition as well as the collection of fluorescence from NV centers in ND on ONFT. (b) Typical FESEM image of ONFT (top) and NV contained nanodiamond (bottom). (c) The observed fluorescence spectrum from the NV centers in ND on the ONFT.

The typical scanning electron microscope image of the ONFT and ND is shown in the top and bottom panels of Fig. 1(b), respectively. The ONFT and ND sizes are about 400 nm and 140 nm, respectively. Regarding the identification of the fluorescent NDs on the ONFT, the sample position is scanned from the tip by observing photon counts through a single photon counting module (SPCM). Subsequently, we record the fluorescence spectrum from the NDs using a Spectrometer. A typical spectrum corresponding to the maximum intense spot is shown in Fig. 1(c). One can readily see that the zero-phonon line is at 638 nm and has a broad phonon sideband width of 200 nm. The above measurements verify the presence of NVs in NDs on the ONFT. The established ND coupled ONFT serves as a stable, easy-to-handle platform for different fluorescence-based sensing, imaging, and quantum communication applications [3, 7].

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Exploring two-photon interference via second harmonic generation

Shibam Mondal, Omshankar, Joyee Ghosh

Quantum Photonics Lab, Department of Physics, Indian Institute of Technology Delhi, New Delhi, 110016

In the current stage of quantum technologies, one of the most important fields is secure quantum communication, which requires highly efficient, robust single-photon sources. One of the most widely used methods for this purpose is Spontaneous Parametric Down Conversion (SPDC), which generates a pair of correlated single photons using nonlinear optical processes. To characterize these photons, the Hong–Ou–Mandel (HOM) interference experiment is commonly employed. The width and visibility of the HOM dip reveal information about the spectral and temporal properties of the biphoton wavefunction [1]. However, these quantum-level measurements are experimentally demanding, requiring precise alignment, low-loss optics, and sensitive coincidence detection schemes.

In this work, we propose a classical approach to estimate quantum interference parameters related to HOM dip width and temporal coherence using Second Harmonic Generation (SHG). This method is based on the theoretical equivalence of SPDC and SHG, which share the same phase matching conditions in a nonlinear crystal. We used a theoretical framework [2-4] linking the joint spectral intensity (JSI) of SPDC photons to the SHG power spectrum. Experimentally, we employed a 1 cm ppKTP crystal in a single-pass configuration and performed SPDC and SHG in the same setup for consistency. By varying beam focusing conditions, crystal temperature, and pump wavelength, we observed corresponding changes in both SHG bandwidth and HOM dip width.

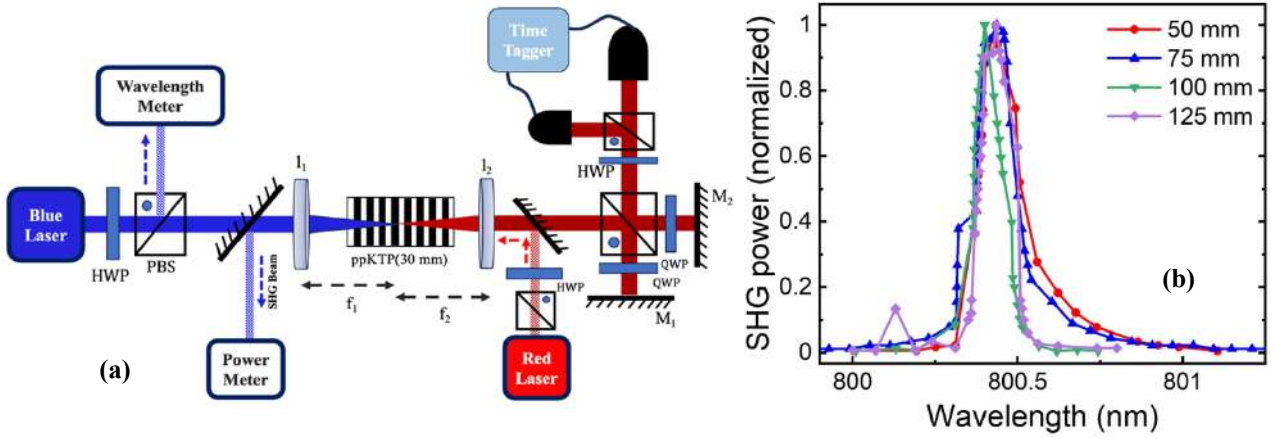


Fig.1:(a)Experimental Setup for SPDC and SHG (b) SHG power as a function of pump wavelength with varying focusing lenses

Our study demonstrates a strong correlation between beam focusing and spectral bandwidth in both classical and quantum regimes. We observed tighter focusing (shorter focal lengths) leads to significant spectral broadening in SHG, i.e. the FWHM increases with decreasing focal lengths (Fig.1(b)). This shows good agreement with the theoretical model [3-4]. A corresponding trend is observed in the quantum domain, where the spectral bandwidth extracted from HOM interference also broadens with tighter collection optics, reflecting reduced temporal coherence. These results confirm that spatial focusing directly impacts phase-matching conditions and spectral properties [3]. Similar studies were done to check the variation of SHG phase matching temperature bandwidth with different focusing lenses. These results validate that spectral, and temperature tuning curves of SHG can effectively predict the coherence properties of SPDC photon pairs. Our approach allows for easy pre-alignment of quantum light sources and may be extended to optimize entanglement, spectral characteristics and photon indistinguishability.

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Enhancement of hydrophobicity of Nanocrystalline AlSiN coated sapphire surface via RF Magnetron Sputtering for marine application

V K Mishra, Raman devi, Somdatta singh, Ramesh Chandra

Thin Film Laboratory, Institute Instrumentation Centre,

Indian Institute of Technology Roorkee, Roorkee, 247667, Uttarakhand, India

Abstract: In order to enhance hydrophobicity along with maintaining the suitable hardness of Nanostructured AlSiN coating on sapphire substrate, a coating of PTFE by RF Magnetron sputtering technique at an optimised parameter of RF power, argon flow and time duration was investigated. As a result, contact angle enhanced upto 116° from 102° while maintaining the transparency.

Nanostructured AlSiN coating on sapphire substrate at temperature 250°C for different duration of deposition has been investigated and it was found that contact angle is in range of 95 to 102 deg. The coating show hydrophobicity and hardness of the order of 33GPa . In order to increase the hydrophobicity for application like windows of electro-optical system in marine environment, idea of coating of PTFE for very short duration like 30 sec in RF Magnetron sputtering system over already coated surface with AlSiN has been investigated. AlSiN coating on glass substrate is quite hard and transparent too. The increase in hydrophobicity will make it good combination to be used in marine environment. It will reduce the micro fouling on surface of glass due to increased hydrophobicity. Hydrophobic coatings exhibit reduced conductivity and enhanced resistance to corrosion.

The sapphire substrate coated with AlSiN with variation of deposition time have been sputtered with polytetrafluoroethylene (PTFE). Coating with PTFE definitely affect the hardness. Effect of PTFE coating depend on thickness of AlSiN coating already done on substrate and nanostructure formed. It reduces the hardness substantially for surfaces having coating thickness less than 500nm but does not affect much when thickness is of the order of micron. The coating was characterised for optical transmission in visible spectrum through UV-VIS spectrometer, hydrophobicity through contact angle measurement and hardness through nanoindentation. In all three sample, increase in contact angle (hydrophobicity) has been observed. But at the same time there is variation in hardness depending on thickness of AlSiN coating on sample. Transmission and contact angle measurement is shown in Fig 1. And Fig2.

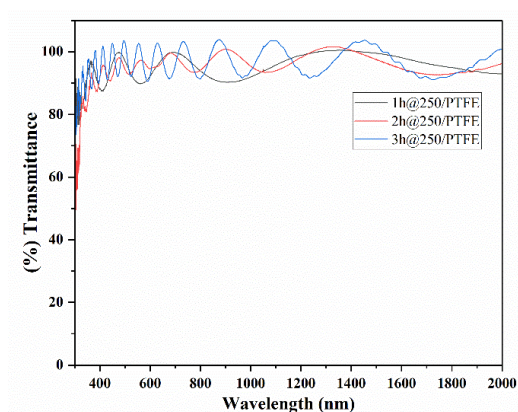


Fig 1. Transmission plot in visible range

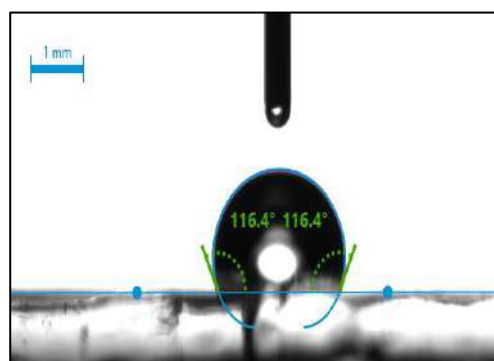


Fig 2. Contact angle of coated surface

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Energy Transfer and Color Tunable Photoluminescence of $\text{Sr}_2\text{P}_2\text{O}_7: \text{Tb}^{3+}, \text{Eu}^{3+}$ Phosphor

Aarsh Thomas¹, Nimesh Patel¹

¹Department of Physics, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara

A series of strontium pyrophosphate $\text{Sr}_2\text{P}_2\text{O}_7$ phosphors were synthesized through solution combustion method by varying concentrations of activator and sensitizer ions, specifically Eu^{3+} at 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6%, while maintaining a constant Tb^{3+} concentration of 0.3%. XRD measurements were carried out to revealed the crystal structure of the phosphor which is very consistent with orthorhombic structure. Photoluminescence (PL) properties of phosphors were examined by the means of excitation and emission spectra of the phosphor. PL emission spectra of Tb^{3+} , Eu^{3+} co-doped $\text{Sr}_2\text{P}_2\text{O}_7$ recorded under 396nm excitation wavelength exhibits characteristic emission of Eu^{3+} , whereas recorded under 380nm excitation wavelength exhibits characteristic emission of Tb^{3+} and Eu^{3+} . The PL emission concentration quenching effect is observe at 0.4% of Eu^{3+} under 396nm excitation. The energy transfer from Tb^{3+} to Eu^{3+} was observed under 380nm excitation. The results suggest that the colour tuning can be made possible by the energy transfer phenomenon that could be very useful. The emission under near UV suggest that the phosphor have wide application in solid state lighting.

The photoluminescence excitation (PLE) spectra of $\text{Sr}_2\text{P}_2\text{O}_7: 0.3\% \text{Tb}^{3+}, 0.4\% \text{Eu}^{3+}$ was recorded under 545nm emission of Tb^{3+} and 618nm emission of Eu^{3+} is as illustrated in Figure 1(a). PLE spectrum recorded under 545nm emission wavelength is separated by two distinct regions: (i) an excitation band centred at 238nm, attributed to the $4f^8 - 4f^75d^1$ allowed transition of Tb^{3+} , and (ii) sharp excitation peaks in the 300–500nm range, corresponding to the $4f - 4f$ transitions of Tb^{3+} i.e., 340nm ($^7F_6 - ^5G_2$), 354nm ($^7F_6 - ^5D_2$), 359nm ($^7F_6 - G_5$), 367nm ($^7F_6 - ^5L_{10}$), 378nm ($^7F_6 - ^5D_3$) and 487nm ($^7F_6 - ^5D_4$), respectively. However, the excitation spectrum recorded under 618nm emission is also divided into two parts: (i) a broad excitation band centred at 272nm, associated with the charge transfer band (CTB) of $\text{O}^{2-} - \text{Eu}^{3+}$, and (ii) sharp excitation peaks in the 300–500nm range, attributed to the intra- $4f$ transitions of Eu^{3+} i.e., 320nm ($^7F_0 - ^5H_6$), 363nm ($^7F_0 - ^5D_4$), 383nm ($^7F_0 - ^5L_7$), 396nm ($^7F_0 - ^5L_6$) and 466nm ($^7F_0 - ^5D_2$), respectively.

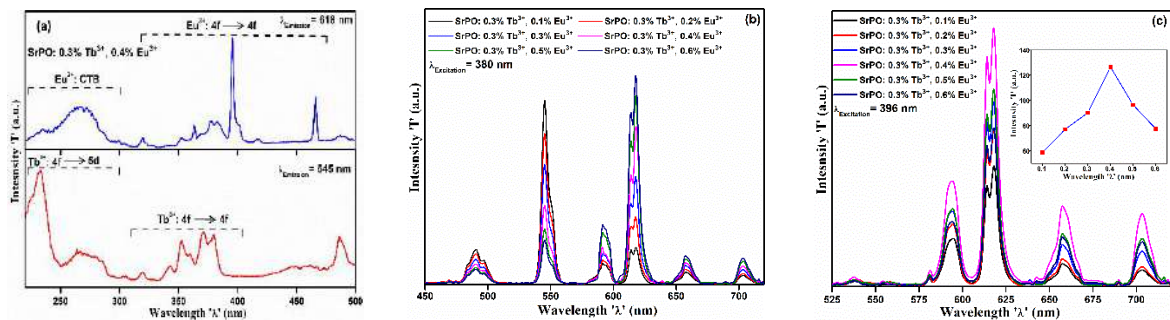


FIGURE 1. (a) PLE spectra of Tb^{3+} , Eu^{3+} -doped $\text{Sr}_2\text{P}_2\text{O}_7$ phosphor; PL emission spectra of Tb^{3+} , Eu^{3+} -doped $\text{Sr}_2\text{P}_2\text{O}_7$ (b) $\lambda_{\text{exc}} = 380 \text{ nm}$; (c) $\lambda_{\text{exc}} = 396 \text{ nm}$.

FIGURE 1 (b) and (c) show the emission spectra of $\text{Sr}_2\text{P}_2\text{O}_7: 0.3\% \text{Tb}^{3+}, x\% \text{Eu}^{3+}$ ($x = 0.1, 0.2, 0.3, 0.4, 0.5$, and 0.6%) under two different excitation of Tb^{3+} (380nm) and Eu^{3+} (396nm). The PL emission spectrum recorded under the 380nm excitations mainly consisted of three sharp peaks of Tb^{3+} located at 494, 545 and 591nm that could be attributed to the $^5D_4 \rightarrow ^7F_6$, $^5D_4 \rightarrow ^7F_5$ and $^5D_4 \rightarrow ^7F_4$ transitions with 593, 618, 658 and 705 nm, which could be attributed to the $^5D_0 \rightarrow ^7F_6$, $^5D_0 \rightarrow ^7F_5$, $^5D_0 \rightarrow ^7F_4$ and $^5D_0 \rightarrow ^7F_3$ transitions of Eu^{3+} ions. However, the emission recorded 396nm excitation exhibit only the sharp peaks corresponding to Eu^{3+} transitions. FIGURE 1 (b) illustrate that under excitation of 380 nm as the doping concentration of Eu^{3+} increases the intensity of the green emission at 545 nm of Tb^{3+} decreased significantly, however the intensity of the red emission at 615 nm of Eu^{3+} increases. The radiative energy transfer is observed because of the addition of Eu^{3+} concentration can reduce the relative distance between Tb^{3+} ions and Eu^{3+} ions in the host lattice occupied at two different sites. The energy transfer is observed from Tb^{3+} to Eu^{3+} , which significantly affect the PL emission from green to red transformation.

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Parallel Water Toxin Detection: A Next Generation 'Lab-on-Chip' Device Using Laser-Based Microbubble Lithography

Om Khare¹, Ankita Choudhary¹, Chandan Kumar², Raja Shunmugam² and Ayan Banerjee¹

1.Light Matter Lab, Department of Physical Sciences, Indian Institute of Science Education and Research Kolkata, Mohanpur, Nadia, West Bengal, 741246, India

2.Department of Chemical Sciences, Indian Institute of Science Education and Research Kolkata, Mohanpur, Nadia, West Bengal, 741246, India

In situ patterning of biomolecules and living matter is challenging due to the potential for thermal damage to sensitive materials and a lack of precise control in bottom-up fabrication methods. We report on a novel approach using **Microbubble Lithography (MBL)**, a versatile, laser-guided bottom-up technique, to address these limitations. MBL uses a focused laser to generate a microbubble that can be precisely manipulated, allowing for the real-time self-assembly and patterning of materials on a substrate. By carefully optimizing laser power and translation speed, we can create continuous patterns while ensuring the patterned material retains its biological activity. We have previously demonstrated the successful patterning of living bacteria and viruses while preserving their functionality [1]

Building on this success, we have now applied MBL to assemble a newly synthesized, biodegradable polymeric sensor system for the rapid and selective detection of fluoride ions (F^-). This system utilizes a BODIPY-based monomer (BDNP) that, upon interaction with F^- , undergoes a deprotonation reaction triggering an intramolecular charge transfer (ICT) process. This results in a significant and immediate color change from pink-to-grey, visible to the naked eye. We also synthesized a biodegradable and biocompatible BDNP- ϵ -caprolactone homopolymer (Poly-BDNP) using ring-opening polymerization (ROP) [2].

Our novelty lies in the use of MBL to assemble this sensor within a microfluidic chip, along with a separate sensor for arsenic developed by the same research group. This precise, laser-based assembly enables the simultaneous, real-time detection of both toxins in a single water sample. The polymeric sensor, Poly-BDNP, demonstrated exceptional sensitivity and selectivity toward F^- , with a limit of detection (LOD) of 87.9 nM, which is significantly lower than that of the monomer (7.73 μ M). The sensor provides a rapid response in less than a minute and shows strong performance even in the presence of competing ions in real-world environmental samples, such as fluoride-contaminated groundwater from Rajasthan, India, and commercial toothpaste. The use of a biodegradable polymer in the sensor platform also offers an environmentally friendly solution for sensor waste. This work establishes MBL as a promising technique for creating a next-generation "lab-on-chip" device for public health and environmental applications.

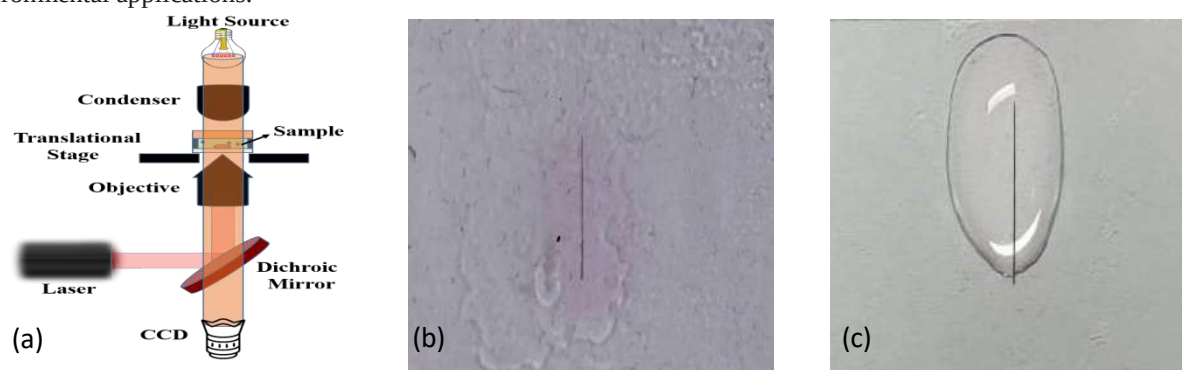


Fig.(a) The schematic of a laser-induced microbubble self-assembling and patterning materials using MBL, Fig. (b): Pink coloration observed upon exposure to fluoride-contaminated water. Fig.(c): Absence of color change following drop-casting of normal water.

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Laser Frequency Stabilization Using Embedded Control for Cesium Atom Trapping and Interferometry Systems

Deepshikha Singh¹, Hemant Yadav¹, Kripali Jain¹, and Bodhaditya Santra¹

¹ Department of Physics, Indian Institute of Technology, New Delhi 110016, India

Laser frequency stabilization is a critical requirement in a wide range of applications, including precision spectroscopy, optical frequency standards and clocks [1], optical communications, gravity measurements [2,3] and atomic physics experiments. Achieving stable laser operation for such precision experiments necessitates an active feedback loop that continuously corrects frequency drifts, thereby maintaining the laser at its desired resonance. To address these requirements, we present a digital laser frequency stabilization system based on a microcontroller (MCU) implementing a proportional–integral–derivative (PID) controller. Our STM32-based implementation achieves performance comparable to FPGA-based systems while offering significantly reduced cost and complexity [4]. The system is characterized through long-term stability tests, overlapping Allan deviation, noise spectral density, and delayed self-heterodyne interferometry (DSHI), yielding a laser linewidth of 93 ± 2 kHz. The stabilized laser was successfully applied to cool and trap approximately 1.5×10^6 cesium atoms in a magneto-optical trap, demonstrating that the system provides the frequency stability required for laser cooling, sub-Doppler techniques, and other cold-atom–based optical experiments. The integration of digital control and data acquisition within a microcontroller framework further enhances the system’s usability for field-deployable quantum technologies. Looking ahead, the incorporation of artificial intelligence (AI) and machine learning (ML) techniques could improve the adaptability and performance of the locking system, enabling autonomous optimization in dynamic experimental environments.

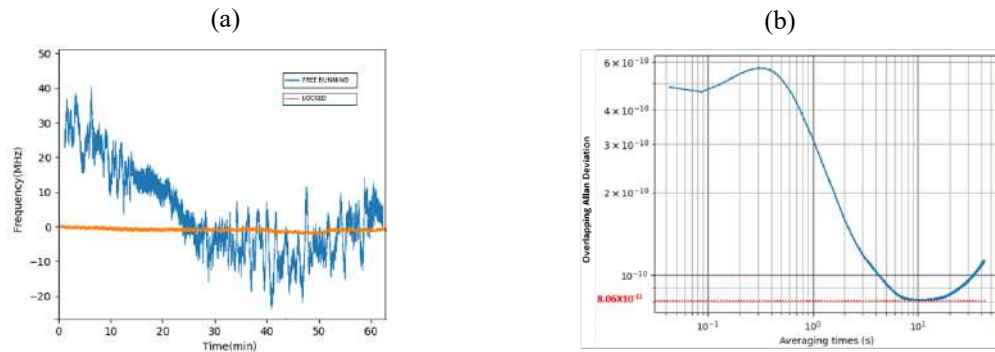


Fig.1 (a) Contrast between the free-running laser frequency span (blue) with the locked frequency (orange). The locking system is able to bring down the free-running laser frequency drift (50-60 MHz) of the laser to < 2.3 MHz. (b) Overlapping Allan deviation as a function of averaging time for the system under investigation. The red dashed line represents the minimum Allan deviation achieved, indicating a stability of 8.06×10^{-11} at a $\tau = 8$ seconds.

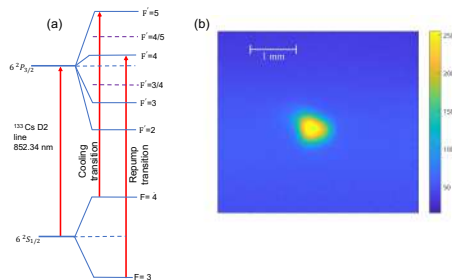


Fig.2 (a) Energy level diagram of the ^{133}Cs D2 transition at 852.34 nm, illustrating the hyperfine energy states relevant to the operation of a magneto-optical trap (MOT). (b) The Fluorescence image of the MOT of ^{133}Cs atoms captured with a CCD camera.

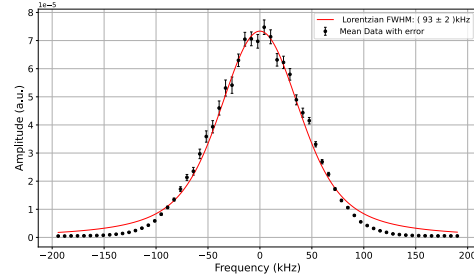


Fig.3 The linewidth of the ECDL from self heterodyne method. The full width half maxima (FWHM) linewidth is 93 ± 2 kHz.

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Impact of Diffuser Selection on Scintillation Mitigation for UOWC Links: Experimental Investigations

Vedant P. Borde¹, Shailendra K. Varshney¹

1. Indian Institute of Technology Kharagpur, West Bengal 721302, India

Underwater Wireless Optical Communication (UWOC) offers high bandwidth and low latency compared to traditional acoustic communication, making it ideal for short to medium range links in applications. However, optical turbulence induced by water temperature gradients, salinity fluctuations, suspended particulates, and bubbles introduces scintillation. The random temporal and spatial fluctuations in received light intensity severely degrade the performance of the UWOC system. This work investigates different diffuser strategies based scintillation mitigation in UWOC systems. The experimental findings are investigated using a 1m clear-water channel link and the effect of these on the bit-error rate (BER) fluctuations, for enhancing link stability. Sun et al. [1] have put forward the practical design strategies, such as beam collimation, aperture averaging, and modulation optimization, for mitigating these effects, whereas the experimental work reported in [2] demonstrates diffuser-based aperture averaging, comparing engineered diffusers, ground glass diffusers, and lens-based solutions. Turbulence effects were studied in [3] using controlled water flows, linking flow-induced scintillation to BER degradation.

Fig. 1 (a), shows the experimental sketch and real experimental set-up in the dark-environment lab condition to eliminate ambient light interference. The optical link was established using a 1 m water tank filled with tap water, which served as the propagation channel. The measured scintillation index is in the range of $\sigma_I \approx 0.003$. A continuous 445 nm blue laser source, emitting 20 mW of optical output power, is used as the transmitter. The beam was modulated using On-Off Keying (OOK) and encoded directly on a Basys 3 FPGA development board. The receiver module consisted of a PIN photodiode (PD) - FDS100 coupled to an in-house designed PCB, which consists of a transimpedance amplifier (TIA), a precision operational amplifier stage, and a high-speed comparator. The processed electrical signal was then fed back into the FPGA for data logging. Different optical diffusers are positioned immediately in front of the receiver, outside the water tank. Three diffuser configurations were tested: a standard 20mm concave lens from Thorlabs, a 25x25mm, 600-grit ground glass diffuser (GGD) from Edmund Optics, and an engineered diffuser (ED1-C50) from Thorlabs. Each diffuser introduced a different divergence profile to the received beam, enabling the analysis of aperture averaging effects on scintillation suppression.

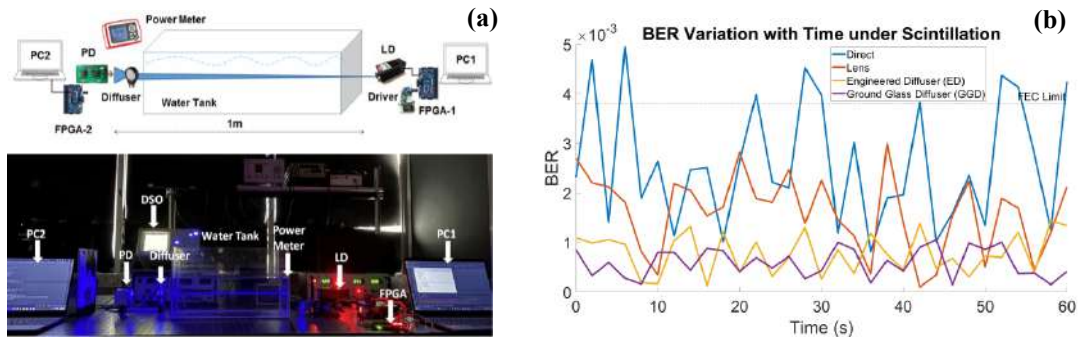


Fig. 1(a) Schematic and Experimental Setup for UOWC System (b) BER vs. Time Plot for different types of diffusers.

Fig.1 (b) illustrates the BER fluctuations for (i) direct exposure of the beam on the PD (without a diffuser), shown by the solid blue curve, (ii) a concave lens as a diffuser, which slightly reduces fluctuations but still exhibits moderate BER variation, and (iii) the engineered diffuser (ED) and ground glass diffuser (GGD) provide the most stable performance, with BER consistently well below the FEC threshold. The GGD achieves the lowest average BER but at a lesser received power, while ED maintains both low BER and high optical power coupling. The experimental findings confirm that diffuser-based aperture averaging effectively suppresses scintillation-induced BER variations over time.

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Design and Development of Maskless Technique for Three Segmented Quasi-Phase Matching Devices

Prashant Povel Dwivedi¹, Ajay Mishra², Nimish Dixit³

1. MUJ-NLO⁺ Research Lab, Department of Electronics and Communication Engineering, Manipal University Jaipur, Jaipur 303 007, Rajasthan India

2. Instruments Research & Development Establishment (IRDE), DRDO, Dehradun- 248 008, Uttarakhand India

A significant improvement in the development of mature quasi-phase-matching (QPM) device fabrication has resulted in its employment in applications such as optical frequency conversion (OFC), optical dispersion compensation (ODC), optical parametric generating (OPG), and so on. The technological feature that permits nonlinear optical characteristics to be modified by varying the size, shape, and periodicity of ferroelectric domains. For example, a three-segment structure optical frequency converter based on a QPM device could operate as an electro-optic (EO) tuning method and provide a rapid wavelength selection method for the optical parametric oscillator (OPO) in the large infrared spectral region.

The purpose of the work is to develop a maskless technique because the traditional fabrication process (mask technique) for QPM devices is expensive and time-consuming in most optical facilities. Getting effective feedback between the design and fabricating steps is another reason why cutting down on fabrication time is desirable. The maskless technology, which involves scanning the electrode pattern with a focused laser beam, can save time and money by eliminating the need for fabricating a photomask [1-6]. An advantage of this "maskless" process is that it is easier and faster to modify the ferroelectric domains' structure to tailor the nonlinear optical properties as shown in Fig. 1. Examples of these structures include 2-D gratings, aperiodic (such as chirped gratings), tandem gratings, fan-out gratings, various gratings on the same wafer, and controlled distribution of d_{eff} and three-segment quasi-phase matching structures.

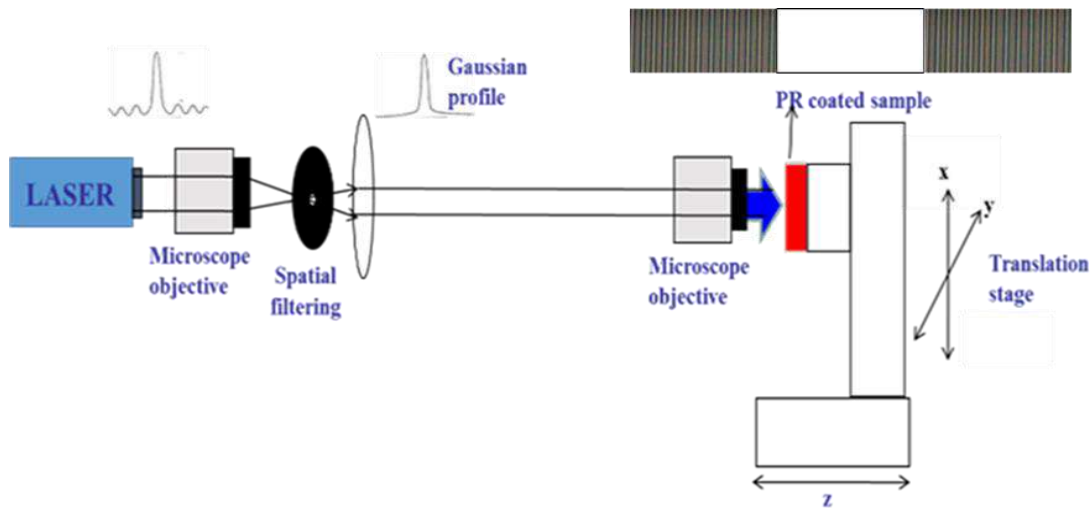


Fig. 1 Schematic diagram of experimental setup used for maskless technique and the resulting three segmented photoresist (PR) pattern.

Any slight design change to quasi-phase matching devices necessitates the fabrication of a completely new set of masks, resulting in extremely high production costs and delays. The current research aims to make it easier and faster to modify the nonlinear optical properties by altering the structure of the ferroelectric domains.

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Improved Common Pulse Retrieval Algorithm for Ultrafast Pulse Characterization

Swapnil Kale and Kanaka Raju P.*

School of Quantum Technology, DIAT(DU), Pune, Maharashtra 411025, India

Email: raju@diat.ac.in

Ultrafast pulse retrieval techniques rely on a 2D trace - a spectrally resolved SHG signal plotted as a function of a control parameter z (e.g., time delay in FROG or glass insertion thickness in D-scan) [1]. This trace encodes both amplitude and phase information of the pulse and serves as the input to the retrieval algorithm. The algorithm begins with an initial guess of the complex electric field and uses it to generate a simulated 2D trace through a forward model that mimics the experimental setup. In each iteration, the algorithm minimizes the error between the measured and simulated trace, typically using gradient-based or projection-based optimization methods. Through this iterative process, the algorithm rapidly converges to the electric field that best reproduces the experimental trace, thereby reconstructing the full temporal and spectral characteristics of the ultrashort pulse.

COPRA (Common Pulse Retrieval Algorithm) [2] is a robust and efficient method for retrieving ultrashort laser pulses. It uses a gradient-based projection scheme to minimize the error between simulated and measured traces, offering reliable convergence even for complex pulses. Although COPRA convergence slows down significantly when dealing with complex or noisy measured ultrashort pulse traces, due to the increased number of iterations required. In this work, we have enhanced the COPRA framework by incorporating advanced optimization techniques to facilitate faster convergence.

COPRA has two stages to fully retrieve an ultrafast pulse: Local iteration and Global iteration. The Local iteration starts with an initial guess for the electric field $\tilde{E}(\omega)$, typically a Gaussian pulse. This field is modified by a phase mask $\tilde{P}_z(\omega) = \exp(i\varphi_z(\omega - \omega_0))$ to introduce dispersion (in D-scan) or pulse delay (in FROG), and then passed through an SHG crystal. After taking the Inverse Fourier transform, a time-domain signal $E_{sig}(t, z)$ is generated. Local iteration minimizes the signal error between the current and updated signal using gradient descent (where the amplitude is replaced with that from the measured trace). If no improvement in trace error is observed for five iterations, the algorithm switches to the Global iteration, which minimizes the trace error directly. The following flowchart explains the Global Iteration stage implementation.

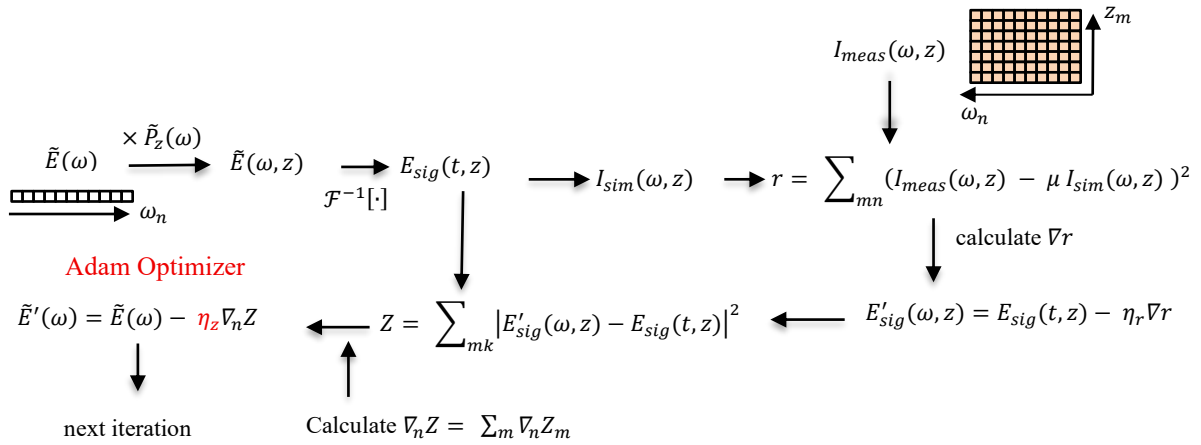


Fig. 1. Improved Global iteration stage for faster convergence.

By incorporating Adam Optimizer [3] into the gradient descent step, the retrieval took 82 iterations to achieve the trace error of $R = 10^{-6}$ for a pulse shape with TBP of 4.0 (very complex pulse) in comparison to the original COPRA, which requires nearly 100 iterations. Our modified approach aims to make COPRA more scalable and effective for noisy or computationally demanding scenarios in pulse retrieval, and it can be used with any 2D trace-based pulse characterizations.

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Laguerre-Gaussian Radial Hilbert Transform Based Penalty for Image Restoration

Muskan Kularia¹, Kedar Khare^{1,2}

1. Optics and Photonics Centre, Indian Institute of Technology Delhi, Hauz Khas, New Delhi, 110016, India

2. Department of Physics, Indian Institute of Technology Delhi, Hauz Khas, New Delhi, 110016, India

Gradient-based regularization penalties, such as Total Variation (TV), are widely used in computational imaging due to their ability to suppress noise while preserving edges. However, standard implementations of these penalties rely solely on gradients computed along Cartesian axes. When used iteratively for image restoration tasks such as denoising or deconvolution, these methods tend to introduce anisotropic artifacts [1]—most notably faint grid-like textures—that degrade the spatial and spectral quality of the reconstructed images. In this work, we present a novel, isotropic penalty based on the Laguerre-Gaussian (LG) radial Hilbert transform. This operator generalizes the concept of the Hilbert derivative to two dimensions using a spiral phase formulation [2], while incorporating radial Gaussian weighting to enhance spectral selectivity. Unlike traditional TV penalties that operate on local, axis-aligned central differences, our proposed penalty leverages the spatial symmetry and non-locality of the LG filter to promote edge enhancement without directional bias [3]. The resulting regularizer suppresses both low-frequency background and high-frequency noise, selectively retaining mid-frequency features critical for texture and structure. The functional derivative of this penalty lacks a closed-form expression but is straightforward to compute using automatic differentiation frameworks, making it easily integrable with existing gradient-based optimization algorithms. To evaluate the effectiveness of this regularizer, we compare its performance in denoising against standard TV regularization using gradient descent optimization.

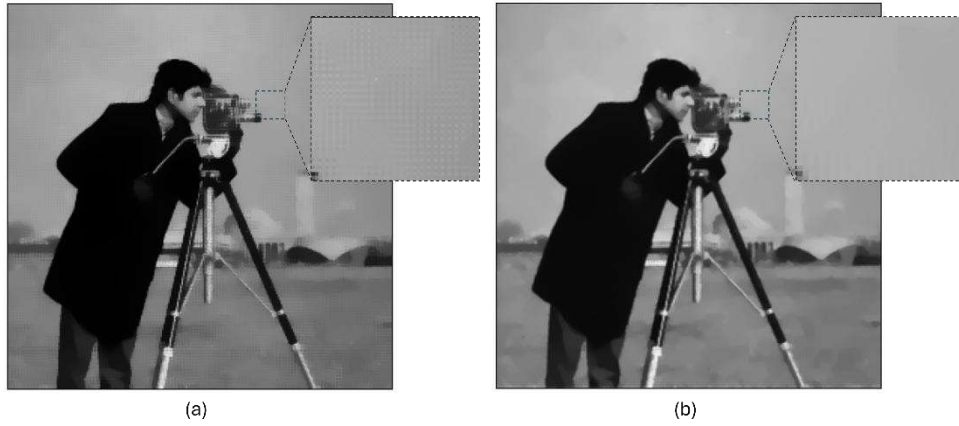


Fig. 1 Image Denoised using Gradient descent-based optimization with regularization using (a) Total Variation Penalty (b) Laguerre-Gaussian Radial Hilbert Transform Penalty

Figure 1 shows results of denoising using Gradient descent-based optimization approach on noisy Cameraman image for the two regularization penalties. Visual inspection of results reveals that the proposed method achieves superior reconstruction fidelity and a marked reduction in the grid patterns that appear in the traditional TV penalty has been observed. Additionally, we observed that the restored images exhibit cleaner Fourier spectra without spurious energy bands that typically arise from repeated directional filtering. These observations confirm that the LG-based penalty better preserves the natural texture and frequency content of images.

Overall, the proposed regularization framework offers a practical and generalizable tool for computational imaging tasks that benefit from structure-preserving, artifact-free restoration. By combining the edge-enhancing power of the Hilbert transform with the spectral control of radial Gaussian weighting, the LG-based penalty provides a more faithful representation of image gradients in two dimensions.

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Controlled Dark Spot Formation via Phase Shaping of Longitudinally Polarized Beams

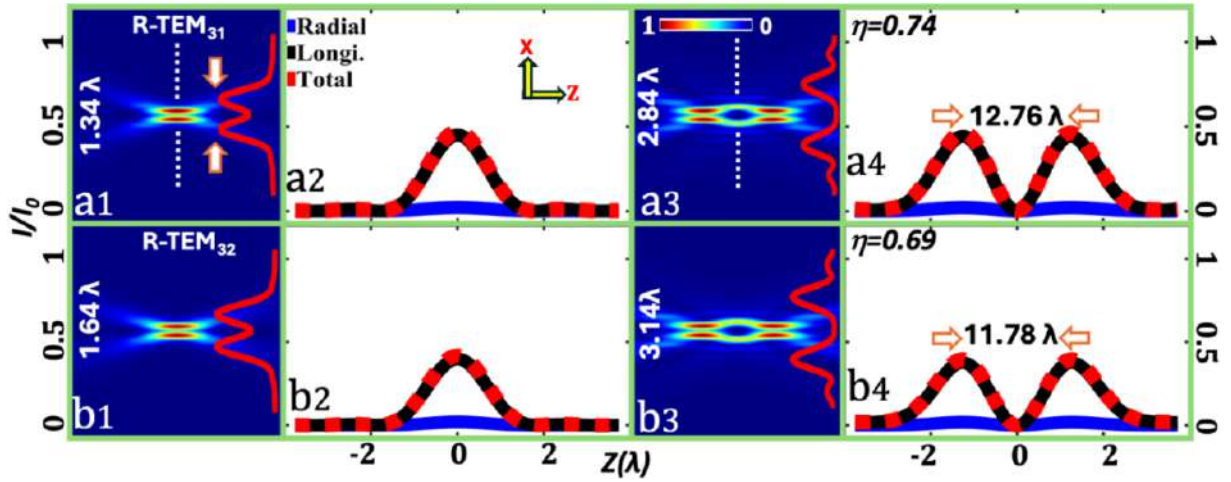
Brijesh Kumar Mishra, and Brijesh Kumar Singh*

Department of Physics, Central University of Rajasthan, Bandarsindri, Ajmer, Rajasthan, 305817

*brijeshsingh@curaj.ac.in, 2020phdph004@curaj.ac.in

Abstract: We propose a method to create tunable three-dimensional (3D) dark spots by focusing high-order longitudinally polarized beams. We used a binary phase mask, which works as a polarization filter, to suppress the longitudinal component in order to shape the focal field that results in the exact 3D intensity nulls. Tunable dark focal spots are generated using the high-order radially polarized transverse (R-TEM₃₁ and R-TEM₃₂) mode focused through low-numerical-aperture optical systems. This dark spot formation can enhance applications such as optical trapping of low-index particles, high-resolution imaging with reduced background, and structured light-matter interactions.

Introduction: By using the concept of destructive interference between two optical beams, a three-dimensional (3D) dark area encircled by an optical field can be created along the focal region. Such a 3D dark spot is also referred to as an optical bottle beam [1]. Various existing methods have used linearly and circularly polarized beams [2], a double-ring radially polarized beam [3], an azimuthally polarized beam [4], and a combined beam of radial and azimuthal polarizations [5] to produce dark-spot formations. Such structured dark spots find potential applications in various fields, such as in atom trapping [6] and used as a depletion beam for the de-excitation of excited fluorescence molecules in the stimulated emission depletion (STED) microscope [7, 8]. Here, we present a systematic method for the controlled formation of 3D dark spots in the focal region with high-order radially polarized R-TEM₃₁ and R-TEM₃₂ modes. We designed an appropriate binary phase mask that consists of two regions of opposite phase. This mask manipulates the superposition of longitudinal and transverse field components of R-TEM mode and converts it into a well-defined 3D dark region in the focal volume of a low numerical aperture optical system.



Result & discussion: The figure illustrates the influence of the binary phase mask on the dark spot characteristics of high-order longitudinally polarized R-TEM₃₁ and R-TEM₃₂ modes, as shown in the first and second rows, respectively. The figure is organized in two rows, corresponding to NA = 0.5 and a four-column layout. The first two columns (a1–b1, a2–b2) show the 2D intensity distributions in the xz-plane and corresponding 1D axial profiles for the unmodulated high-order R-TEM beams, respectively. The third and fourth columns (a3–b3, a4–b4) present the 2D and 1D axial intensity distributions after applying the binary phase mask. For a numerical aperture (NA) of 0.5, the axial peak-to-peak (P–P) distance between the high-intensity lobes along the optical axis is measured to be 12.76 λ for the R-TEM₃₁ and 11.78 λ for the R-TEM₃₂ mode, as shown in Figures a4 and b4, respectively. These measurements are based on the axial intensity profiles obtained after applying the binary phase mask. The lateral extent of the dark focus, determined by the peak-to-peak (P–P) distance between the lateral intensity lobes along the x-axis, also follows a similar trend. For NA = 0.5, the lateral P–P distance is measured to be 2.84 λ for the R-TEM₃₁ mode and 3.14 λ for the R-TEM₃₂ mode.

The dark spot formation in R-TEM₃₁ and R-TEM₃₂ modes arises from the radial polarization structure and vector field superposition under low numerical aperture focusing. In low NA focusing, the symmetric transverse components interfere destructively along the optical axis, suppressing the central electric field and creating a dark focal region. With higher mode orders, the field complexity increases, leading to stronger destructive interference at the centre. The longitudinal field also vanishes at the beam centre, further deepening the intensity null.

Conclusion: Finally, under low numerical aperture focusing conditions, our analysis revealed that the proposed mask significantly influences dark spot characteristics for R-TEM₃₁ mode and R-TEM₃₂ mode. A consistent increase in the peak-to-peak distance in the longitudinal plane was observed for the R-TEM₃₁ mode and R-TEM₃₂ mode, indicating an effective broadening of the dark region. It also produced the smallest spot size in the transverse plane. Such tunable dark regions are particularly useful in optical trapping, in super-resolution microscopy, especially STED, where engineered dark spots serve as effective depletion beams, contributing to enhanced spatial resolution.

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Noise-like pulse generation from nonlinear absorbing loop mirror based Er-doped fiber laser

Aruna Ghosh^{1,2}, Shubhranil Maity^{1,2}, Shyamal Das¹, Sourav Das Chowdhury¹, Mukul Chandra Paul¹

¹Fiber Optics and Photonics Division, CSIR-Central Glass and Ceramic Research Institute, 196, Raja S.C. Mullick Road, Kolkata 700032, India

²Department of Physics, Jadavpur University, Kolkata 700032, India

Artificial saturable absorbers such as nonlinear loop mirrors are widely employed in mode-locked fiber lasers. In addition to the well-known nonlinear optical loop mirrors (NOLM) and nonlinear amplifying loop mirrors (NALM), a third configuration—the nonlinear absorbing loop mirror (NAbLM)—is realized by inserting an absorber asymmetrically within the loop. The NAbLM can deliver equal power levels to the two counter-propagating light waves because the absorber intrinsically exhibits equal absorption for both directions [1]. This symmetry in absorption results in equal-power interference, enabling the NAbLM to achieve a higher extinction ratio compared to NOLM and NALM [2].

In this work, we report a nonlinear absorbing loop mirror (NAbLM) implemented in a figure-8 Er-doped fiber laser (EDFL) cavity. Total cavity length is almost 130 m, including 100 m long extra SMF-28, 1 m EDF, 1.7 m HI1060 fiber and 2 m Bi-doped fiber (BDF) along with other passive components. The additional 100 m SMF-28 fiber is used to provide desired nonlinearity and sufficient nonlinear phase-shift between the two counter-propagating waves in the loop, while the BDF serves as the absorber in the passive loop. The laser generates stable mode-locked pulse train with fundamental repetition rate of 1.57 MHz within pump power range 263 mW to 500 mW as shown in Fig. 1 (a). The mode-locked laser operates in noise-like-pulse (NLP) regime exhibiting a broad optical spectrum centered at 1567 nm with a 3-dB spectral width of 21.87 nm, as shown in Fig. 1 (b). The maximum pulse energy achieved by this laser is 17.2 nJ. In the stable mode-locked regime, pulse width increased from 360 ps to 602 ps with increasing pump power from 263 mW to 500 mW.

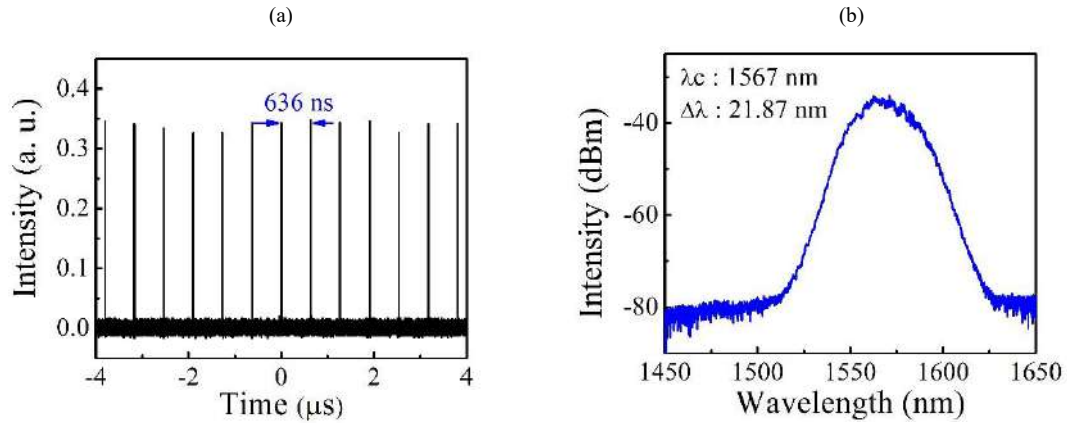


Fig. 1 (a) Pulse train of the output of Er-doped fiber laser (b) Typical output spectrum of NLP

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Plasmonic tweezers: design and fabrication of gold nanostructures

Bhukya Vijay Mohan¹, Sharath Ananthamurthy², and Ramachandrarao Yalla^{1*}

¹*School of Physics, University of Hyderabad, Hyderabad, Telangana 500046, India*

²*Department of Physics, Kuvempu University, Shivamogga, Karnataka 577451, India*

*rrysp@uohyd.ac.in

The localized surface plasmon resonance (LSPR) in gold (Au) nanostructures offers a powerful platform for enhanced light-matter interaction at the nanoscale, enabling advanced optical manipulation tools such as plasmonic tweezers. The optical properties of these structures are tunable via geometrical parameters, enabling spectral alignment with desired excitation wavelengths [2]. The fabrication of Au nanostructures typically employs high-resolution techniques like electron beam lithography (EBL) combined with lift-off or metal deposition processes to achieve precise control over size and gap distance [1]. Among the various geometries, the nano-bowties have demonstrated trapping of single nanoparticles and viruses at low laser intensities [3]. The LSPR shift resulting from local refractive index changes near the nanogap facilitates label-free detection [4, 5].

In this paper, we have designed and fabricated nano-bowties with optimized parameters. We simulate the field enhancement and optimize the parameters. The optimum parameters are fabricated using the EBL method combined with lift-off or metal deposition processes.

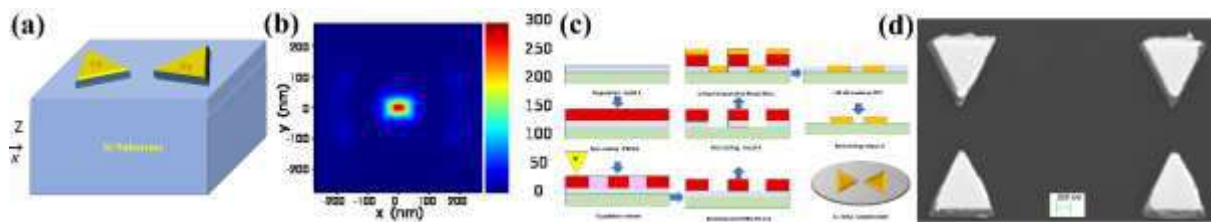


Fig. 1. (a) The schematic of the design, (b) Simulation result, (c) Fabrication procedure of Au nanostructures, and (d) FESEM images.

The illustrated model consists of Cr Au nanostructures with a base size of 200 nm, thickness of the Cr and Au is 5 nm, 50 nm, designed on an ITO-coated glass slide with a thickness of 1 μm , as shown in Fig. 1(a). A plane wave is used to excite the nanostructure, enabling investigation of LSPR and near-field enhancement. The field enhancement of the nanostructures were designed using FDTD software. Enhancement of the Au nanostructures with a gap separation of 10 nm at an external excitation wavelength of 1064 nm. The enhancement occurs at the centre of the nanostructures tip-end-tip, a maximum of 290 times as shown in Fig. 1(b). Also, we studied dependence on the gap separation between the nanostructures tip-end-tip from 10 nm to 100 nm. The gold nanostructures are fabricated through a precise process starting with cleaning a silicon wafer using acetone and IPA, as shown in Fig. 1(c). A 200–250 nm PMMA resist layer is spin-coated and baked at 180°C. The nanostructures are patterned using Electron Beam Lithography. A 5 nm Cr adhesion layer and 100 nm Au layer are deposited via e-beam evaporation. The lift-off is achieved by heating the acetone-soaked sample at 40–50°C for 10 minutes. The fabricated Au nanostructures were inspected under the FESEM (Field emission scanning electron microscopy), and the images were recorded as shown in Fig. 1(d). One can readily observe that 500 nm Au nanostructures with a gap separation of 250 nm.

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Saturated Absorption Spectroscopy lineshapes for Laguerre-Gaussian pump-probe beams in thermal Rb vapor

Abhishek Dutta¹, Vivek Venkataraman¹

¹Department of Electrical Engineering, Indian Institute of Technology Delhi, Delhi 110016, India

¹Email: eez248411@iitd.ac.in

We calculate Saturated Absorption Spectroscopy (SAS) lineshapes for thermal Rubidium-85 (⁸⁵Rb) vapor using Laguerre Gaussian (LG) beams with different azimuthal quantum numbers $\ell_{1,2}$ for the pump and probe, respectively. Our study reveals that the SAS Doppler-free linewidth narrows down with increasing probe charge ℓ_2 (due to a wider central null in the beam intensity) for low values of the pump charge $\ell_1 = 0, 1$. For higher values of the pump charge $\ell_1 > 1$, however, the narrowing with increasing ℓ_2 is not significant compared to the Gaussian case ($\ell_2 = 0$).

In thermal atomic vapor, Doppler broadening [1] washes out the hyperfine structure. For Rb atoms at room temperature, the Doppler width is ~ 500 MHz, much larger than the natural linewidth of ~ 6 MHz. SAS is a spectroscopy technique where only the near-zero velocity atoms are saturated using a strong counter-propagating pump, thus reducing the absorption for a weak probe field on atomic resonance via spectral hole burning. Generally, this process can be simulated using a standing wave approximation up to a first-order correction. Considering different LG beams for the pump and probe, and using the Rotating Wave Approximation (RWA) in the Optical Bloch Equations (OBE) [2], we found the steady state solution for the probe absorption,

$$\alpha_+ = -\frac{\mu E_0^{LG} \Lambda_0}{4\hbar\sqrt{\pi}u^2} \int \int \int \int \frac{\gamma_{21} \left[\frac{\sqrt{2}r}{w(z)} \right]^{|\ell_2|} e^{-\frac{v_z^2 + v_\phi^2}{u^2} - \left[\frac{r}{w(z)} \right]^2} r dr d\phi dz dv_\phi dv_z}{\left[\gamma_{21}^2 + \left(\Delta + kv_z + \frac{l_2 v_\phi}{r} \right)^2 \right] \left(1 + \eta \frac{\mu^2 E_0^2}{4\hbar^2 \gamma_1 \gamma_2} e^{-2 \left[\frac{r}{w(z)} \right]^2} \left[\left(\frac{\sqrt{2}r}{w(z)} \right)^{|\ell_2|} L\left(\Delta + kv_z + \frac{l_2 v_\phi}{r} \right) + \left(\frac{\sqrt{2}r}{w(z)} \right)^{|\ell_1|} L\left(\Delta - kv_z - \frac{l_1 v_\phi}{r} \right) \right] \right)}$$

where, $L(\Delta \pm kv_z \pm l_2 v_\phi/r)$ is the normalized Lorentzian [2,3], μ is the atomic dipole moment, u is the most probable velocity, and $\eta = (\gamma_1 + \gamma_2)/2\gamma_{12}$ is a normalized decay parameter, and ℓ_1, ℓ_2 represents the azimuthal quantum numbers for the pump and probe LG modes, respectively. We plotted the resultant absorption spectrum, exhibiting a Lamb dip at the center of the Doppler absorption profile of the probe beam (see Fig. 1). In our simulation we focus on the $F = 2 \rightarrow F' = 3$ hyperfine transition in ⁸⁵Rb atoms for two scenarios, (i) a Gaussian beam as the pump ($\ell_1 = 0$) and varying LG beam (with $\ell_2 = 0, 1, 2, 3$) as the probe (Fig. 1a), and (ii) LG beam with $\ell_1 = 1$ as the pump with varying $\ell_2 = 0, 1, 2, 3$ for the probe (Fig. 1b), to investigate the impact of the spatial structure of the beams on the lineshape and linewidth. We found that as the pump charge ℓ_1 increases, the narrowing of the Lamb dip with increasing probe charge ℓ_2 becomes insignificant due to the dependence of spatial Rabi frequency. The line narrowing with increasing probe charge ℓ_2 the LG beam is attributed to the intensity profile being pushed outwards radially which leads to insufficient saturation due to reduced overlap with the Gaussian pump beam. This effect becomes less significant if the pump is also an LG beam with intensity null at the center.

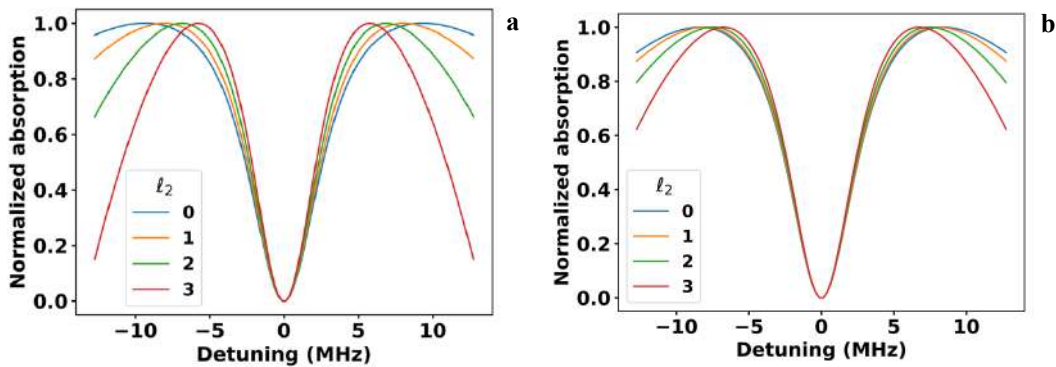


Fig. 1 Doppler-free probe absorption lineshapes at different l values, where a pump power of $18\mu\text{W}$, and beam waist of 2-mm is used for the simulation. (a) pump is Gaussian ($l = 0$), (b) pump is an LG beam with $l = 1$.

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Quantum-Induced Coherence in Bright Two-Mode Squeezed Light

Sandra Susil[†], and Ashok Kumar^{*}

Department of Physics, Indian Institute of Space Science and Technology
Thiruvananthapuram, Kerala, 695547, India

[†]sandrasusiln@gmail.com, ^{*}ashokkumar@iist.ac.in

The phenomenon of quantum-induced coherence (QIC) provides a powerful demonstration of the non-classical nature of light. It shows the quantum correlation, can establish a coherent phase relationship between two or more physically separated and otherwise statistically independent light fields [1]. This unique quantum effect has significant potential for applications in quantum sensing, metrology, and imaging [2, 3]. In the current work, we theoretically investigate the QIC in bright two-mode squeezed light (TMSL) generated via the four-wave mixing (FWM) process in a hot rubidium (Rb) vapor cell. The FWM process in hot Rb vapor is known to generate intense TMSL, making it an ideal platform for exploring QIC in the high-photon-number regime. Our study investigates how seeding one mode of the TMSL with a coherent state affects the visibility of interference in the unseeded modes. In what follows, we give a brief description of our theoretical investigations and the results.

The bright two-mode squeezed light is generated by applying a two-mode squeezing operator, $\hat{S}(\xi) = \exp(\xi \hat{p}^\dagger \hat{c}^\dagger - \xi^* \hat{p} \hat{c})$ and a displacement operator, $\hat{D}(\alpha) = \exp(\alpha \hat{p}^\dagger - \alpha^* \hat{p})$ on a two-mode vacuum state, as

$$|\xi\rangle = \hat{S}(\xi)\hat{D}(\alpha)|0,0\rangle,$$

here $\xi = re^{i\theta}$, r and θ are the degree of squeezing and the squeezing phase, respectively. α is a complex parameter that characterizes the input coherent state, and $\hat{p}$ and $\hat{c}$ are the annihilation operators of the two modes of the TMSL, named as probe and conjugate, respectively.

The individual modes of the TMSL are in thermal states having random phases with very short coherence time, while they exhibit strong mutual correlations and are entangled. To analyze the coherence and induced coherence of the individual modes of the TMSL, we theoretically investigate the output of a Michelson interferometric setup. This setup is placed in the unseeded (conjugate) mode and allows us to calculate the interference visibility as a function of the input coherent seed probe intensity, as

$$V = \exp\left(-\frac{1}{4}\mu^2\tau^2\right) \frac{1}{\left(\frac{\langle I_{vac} \rangle}{\langle I_\alpha \rangle} - 1\right)}.$$

Here μ is the spectral width of the conjugate, τ is the time delay between two arms of the interferometers, $\langle I_{vac} \rangle$ and $\langle I_\alpha \rangle$ are the intensity contributions to the interference pattern due to the vacuum seed and the coherent probe seed, respectively.

Figure 1 shows visibility as a function of $\langle I_{vac} \rangle / \langle I_\alpha \rangle$. We find that seeding one of the entangled modes modifies the phase relationship between the generated TMSL modes, and leads to a more pronounced QIC effect, as demonstrated by an enhanced visibility of the interference fringe pattern.

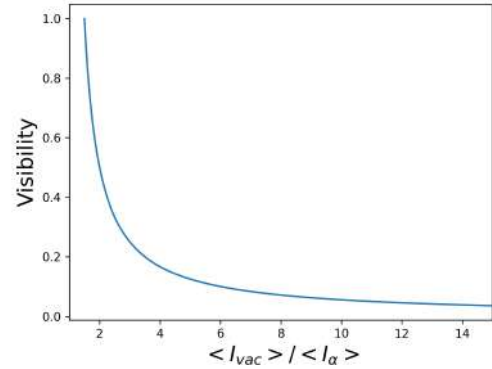


Figure 1: Interference visibility of the conjugate beam for different intensities of the seed beam.

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Rapid detection of Rhodamine B using Surface Enhanced Raman Scattering (SERS) probe

Deepak Kumar, Sibashish Chakraborty, Satish K. Dubey*

Centre for Sensors, Instrumentation and Cyber Physical System Engineering (SeNSE), Indian Institute of Technology Delhi, New Delhi-110016,

Surface Enhanced Raman Scattering (SERS) is a rapid spectroscopic detection technology used to detect trace concentrations of target samples [1]. SERS is widely used in sensing for food adulteration, medicine and materials industry [2] because of its high sensitivity, precise molecular finger-printing and narrow spectral bandwidth. A benchtop Raman spectrometer is employed for SERS instead of large-scale equipment (such as GC-MS, HPLC) to detect adulteration in food at real time [3]. Rhodamine-B (RB) is a synthetic dye (molecular formula $C_{28}H_{31}ClN_2O_3$) and is identified as an illegal food additive by European Food Safety Authority (EFSA) due to carcinogenic properties and neurotoxicity [4]. It is found in chili powder, which acts as an essential seasoning for food.

In this work, we fabricated Au-nanoparticles for detection of standard solution of RB. The schematic for SERS substrate is shown in Fig. 1a. The nanoparticle was fabricated using chemical reduction of water-soluble salt of $HAuCl_4$ with citrate ion as a reducing agent. For the synthesis process, 1.8 mL of 0.01M hydrogen tetrachloroaurate ($HAuCl_4 \cdot 3H_2O$) in DI water and 0.5 mL of 0.01M sodium citrate ($Na_3C_6H_5O_7$) in DI water were added to 40 mL of DI water. The TEM image of synthesized Au nanoparticle is shown in Fig. 1b. TEM image shows a range of 10-40 nm size for nanoparticles. Au nanoparticles were drop-casted over SiO_2 surface ensuring electromagnetic enhancement due to excitation of SPP. For analysis of SERS performance, R6G was taken as a probe molecule. Different concentrations of R6G and RB with the volume of 20 μ L, were drop casted over surface and allowed to air dry. The SERS signal was collected and Raman spectra at different locations were captured as shown in Fig. 1c. Distinct peaks were detected for R6G and RB which indicate that Au nanoparticles act as an efficient SERS substrate.

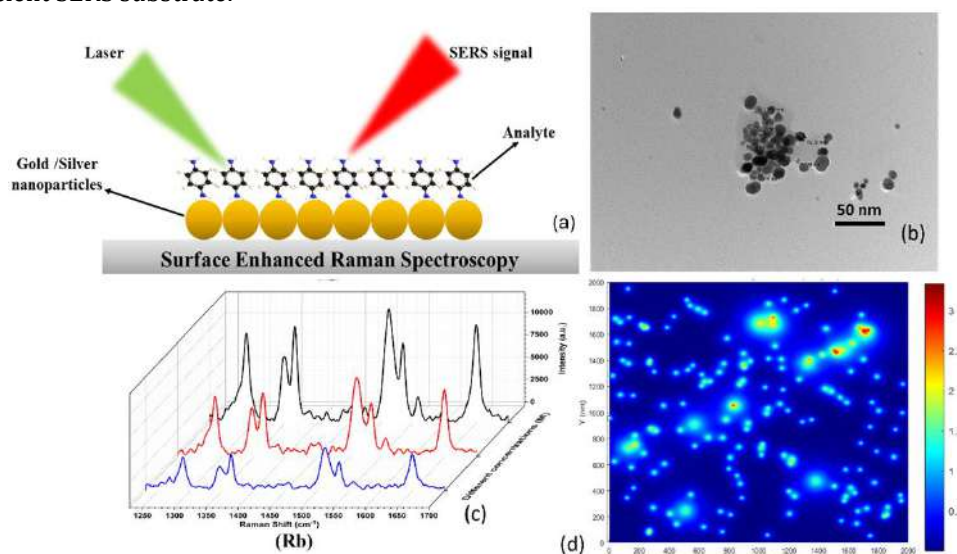


Fig. 1(a) Schematic showing SERS substrate, (b) TEM image of Au nanoparticles, (c) SERS spectra of 10^{-6} RB, (d) FDTD results

The electric field profile was further analyzed using FDTD simulations as shown in Fig. 1d with blue to red color bar representing increasing electric field. It was observed that hotspots were formed between Au nanoparticles. When the substrate surface was illuminated by a Gaussian source of 785 nm, the theoretical enhancement factor was calculated and found to be 8.65×10^5 . Proposed SERS-active substrate could detect up to 10^{-6} M of R6G showing potential applications in food safety, medicine, narco-analysis and explosive detection.

Example References

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Self-Focusing Grating Couplers for Integrated Non-Linear Photonics

Pranav Chokkara, Anagha K V, Jasleen Lugani

Centre of Sensors, Instrumentation and Cyber Physical System Engineering (SeNSE),
Indian Institute of Technology Delhi, Hauz Khas, New Delhi, 110016, India

Grating couplers are an efficient method for coupling light in and out of a photonic chip, offering ease of fabrication, flexible placement, and enabling wafer-scale testing. In an integrated non-linear photonic chip, the parameters crucial for a grating coupler's efficiency, such as the thin film thickness and the waveguide height, are often decided by the non-linear process. Additionally, the preference for shallow etching and the relatively low index contrast of popular photonic platforms like LNOI (lithium niobate (LN) on insulator) [1] and thin-film Si_3N_4 (silicon nitride) [2] impose further design constraints. This often requires a long grating region, possibly more than the fiber mode size, which introduces large mode mismatch and coupling losses. Here, we propose a self-focusing grating coupler that focuses the radiated beam into a predetermined spot size at a targeted height above the grating coupler, thereby overcoming these limitations. The grating period and duty cycle of the gratings together decide the radiation strength and the radiation angle of a periodic grating. So, the design process begins with calculating the radiation angle and strength of the uniform gratings for a range of grating periods and duty cycles, followed by the optimization of the local period and duty cycle to achieve the desired radiation profile at the grating surface, which, upon propagating the targeted distance, focuses to the designed spot size [2]. Considering the case of a Si_3N_4 loaded LNOI (100 nm Si_3N_4 on 300 nm LN), the 2D electric field distribution for the grating coupler for a fundamental TE mode at 1550 nm, shown in Fig. 1(g), confirms that the radiated field converges to a Gaussian spot of MFD (mode field diameter) $2\text{ }\mu\text{m}$ at a height of $\sim 350\text{ }\mu\text{m}$ above the grating plane, demonstrating efficient outcoupling. This approach provides an efficient route to compact, high-efficiency couplers in non-linear integrated photonics.

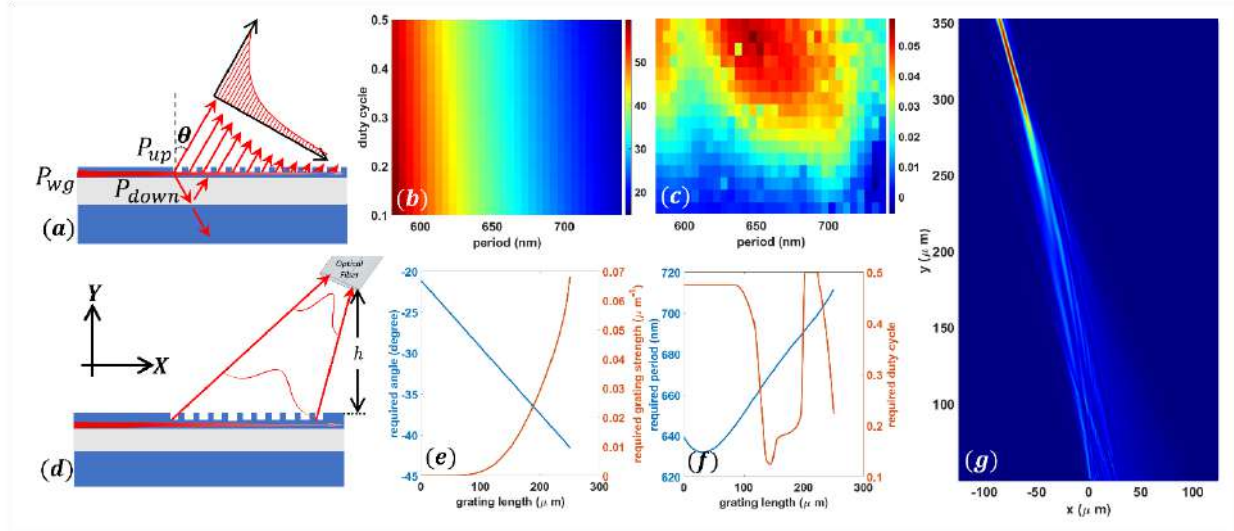


Fig. 1. (a) Schematic of a uniform grating coupler, showing the constant radiation angle and the exponential drop in the radiated power. (b),(c) The radiation angle and strength of a uniform grating coupler for various combinations of grating period and duty cycles. (d) Schematic for a self-focusing grating coupler. (e),(f) The analytically calculated grating angle and strength, and the grating period and duty cycle combination, along the grating length. (g) The 2D profile of the radiated electric field, the optical field converges to a Gaussian beam of MFD $2\text{ }\mu\text{m}$ at a height of $\sim 350\text{ }\mu\text{m}$ above the grating plane.

Conclusion:

We demonstrate a flexible design strategy to achieve efficient coupling to address the limitations of uniform or chirped gratings in low-index contrast photonic platforms. This design enables tailoring the profile of the radiated beam and works well even in the case of low waveguide (grating) height. Using this design, we achieve a focused Gaussian spot with $2\text{ }\mu\text{m}$ MFD at a height of $\sim 350\text{ }\mu\text{m}$, demonstrating the effectiveness of the design.

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Correlations in scattered Bessel-Gauss beams: Perfect coherence vortices

MD. Haider Ansari¹, Velagala Ganesh¹, Ravi Kumar¹, Shashi Prabhakar², Salla Gangi Reddy^{1*}, R. P. Singh²

1. Department of Physics, School of Engineering and Sciences, SRM University AP, Amaravati, 522240, India

2. Quantum Science and Technology Laboratory, Physics Research Laboratory, Ahmedabad, 380009, India

Optical vortices are light waves that carry a spatial phase described by $e^{i\ell\theta}$, where θ is the azimuthal angle and ℓ is the topological charge (TC). The identification of a direct relationship between OV's and orbital angular momentum (OAM) has led to extensive exploration of their properties and applications in areas such as optical communications, particle manipulations, imaging systems, and optical processing. In the coherent vortex beams, the position of the phase singularity, which appears as a point of zero intensity, is strongly related to the TC. The perfect vortex beams have been developed to resolve this dependence. These beams possess ring-shaped intensity profiles, whose size and width are controllable and independent of the TC. The singularity of the vortex beams remains stable during propagation in free space, and their topological charge has been used as an information carrier in free-space optical communications. However, when the vortex beams propagate through random media and atmospheric turbulence, the structure of the beams degrades due to the beam wandering and scintillation. To overcome these limitations, the coherence vortex beams have been introduced, which are observed in the partially coherent beams. Coherence vortex beams can be generated through the spatial correlation of coherent vortex beams.

In this work, we generated perfect coherence vortices through the intensity correlations of speckle patterns obtained by the scattering of Bessel-Gauss beams with different combinations of topological charge. We observed that the coherence vortices exhibit ring structures whose size and width are invariant with their topological charge. This charge-independent feature, along with its robustness against scattering-induced distortions, makes perfect coherence vortices highly suitable for applications in free-space optical communications.

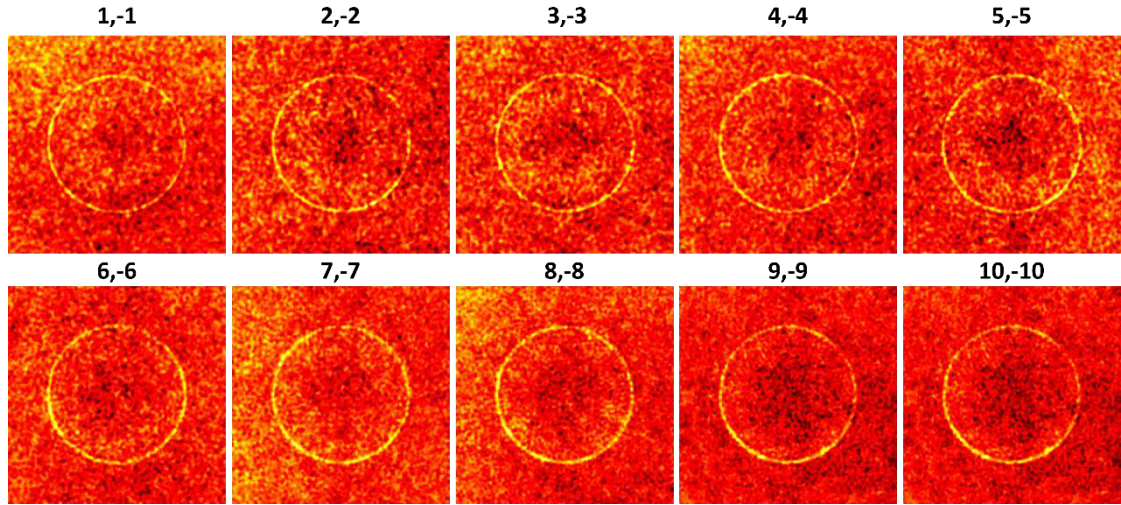


Fig. 1 Experimentally realised intensity cross-correlation function when ℓ_1 and ℓ_2 have opposite signs. Coherence vortices of order $m = |\ell_1| + \ell_2 = 2, 4, 6, 8, 10, 12, 14, 16, 18$, and 20 appear in the intensity distribution for combinations of ℓ_1 and ℓ_2 as mentioned at the top of each plot.

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Effect of residual absorption on the beam quality at 1 μm in CdSiP_2

Bhanu Chauhan¹, K. T. Zawilski², P. G. Schunemann², M. Ebrahim-Zadeh^{3,4},
S. Chaitanya Kumar^{1,*}

¹Tata Institute of Fundamental Research, 36/P Gopanpally, 500046 Hyderabad, India

²BAE Systems Inc., MER15-1813, P.O. Box 868, Nashua, New Hampshire 03061-0868, USA

³ICFO—Institut de Ciències Fotòniques, 08860 Castelldefels (Barcelona), Spain

⁴Institució Catalana de Recerca i Estudis Avançats (ICREA), Passeig Lluís Companys 23, Barcelona 08010, Spain

Author email address: chaitanya.suddapalli@tifrh.res.in

Mid-infrared (mid-IR) frequency conversion sources are often driven by high-power lasers at 1 μm . However, the residual absorption in the mid-IR nonlinear crystals at the pump wavelength can degrade the beam quality effecting the long-term performance of the source [1]. A clear understanding of these thermal effects is critical for the design of efficient nonlinear frequency conversion sources [2]. Here, we investigate the beam quality distortion caused by the thermal effects in a highly promising mid-IR nonlinear crystal, Cadmium silicon phosphide (CSP) at the typical pump wavelength of 1063 nm [3]. The nonlinear crystal is a 16.3 mm-long CSP crystal, cut for type-I ($e \rightarrow oo$) noncritical phase matching ($\theta=90^\circ$, $\phi=45^\circ$) and is pumped by a Yb-doped fiber laser delivering 6.4 ps pulses at 1063 nm, with 20 W average power and 78 MHz repetition rate. The pump beam is focused to a waist radius of $w_0 \sim 72 \mu\text{m}$ at the center of the crystal corresponding to a focusing parameter $\xi \sim 0.17$. The transmitted beam profiles were recorded using a Thorlabs BC106N-VIS/M profiler positioned ~ 10 cm from the crystal output facet. As the pump power was increased from 0.8 W to 1.8 W in 200 mW steps, we observed the emergence and growth of concentric diffraction rings in the far-field, characteristic of spatial self-phase modulation caused by thermally induced refractive index gradients.

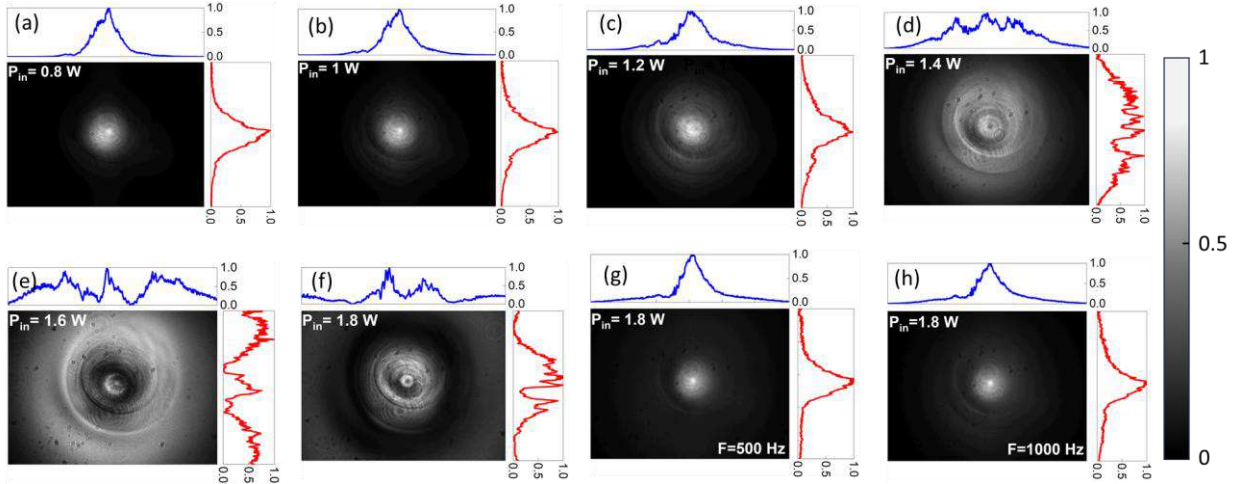


Fig. 1 (a-f): Spatial beam profile of the transmitted beam through the CSP crystal as a function of input power for ordinary-polarization. Spatial beam profile with chopper at 1.8 W of input power at a modulation frequency of (g) 500 Hz, (h) 1000 Hz.

Fig. 1(a-f) clearly shows the power-dependent evolution of the transmitted beam structure. At lower pump powers (0.8–1.2 W), the beam remains near-Gaussian. However, as the input power increases to 1.4 W and beyond, strong concentric ring structures appear, accompanied by significant increase in the beam diameter with modulated intensity profiles along both horizontal and vertical axes. This transition from a clean beam to a modulated ring structure provides direct visual evidence of increasing thermal load and spatial phase modulation inside the CSP crystal. The ring patterns were pronounced when the incident light was *ordinary-polarization* as compared to *extraordinary-polarization*, reflecting the higher absorption of *ordinary-polarized* light in CSP. In order to confirm the origin of the rings, a mechanical chopper was introduced into the beam path at modulation frequencies of 250, 500, 750, and 1000 Hz and observed that the ring formation threshold increased significantly with faint rings starting to appear at 1.8 W of incident power, as shown in Fig. 1(g-h). Additionally, temperature-dependent measurements at constant power showed enhanced ring contrast and beam expansion with rising temperature, indicating the thermal origin.

In summary, this study offers critical insights into the combined effects of pump power, polarization, temperature, and thermal dynamics in CSP crystals under high-repetition-rate ultrafast pumping, useful for designing mid-IR frequency conversion sources. A comprehensive set of experimental results, including both polarization states, temperature variations, and dynamic thermal response, will be presented.

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Optical properties of bioinspired wavelength-scale spheroid arrays

Rohit Kumar¹, Nikhil Shrivastava², Venkata Jayasurya Yallapragada³

Department of Physics, Indian Institute of Technology Kanpur, Kanpur 208016 India

Arrays of oriented spheroids are central to the optical properties of the wings of several butterflies. For example, in Pierid butterflies, these particles are attached at random locations to a chitin-based grid which forms the structural basis of the wing. The orientation, refractive index, eccentricity, birefringence and arrangement of the spheroid all contribute to the scattering and structural colour of the wing. Recent studies have revealed that pterin pigments can exhibit a high refractive index, highlighting its significance in enhancing optical phenomena [1]. Additionally, nanoparticles of pterins often exhibit optical anisotropy [2]. Our current work explores the role of oriented, disordered 2D spheroidal arrays in structural colour, seeking to understand the effects of refractive index, absorption and structural and material anisotropy of the particles and their arrangement on the optical properties of the array.

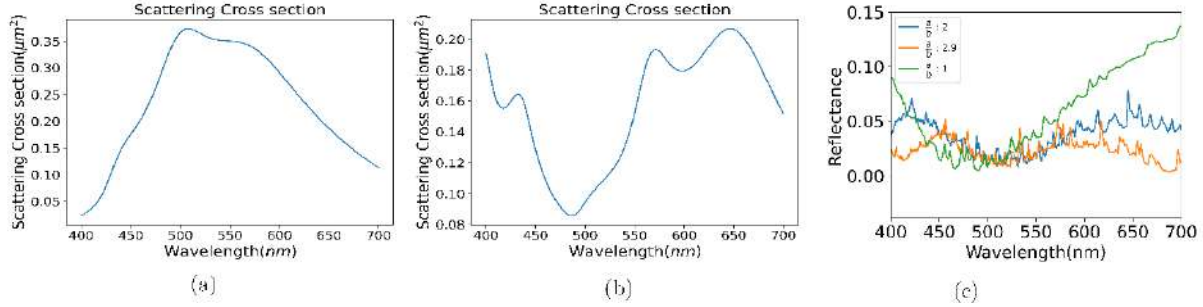


Fig. 1 Simulation Result of Single spheroid and spheroid arrays. (a) polarization-averaged scattering cross-section for Isotropic particle (semi major axis $a=325\text{nm}$, semi minor axis $b=100\text{nm}$) having refractive index 2.3. (b) polarization-averaged scattering cross-section for anisotropic particles having refractive index 2.58, 2.58 and 1.54. (c) simulated reflectance spectra for varying values of elongation of the spheroid, quantified by the major-minor axis ratio. The effects of thin film interference dominate lower elongations, and for more elongated spheroids, the effects of multiple scattering smoothen out the reflectance spectrum.

We first compute the scattering cross-section of single spheroids using the Finite Difference Time Domain (FDTD) method for a broad range of orientations, optical anisotropy and absorption resonances. Scattering cross-sections for isotropic and anisotropic particles oriented in z direction obtained using such simulations has been shown in Figure 1(a) and 1(b). We then proceed to model the wings as a 2D arrays of spheroidal particles arranged randomly in plane, so we generate a set of coordinates corresponding to a disordered 2D array of circular disks of equal radius using a Lubachevsky-Stillinger type algorithm [3]. Reflection and transmission from these arrays are simulated using perfectly matched layers (PML) for the z -normal boundaries and periodic boundaries in the lateral directions. Results for spheres and spheroids of varying elongations are shown in Figure 1(c). For a spherical particle, the spectra predominantly exhibit contributions from interference effects, which can be explained qualitatively by approximating the array of spheres to a thin film. At higher elongations, multiple scattering becomes the dominant phenomenon in reflection, and the spectrum becomes relatively featureless. Since a monolayer of wavelength scale particles is optically quite thin, thin-film-like effects contribute significantly to the reflectance spectra. Changing this thickness changes the location of constructive interference peaks in the spectrum and offer a way to tune the spectrum, while retaining the spectral broadening caused by lateral positional disorder. Our study provides insight into how natural pigments and structural elements are optimally utilized in butterfly wings. These observations can readily be applied to the field of fabricating thinner and more efficient reflecting layers and paints, potentially using biocompatible materials.

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Comparative Simulation of Thermally and Electro-Optically Tuned in Segmented QPM OPOs Based on Lithium Niobate

Abhinav Kumar¹, Ugrasen Singh², Prashant Povel Dwivedi^{1*}, Ajay Mishra³, Nimish Dixit³

¹ MUJ-NLO+ Research Lab, Department of Electronics and Communication Engineering, Manipal University Jaipur, Rajasthan, India

² Department of Physics, Manipal University Jaipur, Jaipur 303007 Rajasthan, India

³ Instruments Research & Development Establishment (IRDE), DRDO, Dehradun, Uttarakhand, India

Recent developments in quasi-phase-matching (QPM) technology have significantly enhanced the tunability and efficiency of optical parametric oscillators (OPOs) across the infrared spectrum. In particular, segmented QPM devices based on lithium niobate have enabled compact and efficient systems for frequency conversion, sensing, and coherent light generation. Among the various tuning techniques, thermal tuning has emerged as a dominant approach.

The conventional approach temperature tuning relies on exploiting the thermo-optic effect in three-segmented lithium niobate crystals. In this configuration, the outer segments are periodically poled, while the central segment remains unpoled. Adjusting the crystal temperature alters the refractive indices of the material, thereby shifting the phase-matching condition and enabling wavelength tuning. Although this method provides a broad tuning range, it is limited by slow tuning [1], increased heat load, and potential mechanical stress on the crystal during extended operation, shown in fig 1(a). In contrast, the electro-optic tuning shown in fig 1(b) technique also uses the same segmented APPLN structure, where electrodes are applied to the unpoled central segment [1,2]. When a voltage is applied, the electro-optic effect induces a refractive index change in the central segment, leading to a voltage-controlled phase shift between the outer poled sections. This enables real-time modulation of the gain spectrum [3,4]. A key advantage of electro-optic tuning is its ability to provide fast, reversible wavelength tuning without physical movement or thermal delay.

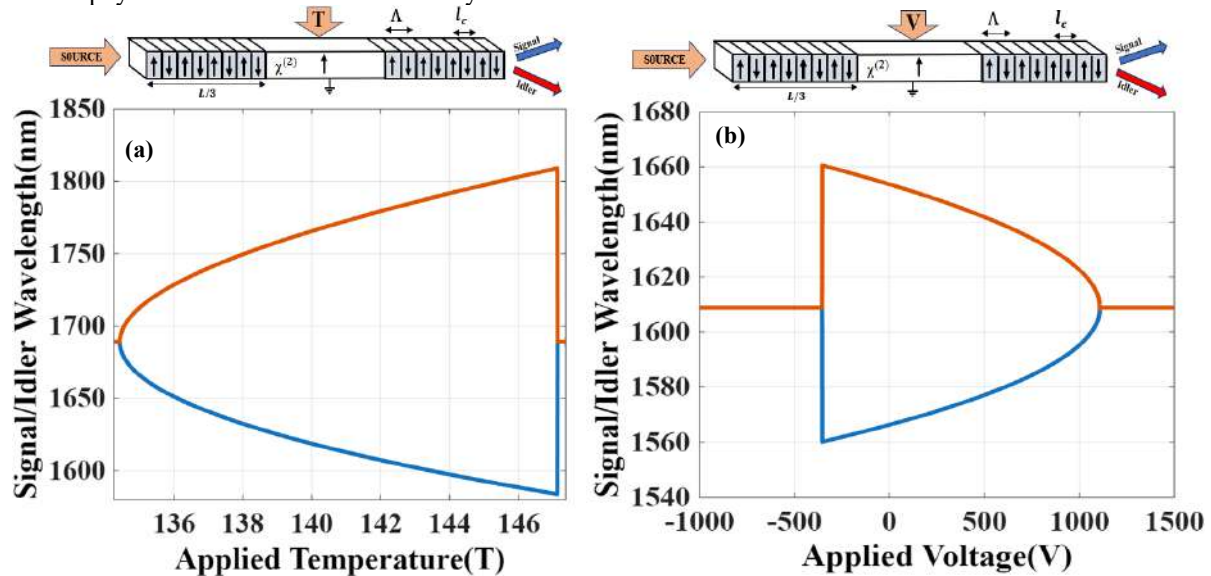


Fig 1: Model of a three-segmented PPLN structure; and the simulated results showing (a) temperature tuning and (b) electro-optic tuning of signal/idler wavelengths.

The core idea behind this comparison is to assess both methods based on their tuning efficiency, stability, and response time. Temperature tuning is slow due to thermal lag, requiring seconds for stabilization and more complex hardware. On the other hand, electro-optic tuning offers rapid, precise, and reversible wavelength control, achieving sub-millisecond response times ideal for high-speed applications like LIDAR, spectroscopy, and optical communication.

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Measurement of 3D – Photonic Spin-Hall Effect

Dileep Kumar Upadhyay* and Nirmal K. Viswanathan

School of Physics, University of Hyderabad, Gachibowli, Hyderabad 500046, India

*Email: 23phph14@uohyd.ac.in

Nonparaxial focusing of uniform linearly polarized paraxial light beam produces all three components (E_x , E_y , and E_z) in the focal region leading to inhomogeneous polarization in the beam cross-section due to their superposition [1]. At the focal plane, however, the polarization is almost linear (same as the input) with no spin angular momentum (SAM) and with the Stokes parameter $S_3 = 0$. But at planes before and after the focus, the polarization is spatially non-uniform with circular, elliptical and linear state of polarization (SoP) in the beam cross-section. In addition, the SoP or equivalently the S_3 flips sign before and after focus, i.e., if in certain region before focus the polarization is right-circular polarized (RCP) then after focus it is left-circular polarized (LCP) and vice-versa [2]. This flipping of the SAM sign at different spatial location of the beam along propagation, corresponding to the role of the extrinsic orbital angular momentum (e-OAM) is known as the photonic spin-Hall effect (PSHE). The PSHE is one of the important effects that arise due to the spin-orbit interaction (SOI) of light and is the symmetry broken counterpart of the spin-to-orbital AM conversion [1].

The SOI of light in focusing imposes geometric phase on the right- and left- circular polarized components which induce momentum shift and hence azimuthal splitting of the two spin components [2]. This phenomenon, well described as the PSHE, exists in various situations such as in reflection or refraction between two media, scattering, and focusing by lens. Due to its demonstration in diverse optical configuration and in applications such as probing nano-displacement, characterising nanostructure, in imaging and optical trapping, the PSHE has attracted major research interests during the past two decades [1, 2].

In this abstract we present the theoretical simulation and experimental results of the PSHE in the nonparaxial focal region, realized by retroreflecting the focused beam of light by a mirror and measuring the effects in the far-field. Focusing of the input linear polarized Gaussian beam leads to the appearance of azimuthally-varying non-zero spin components, and hence the PSHE, characterized by the Stokes parameter S_3 , given by: $S_3 = 2\text{Im}(E_x E_y^*)$.

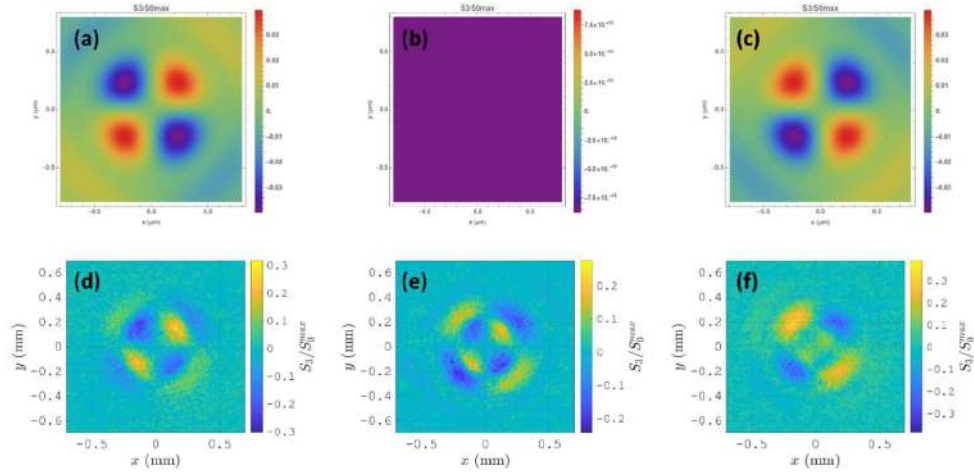


Fig. 1. Simulated at the focal plane (top row) and experimentally measured (bottom row) behaviour of normalized S_3 is shown. (a, d): before focus (b, e): at (near) the focus and (c, f): after focus.

Figure 1 shows the spatial azimuthal spin separation before the focal plane – in quadrant 1 and 3, the SoP is RCP (S_3 is positive) and in 2 & 4 quadrants the SoP is LCP (S_3 is negative). This spatial polarization variation flips sign after the focus. While the simulated S_3 is zero at the focal plane, the experimentally measured variation is non-zero due to the exact focal plane not identifiable with sub-1 precision. Thus, as the beam propagates through the focal region, transformation of RCP-to-LCP and LCP-to-RCP takes place periodically [2]. The experimental results match well with the theoretical anticipations, demonstrating the direct experimental measurement of the PSHE in the 3D, along the propagation direction. More details on the retroreflection-based experimental setup and related measurements supporting the 3D-PSHE will be presented at the conference.

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Tunable Optical Bistability through Gain-Assisted Nonlinear Interactions

Parkhi Bhardwaj ¹ and Shubhrangshu Dasgupta ¹

¹. Indian Institute of Technology Ropar, Rupnagar, Punjab 140001, Indian

Optical bistability (OB) is a nonlinear optical phenomenon in which an atomic medium exhibits two distinct stable output states for a given input intensity. This intriguing behavior emerges from the complex interplay between light propagation and the medium's nonlinear response, influenced by mechanisms such as absorption, dispersion, and coherent interactions. In atomic systems, OB typically arises when the refractive index or absorption becomes intensity-dependent. Coherent phenomena such as Electromagnetically Induced Transparency (EIT) [1,2] and Four-Wave Mixing (FWM) [3,4] play a significant role in enhancing and controlling bistable behavior. Through careful tuning of parameters like input intensity, detuning, and atomic density, OB has been demonstrated in both free-space and cavity-based systems [5,6].

In this work, we investigate an N-type atomic configuration and explore the conditions under which the medium can exhibit gain. We further examine the coherent control of population distribution among the energy levels. To analyze the impact of gain on OB, we first compute the coherence associated with the probe field and, by applying appropriate boundary conditions, solve Maxwell's propagation equation to obtain the output field as a function of the input intensity.

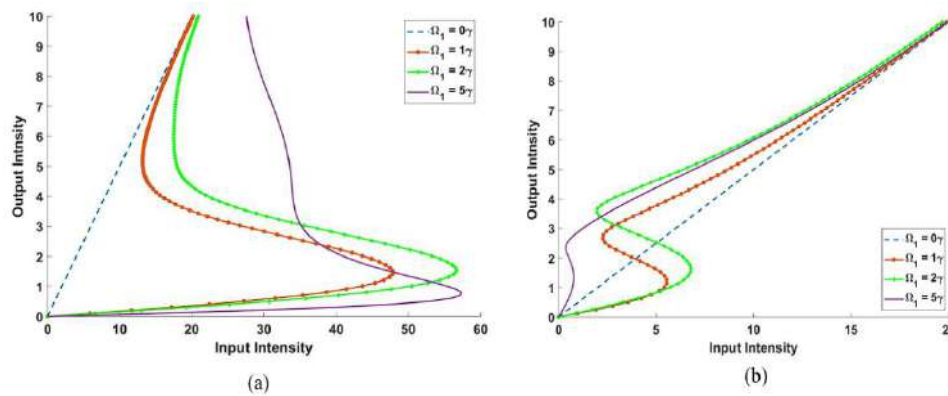


Fig. 1 Variation of OB for $\Delta_2 = 5\gamma$, $\Delta_1 = \Delta_3 = 0$ and $C = 300$, in (a), the results are shown for Ω_1 : 0 γ (blue, dashed), 1 γ (orange, dotted), 2 γ (green, +), and 5 γ (violet, solid), with $\Omega_3 = 0\gamma$. In (4b), the results are shown for Ω_1 : 0 γ (blue, dashed), 1 γ (orange, dotted), 2 γ (green, +), and 5 γ (violet, solid), with $\Omega_3 = 5\gamma$.

Fig.1 presents a representative result illustrating the OB behavior under varying field conditions, with the atomic detuning fixed at $\Delta_2 = 5\gamma$ and the cooperation parameter set to $C = 300$. In Fig. 1(a), we examine the OB response for increasing values of Ω_1 (rabi frequency of first field) in the absence of the field Ω_3 (rabi frequency of third field). As Ω_1 increases, the OB threshold shifts toward higher input intensities, indicating a reduction in nonlinearity at lower input levels due to enhanced absorption of the probe field. Conversely, Figure 1(b) shows the OB curves for a fixed $\Omega_3 = 5\gamma$ while varying Ω_1 . In this case, increasing Ω_1 results in a lower OB threshold, as the additional field introduces gain and amplifies the nonlinear response of the medium. These findings underscore the critical role of jointly tuning Ω_1 and Ω_3 to achieve low-threshold optical switching while maintaining robust bistable behavior. Our findings contribute to the advancement of quantum electronics by highlighting the potential of nonlinear optical effects.

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Hong-Ou-Mandel Interferometry for fiber optic quantum gyroscope

Gopal Prasad Sahu^{1,2}, Kavita Devi¹ and G. K. Samanta²

¹ Indian Institute of Technology Dharwad, Dharwad, Karnataka 580011, India

² Photonic Sciences Laboratory, Physical Research Laboratory, Navrangpura, Ahmedabad 380009, India

Hong-Ou-Mandel (HOM) interferometry with spectrally broadband biphoton states generated via spontaneous parametric down-conversion (SPDC) has emerged as a powerful technique for quantum-enhanced sensing, enabling applications such as group-delay dispersion measurements over long sample lengths [1] and fiber-optic gyroscopes for rotational velocity sensing [2]. The measurement resolution in such systems is determined by the width of the HOM dip, with higher resolution requiring narrower dips that result from the large spectral bandwidth of the SPDC photons. While dip narrowing and the resulting resolution enhancement have been demonstrated for group-delay dispersion measurements [1], no such approach has yet been implemented to improve the sensitivity of quantum gyroscopes. Here, we report the characterization of an HOM interferometer using broadband SPDC photons and its integration into a fiber-optic quantum gyroscope to enable enhanced rotational sensitivity.

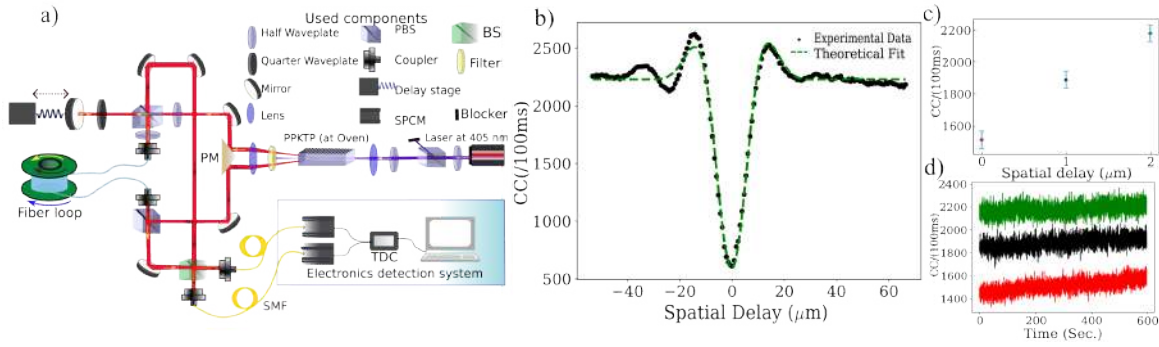


Figure 1: a. Schematic of experimental setup. b. Characterization of HOM interference dip. c. Variation of coincidence counts (CC) with the relative optical delay. d. Temporal variation of coincidence counts.

The schematic of the experimental setup is shown in Fig. 1a. The cw diode laser at 405.17 nm produces non-collinear, degenerate, phase-matched broadband SPDC pair photons centered at 810 nm in an annular ring distribution from a 2 mm long, temperature-controlled PPKTP crystal. The photon pairs are coupled into a single-mode fiber spool of radius $R_e = 7.75$ cm and length $L = 500$ m, forming a Sagnac loop. The outputs are interfered on a beam splitter (BS) to realize the HOM interferometer. A delay line is added to compensate for any residual path delays between the photons in the experiment. To characterize the gyroscope, we reproduced the HOM interference curve by measuring delay-dependent coincidence counts between outputs of the BS. As shown in Fig. 1b, the inclusion of the fiber loop and associated optical components increases the HOM dip width from $6\mu\text{m}$ reported in Ref. [3] to approximately $10.6\mu\text{m}$ for a pump power of 3 mW and a coincidence window of 2 ns due to the dispersion to the broadband (110 nm) biphoton state. The slope of the linear region of the HOM curve (positive delay side) is found to be 183 counts/ μm . Using this slope, we set the interferometer to operate at the mid-point of the HOM dip (dotted line in Fig. 1b) and tested the performance by varying the relative delay in $1\mu\text{m}$ steps. As shown in Fig. 1c, the difference in coincidence counts between consecutive delay steps is over 290 counts/ μm for an integration time of 100 ms is significantly higher than the dark counts and background noise of the detection system, confirming reliable delay measurements at the $1\mu\text{m}$ level. Stability tests at three different relative delays (as shown in Fig. 1d) further confirm the robustness of the measurement. These initial results demonstrate that the interferometer can resolve relative optical delays below $1\mu\text{m}$, corresponding to a temporal resolution of $\Delta t = 3.33$ fs. Using the gyroscope relation, $\omega = \frac{c^2 \Delta t}{2LR_en^2}$, and the experimental parameters $L = 500$ m, $R_e = 7.75$ cm, $n = 1.45$, and $\Delta t = 3.33$ fs, we obtain an angular velocity resolution of $\omega = 2.66$ rad/s. Further results, including strategies for improving the angular velocity resolution, complete system characterization, and comparison with previous reports, will be presented.

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Phase Reconstruction Accuracy for Propagation Based Reconstruction Algorithms by Simultaneous Recording of Fourier and Image Plane Holograms

Sree Renjini R S¹, Akshara S Kumar², Harikrishnan P¹, Dinesh N Naik¹, C S Narayanamurthy¹

1. Applied and Adaptive Optics Laboratory, Department of Physics, Indian Institute of Space Science and Technology, Thiruvananthapuram, Kerala 695547, India

2. Sree Narayana College, Kollam, Kerala 691001, India

The potential of digital holography has been extensively explored over the past few decades. Different holography techniques have their advantages and disadvantages and are chosen based on their specific application. While some studies discuss recording and reconstruction of various holograms within the same setup [1], few address the simultaneous measurement of two holograms and their combined reconstruction results. Here, we introduce an optical setup where both Fourier and Image plane holograms of an object are recorded simultaneously. We then examine how both holograms correlate with each other and draw conclusions about their characteristic behaviours.

A He-Ne laser having a wavelength of 632 nm is used as the source. After reflecting from the beam splitter BS1, the beam illuminates the object. A dual reference beam is created using a Sagnac setup consisting of PBS, M1 and M2. The transmitted beam from BS1 passes through this Sagnac. A combination of convex lenses L1, L2, having focal lengths of 150mm, makes one of the beams collimated and the other converging, and they act as references R1 and R2. After reflecting from the object, the object beam passes through a 4f imaging system. Just before the Fourier plane of the object, another beamsplitter BS2 is introduced so that we will have the Fourier plane in one arm and the image plane in another arm. Reference beams are carefully introduced in this area, such that R1 serves as the reference for the Fourier hologram, and R2 serves as the reference for the image hologram. Two CCD cameras (PCO Pixelfly 1392×1040 pixels) are used to record both holograms simultaneously.

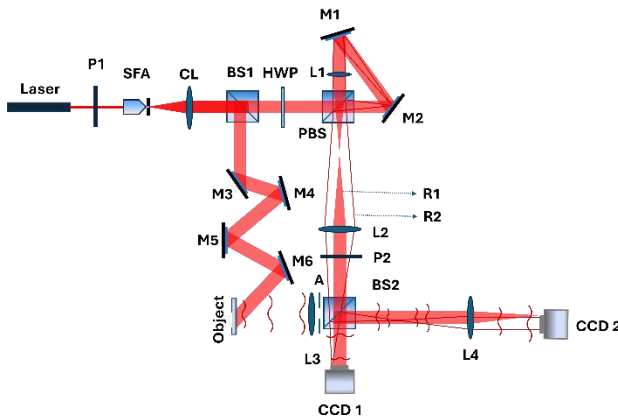


Fig. 1 Schematic Representation of Experimental Setup

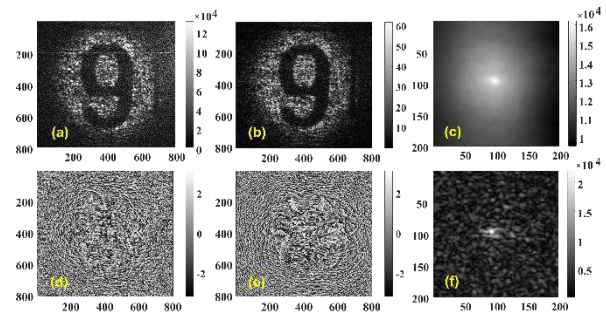


Fig. 2 (a), (d) show reconstructed amplitude and phase of the object from Fourier hologram, and (b), (e) show that from Image plane hologram. (c), (f) are the correlations of the normalized amplitude and phase of the object reconstructed through the Fourier and the Image plane hologram.

Recorded and reconstructed Fourier and Image plane holograms are shown in Fig. 2. Here, we took a metallic scale, almost a 2D kind of material, as an object. Reconstructed amplitude and phase from both the holograms show a good amount of correlation. A noted difference was observed in the reconstruction of phases from both holograms. Phase reconstructed from image plane holograms shows a smooth variation in darker regions, whereas that of the Fourier plane hologram shows a pixel-to-pixel deviation.

The only difference between the two holograms is the plane of recording. All the other factors are nearly the same for both of them. However, this variation shows a scope of study. Image of the object formed on the CCD has extreme dark and bright points. Using a plane reference beam having a particular brightness will not give a good amount of fringe contrast in all areas. At the Fourier plane, all points on the object contribute to every speckle, making the reconstructed phase more reliable. Now, we are focusing on the quantitative analysis of the reconstructed phase and planning to research the combination of both these holographic techniques for better results.

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Design and Optimization of Intraoral Endoscope Lens System

Anuprabha Dutta¹, Totan Chand², Shravana Kumar RR³, Amit Laddi³, Sourabh Roy¹

1. National Institute of Technology Warangal, Department of Physics, Hanamkonda, Telangana-506004, India

2. Indian Institute of Astrophysics, II Block, Koramangala, Bengaluru-560033, India

3. CSIR-Central Scientific Instruments Organisation (CSIO), Sector-30C, Chandigarh-160030, India

Intraoral endoscopy has emerged as a valuable tool in modern dentistry, enabling clinicians to visualize and diagnose oral conditions with enhanced precision and accuracy. The optical lens system used in intraoral endoscope plays a crucial role in determining image quality and diagnostic capabilities.

The main focus of the design is a short length intraoral endoscope system with prism-based configuration consisting of low f-number lens which can offer a wide field-of-view with high resolution imaging [1]. At the distal end of this optical system a right-angle prism is used for the bending of the light reflecting from the object and then directed towards the lens groups and ultimately reaches to the imaging sensor. Visible wavelength range (400nm-700nm) is chosen for the optical system with a targeted working f/# of 2.5 to work in the dim light environment [2]. The total length of the system from the first optical component to the image plane is set to 80 mm with consideration of the short length of the endoscope device for intraoral imaging purpose. The lens diameter is targeted under 12 mm to guarantee enough space for other instruments. This design has yielded a 30° wide field-of-view with good performance and acceptable results for getting detailed diagnostic information, at 5mm working distance.

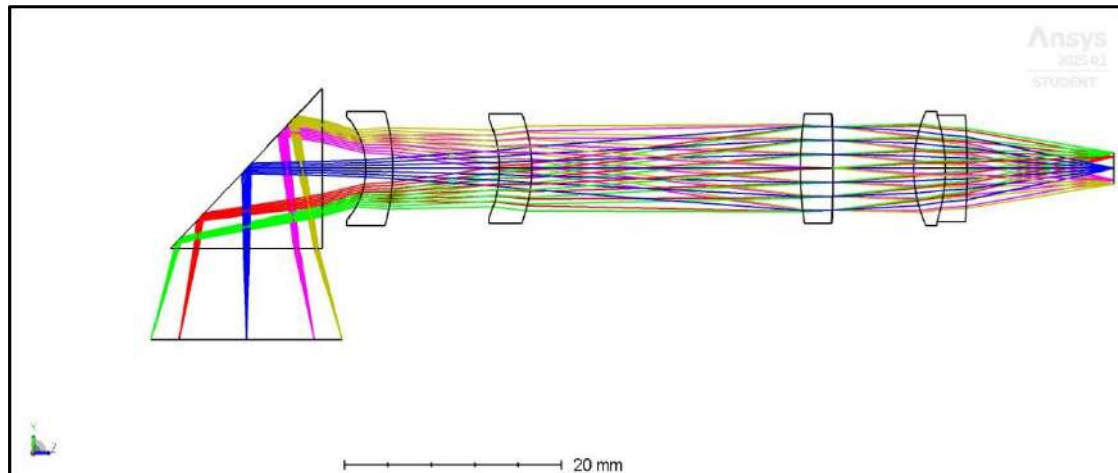


Fig. 1 Configuration of the Intraoral Endoscopic Lens System with Prism

A 1/6" CMOS image sensor (1296×976) of 1.9μm pixel is used to evaluate the optical quality parameters of the final optimized system [2]. Zemax Opticstudio® is used for the repeated optimization of this optical system by specifying constraints and choosing variables carefully so that it effectively meets all performance criteria such as high MTF, low distortion, low f/#, wide field-of-view while taking into account of materials availability and manufacturability [1-4].

Keywords: Intraoral Endoscope, Optical System, Imaging, Optimization.

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Telecom-Band Photon Pair Generation Using SOI Waveguide

Vijay^{1,†}, Awanish Pandey², Joyee Ghosh¹, and Vivek Venkataraman^{1,3}

¹Department of Physics, Indian Institute of Technology Delhi, New Delhi – 110016, India

²Optics & Photonics Centre, Indian Institute of Technology Delhi, New Delhi – 110016, India

³Department of Electrical Engineering, Indian Institute of Technology Delhi, New Delhi – 110016, India

[†]phz218659@physics.iitd.ac.in

In this work, we have experimentally explored the classical four-wave mixing (FWM) process in silicon-on-insulator (SOI) rib waveguide, and generated the frequency correlated photon pairs in the telecom band using spontaneous four-wave mixing (SFWM) with a peak spectral brightness of $\sim 1.3 \times 10^4$ photon pairs/s/nm/mW². Our integrated on-chip photon-pair source can potentially be employed for various quantum technologies like communication, metrology, and computing [1].

Four-wave mixing is a third-order nonlinear process in which two photons from a bright pump laser get annihilated to generate two daughter photons called signal and idler, while conserving the momentum and energy [2]. Our SOI waveguide design consists of a silicon rib waveguide of length 2.5 mm with a width of 450 nm and etching depth 150 nm, having air as top cladding, see inset (1) in Fig. 1(a). The design is phase-matched through dispersion engineering to generate photon pairs with a bandwidth of ~ 100 nm while pumping at 1550 nm. The waveguide has grating couplers [3] at both ends for coupling light into and out of the waveguide. While pumping the waveguide at 1550 nm and using a classical input signal at 1545 nm to stimulate FWM, the conversion efficiency (CE) [4] is shown as a function of input pump power in Fig. 1(a), and the inset (2) shows the output FWM spectrum recorded using an optical spectrum analyzer (OSA) for the incident pump and signal power of 132.7 and 23.4 mW, respectively. The slope of the curve is 2.07, which is in good agreement with the theoretical value of 2. For an input pump power of 10 dBm, the FWM CE is around -44 dB. For the SFWM, the input pump wavelength is tuned slightly to 1550.12 nm in order to map the generated photons to the channel pairs of the arrayed-waveguide grating (AWG) employed at the output to split the generated photon spectrum for coincidence measurement. The source's spectral brightness [4] is shown in Fig. 1(b) as a function of photon wavelength λ , back-calculated from the coincidence measurement performed with an input pump power of 1.94 mW. The coincidence measurement was performed for 15 different channel pairs of the AWG. The zero spectral brightness around the input pump wavelength, as shown in Fig. 1(b), is due to very high losses present in the optical circuit at the pump wavelength, which is required for suppressing the input pump. The variation of spectral brightness with wavelength is due to unstable fiber-chip coupling during the accumulation window, which needs to be improved for future work. The peak spectral brightness of the source is $\sim 1.3 \times 10^4$ photon pairs/s/nm/mW².

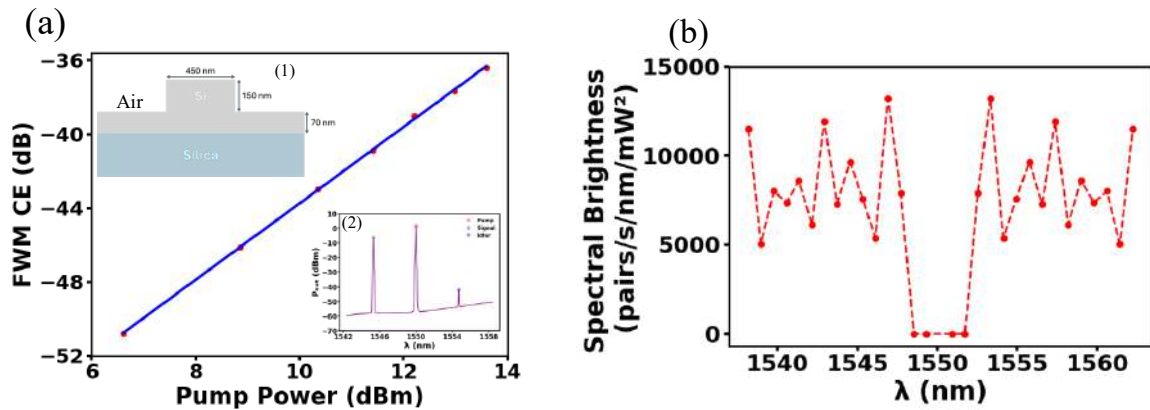


Fig. 1 (a) FWM CE as a function of input pump power. The inset (1) shows the cross-sectional view of the waveguide design. The inset (2) shows the FWM recorded using OSA with incident pump and signal power of 132.7 and 23.4 mW, respectively. (b) The generated photon flux or spectral brightness as a function of photon wavelength λ .

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Characterization of Dyson Imaging Spectrometer operating in LWIR

Archit Dube¹, Nikhil Raj¹, Sagar Gohil¹, Anand Kumar¹, H. P. Yendluri¹, Sami Ur Rehman¹, Moumita Dutta¹, S. S. Sarkar¹

1. Space Applications Centre, Indian Space Research Organisation, Ahmedabad, Gujarat 380058, India

Abstract: Imaging Spectrometer operating in LWIR have many potential applications in planetary exploration, detection of gases, mineralogy and defence. Dyson type spectrometer is a configuration where the size and weight is reduced by utilizing a powered diffracting element i.e. concave grating. Characterization of optical parameters is essential to evaluate the performance of the imaging spectrometer. We have characterized optical parameters of a Dyson type imaging spectrometer operating in Long Wave Infrared Range (7.7-11 μ m) operating with f/2 and 37mm EFL. Characterization is carried out right from the components level to the integrated system level. Interferometric measurements of components like Dyson and Corrector lens carried out. Parameters like transmission, SWR and EFL are measured for fore-optics. For Full-optical chain measurements carried out using different filters in LWIR and are verified by Spectral characterization. Parameters like SWR, spectral dispersion and bandwidth are measured and the results match well with the design values.

Keywords: Dyson, spectrometer, LWIR, infrared, concave grating, imaging spectrometer, SWR

Introduction: The characterization of optical parameters is essential to evaluate the performance of the Imaging Spectrometer. Measurement of various optical parameters require specialized test setups for evaluating the performance. Right from the component level till the integrated system level characterization is integral to the development of the complete system. We have developed the test setups to characterize imaging spectrometer operational in the LWIR wavelength range on the basis of SWR, EFL and transmission for fore-optics and Spectral Characterization of full optical chain.

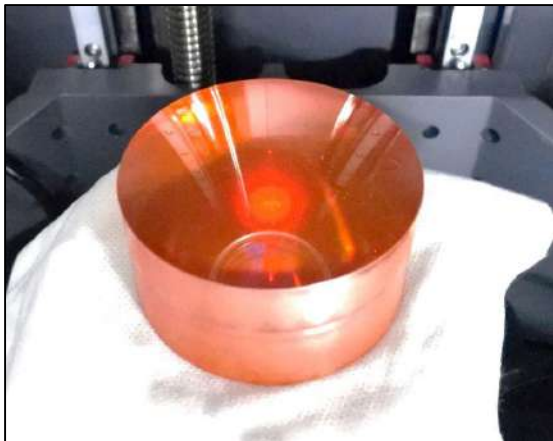


Fig 1: Dyson Lens

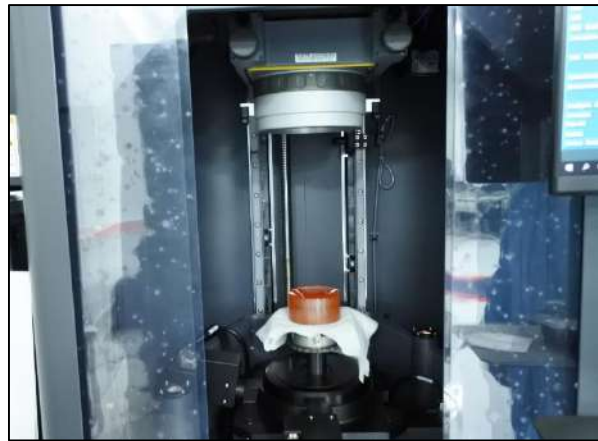


Fig 2: Interferometric testing of Dyson Lens

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Vibration-insensitive sub-Hz linewidth laser system

Sankalpa Banerjee^{1,3}, Sandip Haldar², Kanik Palodhi³ and Subhadeep De^{*1}

1. Inter-University Centre for Astronomy and Astrophysics (IUCAA), Post Bag 4, Ganeshkhind, Pune 411007, India

2 School of Mechanical Sciences, Indian Institute of Technology, Farmagudi, Goa 403401, India

3. Department of Applied Optics and Photonics, University of Calcutta, 92 A.P.C. Road, Kolkata 700009, India

A narrow linewidth and high frequency stability laser have wide range of applications in optical atomic clocks, optical qubit preparation, quantum sensing, precision laser spectroscopy and many other precision metrology experiments. This work presents a comprehensive design and related simulations to develop a room temperature Fabry-Pérot (FP) optical cavity with a fractional length instability of the order of 10^{-16} , which will act as a stability reference to produce the desired laser.

Pound Drever Hall (PDH) locking is used to transfer the length stability of an FP-cavity to the frequency stability of a tuneable free-running laser [1], thus linewidth narrowing of the laser as well upon using of a high finesse FP-cavity. We performed extensive optimisations for lowering the fractional length fluctuation of the FP-cavity through optical calculations and thermo-mechanical simulations using FEA [2]. We opt to use a hemispherical FP-cavity having radii of curvature of 1 m and infinity, respectively, with a spacer length (L) of 293.4 mm [3]. The cavity length is optimized to reduce the optical power in higher order transverse modes (HOMs) and also to avoid any frequency overlap between HOMs of other longitudinal modes with the mode is used to lock the laser. A FP cavity having cuboidal cross-section is chosen, constructed of ultra-low expansion (ULE) glass having a zero crossing of its coefficient of thermal expansion (CTE) between 5 to 35 °C and is mounted using a vibration-insensitive monolithic mount holding the cavity at four optimum points of support. Further, it has to be kept within ± 5 mK of its zero-crossing temperature so that the cavity suffers minimum length deformation due to temperature fluctuation. FP-cavity, along with its mounting, is within three layers of duralumin shielding mutually separated by three ceramic spheres at their bottom layers, thus minimising conduction. The entire system is under a vacuum of 1×10^{-9} mBar resulting to a negligible convection. Therefore, the heating is radiation dominated, which is minimized by polishing surfaces of the shields (emissivity coefficient of 0.03), so that any temperature change reaches from the outer to the inner shield over 6.53 days. Further, the cavity is under an active temperature control system that will keep the system within the specified temperature range with less than ± 5 mK.

One of the primary limitations of achieving fractional length stability $\sim 10^{-16}$ is vibration, especially low-frequency vibration, which is nontrivial to decouple from the cavity. To understand how vibration affects an ultra-stable FP-cavity, we studied simulation techniques used in the literature for such cavities. The most common technique is by applying a fixed vertical acceleration or acceleration in all three axes and finding the fractional length deformation for those accelerations, let's call it method 1 and 2, respectively. Another well-known simulation technique commonly used in engineering applications is random vibration analysis (method 3) [4]. We proposed a novel method that includes transient analysis along with giving sinusoidal acceleration in all three axes at different frequencies. That gives us frequency-dependent acceleration sensitivity in all three axes, which we call forced vibration (method 4). Table 1 shows the comparison between these methods; to have confidence in our proposed method, we implemented all the above-mentioned methods in the cavity used in Ref [5] and compared them with their experimental results. The values are quoted considering an acceleration due to gravity g is applied to the cavity. It is evident that method 4 best replicates the experimental results. Implementing method 4 on a 293.4 mm long FP-cavity, the ADEV of frequency instability due to vibration is 5.8×10^{-18} at 1 s integration time. Considering all the possible sources of instabilities, the combined fractional frequency instability ADEV at 1 s integration time is 2.59×10^{-16} . At present we are assembling the FP-cavity that is fabricated following our design specifications.

Table 1. Fractional instability of the cavity length described in Ref. [4], due to vibration, is calculated using different methods.

Method	Method-1	Method-2	Method-3	Method-4	Experimental [1]
$\Delta L/L \times 10^{-11}/g$	2.5	20	4.55	58.4	59

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Broadband uniform-efficiency two-photon OAM detector

Suman Karan and Anand K. Jha

Department of Physics, Indian Institute of Technology Kanpur, Kanpur, UP 208016, India

Orbital angular momentum (OAM) entangled two-photons have emerged as promising candidates for high-dimensional quantum information applications [1]. However, accurate characterization of these quantum states requires precise measurement of their OAM spectra. A true two-photon OAM spectrum detector refers to a detector capable of measuring the OAM probability as the sum of probabilities from different radial modes with equal OAM mode index l [2]. Spontaneous parametric down-conversion (SPDC) is the most widely used method for generating entangled two-photon fields in high-dimensional OAM basis [3]. However, the existing widely accepted OAM detection technique introduced in 2001 by Mair et al. suffers from radial index mode equal to zero ($p=0$) selectivity, meaning it cannot measure the actual OAM spectrum generated from SPDC where the input state contains multiple radial modes with the same OAM mode index [4].

Although multiple efforts have been made, developing a detector capable of measuring a broad range of two-photon OAM spectra with uniform efficiency and without prior knowledge of the input state remains a longstanding challenge in the two-photon domain. Here we report such an OAM detector based on the two-photon angular interference effect that overcomes these existing limitations.

Briefly, our experimental setup consists of a Franson-type interferometer where the path difference between the long and short arms is maintained at 80 cm to eliminate two of the four possible two-photon alternatives. Each short path of the interferometer contains a K-mirror, which essentially rotates the wavefront by 2θ when rotated by an angle θ . The interferogram is captured via time-tagger coincidence measurements at two different interferometric settings, and the subtracted coincidence counts at various rotation angles of the two K-mirrors are recorded. Fourier transformation of this data provides direct observation of the two-photon OAM spectrum P_{li}^{ls} .

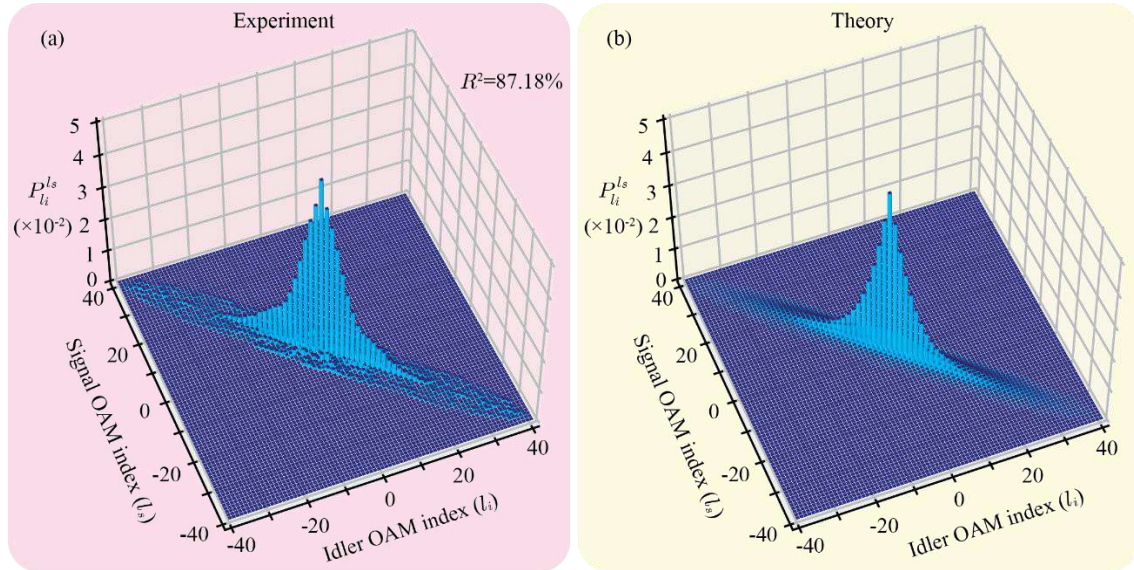


Fig. 1 Plot of (a) experimentally measured and (b) theoretical two-photon OAM spectrum generated from the SPDC process.

Figure 1(a) shows the experimentally obtained P_{li}^{ls} of the entangled state generated from type-I collinear SPDC, whereas Figure 1(b) represents the theoretically expected result. We demonstrate measurement accuracy of 87.18% for such a massive (81×81)-dimensional entangled state. This represents the first experimental demonstration of broadband uniform-efficiency two-photon true OAM spectrum detection without any prior information of the input state. We believe this measurement technique will have significant implications for photonic quantum technology applications where precise measurements of two-photon OAM spectra are required.

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Spontaneous Parametric Down Conversion (SPDC): Maximizing Pair Rate for Type-II SPDC With PPKTP

Shreyansh Agarwal¹, Tomis Prajapati¹, and V. Narayanan^{1,2}

¹. Department of Physics, Indian Institute of Technology Jodhpur-342030, India

². IDRP-Quantum Information and Computation (IDRP-QIC), Indian Institute of Technology Jodhpur-342030, India

Entangled photons are essential for quantum communication and computation, where high heralding efficiency—i.e., the likelihood of detecting a photon given its entangled counterpart is detected—is critical for reliable operations [1,2]. Spontaneous Parametric Down Conversion (SPDC), a second-order nonlinear optical process (χ^2), is the most common technique for generating such photons. The efficiency and generation rate depend upon factors like crystal type, crystal length, pump power, and the beam waists of the pump, signal and idler.

In this work, we theoretically modelled the optimal parameters for high photon pair generation using a type-II SPDC process in a periodically poled KTiOPO_4 (PPKTP) crystal with a poling period of $10\mu\text{m}$ and a length of 2mm . Based on quasi-phase matching conditions, (i) $K_p = K_s \cos(\theta_s) + K_i \cos(\theta_i) + 2\pi/\Lambda$ and (ii) $\omega_p = \omega_s + \omega_i$, with $K_j = 2\pi n_j / \lambda_j$ and refractive indices n_j given by temperature-dependent Sellmeier equations [3–5]—we found the quasi-phase matching temperature for degenerate, collinear case to be 40.66°C for a 405 nm pump. Fig. 1 (a) shows how the quasi-phase matching temperature varies with SPDC emission angle.

Now, we proceed to calculate the photon pair generation rate and heralding efficiency in a non-collinear, degenerate SPDC setup, with emission angles $\theta_s = \theta_i = 3^\circ$. For such small angles ($\leq 3^\circ$), the effects of the Poynting vector and spatial walk-off can be neglected. The method outlined by Rockovich et. al. [6] is used to perform these calculations. Photon pair rates (in pairs/s.mW) are computed using the following expression:

$$R = \frac{\eta_s \eta_i P d_{eff}^2 \omega_s \omega_i}{\sqrt{2} \pi^{3/2} \epsilon_0 c^3 n_s n_i n_p B_p} \int_{-\infty}^{\infty} T_s(\omega_s) \int_{-\infty}^{\infty} T_i(\omega_p - \omega_s) |\Phi(\omega_s, \omega_i)|^2 d\omega_s d\omega_p \quad (1)$$

where η ($=1$ ideal) is efficiency of filters, B_p ($=30\text{THz}$) is pump beam spectral bandwidth, d_{eff} ($=2d_{24}/\pi$) is effective second order nonlinear coefficient, T_j are filter transmission functions (unit bandpass filter here) and Joint Spectral Amplitude Φ is given in [6]. We obtained highest pair rate of 2595.60 pairs/s.mW at pump beam waist of $119.22\mu\text{m}$ as shown in Fig. 1 (b). Further we show variation of pair rate with signal and idler beam waist [Fig. 1 (c)], power of pump beam [Fig. 1 (d)] and length of the crystal [Fig. 1 (e)].

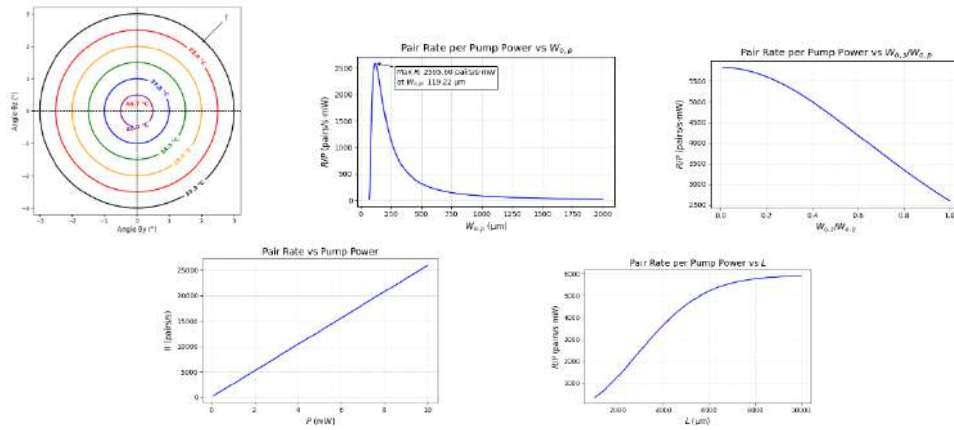


Fig. 1. (a) Quasi-phase matching temperature at different angles. (b) The pair production rate as a function of the pump beam waist. (c) Pair production rate as a function of $W_{0,s}/W_{0,p}$. (d) The pair production rate as a function of the power of the pump beam. (e) The pair production rate as a function of the length of the crystal.

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Detection of cotinine (spiked in human urine) using plasmonic quasi crystal as SERS-active substrate

Sibashish Chakraborty¹, Rishabh Vij², Sudip Kumar Datta³, Venu Gopal Achanta^{2,4,†}, Satish Kumar Dubey^{1,*}

1. SeNSE, Indian Institute of Technology (IIT) Delhi, New Delhi; India

2. Tata Institute of Fundamental Research (TIFR), Mumbai; India

3. AIIMS, New Delhi, India

4. On lien at National Physical laboratory (NPL), New Delhi ; India

During light-matter interaction, light gets absorbed, reflected, transmitted, and scattered. Depending on the scattering behaviour of light, in 1928, Sir C.V. Raman discovered that one in a million photons can get inelastically scattered when light interacts with matter. Raman signals provide the unique spectral fingerprint of a Raman active analyte; however, owing to their low scattering cross-sections, Raman signals are weak in nature [1]. A variant of Raman spectroscopy, that is Surface enhanced Raman spectroscopy (SERS) can detect single molecules and provide comprehensive chemical information about molecular assemblies by enhancing Raman signals substantially by increasing the Raman scattering cross-section. It is a label-free, non-destructive detection method that is rapid, sensitive, accurate, and precise. The major applications of SERS are: (a) environmental monitoring; (b) narco-analysis; (c) gas sensing; (d) food adulteration; and (e) bio-diagnostics, among others [2-3]. In this study, we have employed plasmonic quasi crystal made of gold as a SERS-active substrate for the detection of cotinine. Cotinine is the major degradation product of nicotine metabolism and has a serum half-life of about 17 hours compared to two hours for the parent compound. The current objective is aimed at detecting the cotinine levels in saliva/urine among smokers/passive-smokers/non-smokers and tobacco consumers. Current methods involved in detecting nicotine addiction in biological matrices can be assessed by gas chromatography (GC) and liquid chromatography (LC). These methods are slow and need pre-processing which means on-the-spot results are not possible, which affects the overall opportunity to save people from a nicotine-related medical disorder. We aim to realize the state-of-the-art use of SERS as a confirmatory method for the identification of cotinine.

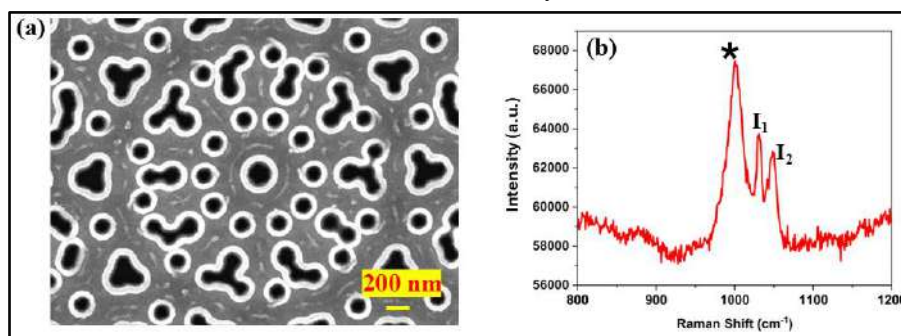


Fig. 1(a) : FESEM image of PIQC and 1 (b) : SERS spectra of cotinine spiked in human urine

Fig. 1(a) shows the FESEM image of Plasmonic quasi crystal, which is being employed to detect the micro-molar concentration of cotinine (SERS-spectra has been illustrated in Fig.1(b)), spiked in human urine. In fig. 1 (b) the peak marked as “starred”, represents the prominent Raman peak of urine and I₁ and I₂ are the two prominent peaks of cotinine at 1032 cm⁻¹ and 1052 cm⁻¹.

This study provides an innovative non-invasive method to detect cotinine at concentrations as low as micromolar, which is spiked in human urine, using a plasmonic quasi crystal (PIQC)-based SERS-active substrate. The detection of cotinine levels can provide a sensitive estimate of tobacco smoke exposure, which can go a long way in helping patients suffering from nicotine addiction. The findings in this study indicate the potential of the proposed technique that provides a sensitive, rapid and accurate method to verify smoking status among smokers, passive smokers, non-smokers and tobacco consumers. This would be very useful in developing epidemiologic studies pertaining to nicotine addiction amongst smokers, non-smokers, passive smokers, and tobacco consumers.

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Effect of plasmonic nanoparticle in thermo-optical properties of cobalt ferrite

Dency John¹ and Pramod Gopinath^{1*}

1. International School of Photonics, Cochin University of Science and Technology, Cochin 682022, India

*E-mail: pramod@cusat.ac.in

Magnetoplasmonic nanoparticles (MNPs) which combine magnetic and plasmonic properties are of great interest due to their potential biomedical applications like magnetic resonance imaging, drug delivery and magnetic hyperthermia. Among magnetic materials, cobalt ferrite (CF) has high magnetocrystalline anisotropy, high saturation magnetization and high thermal stability. So we combine the CF with gold (Au) NPs which have specific optical properties associated with localized plasmon resonance to form CF-Au NPs [1]. Thermal diffusivity is a fundamental property that characterizes how quickly heat propagates through a material. Thermal Lens Spectroscopy (TLS) is a technique to study thermal diffusivity which utilizes the principle that absorbed light generates heat, creating a thermal lens due to temperature-dependent changes in the refractive index of the material. By analyzing the distortion of a probe beam passing through this thermal lens, the thermal diffusivity can be determined [2]. This work aims to study the effect of plasmonic nanoparticle in thermal diffusivity with varying concentrations of CF-Au.

CF-Au NPs were synthesized using thermal decomposition method and the structural, morphological and compositional analysis of the synthesized nanoparticles have been done. The thermal diffusivity studies have been done using dual beam thermal lens setup. Pulses from a continuous wave (cw) single-mode laser beam of 403 nm, 150mW controlled by a mechanical shutter, are used to excite the sample and generate the thermal lens. This thermal lens is then probed by a 633 nm, 10mW second cw single-mode laser. Photodetectors are used to monitor the temporal dependence of the transmitted probe-beam intensity in the far field at the center of the probe beam.

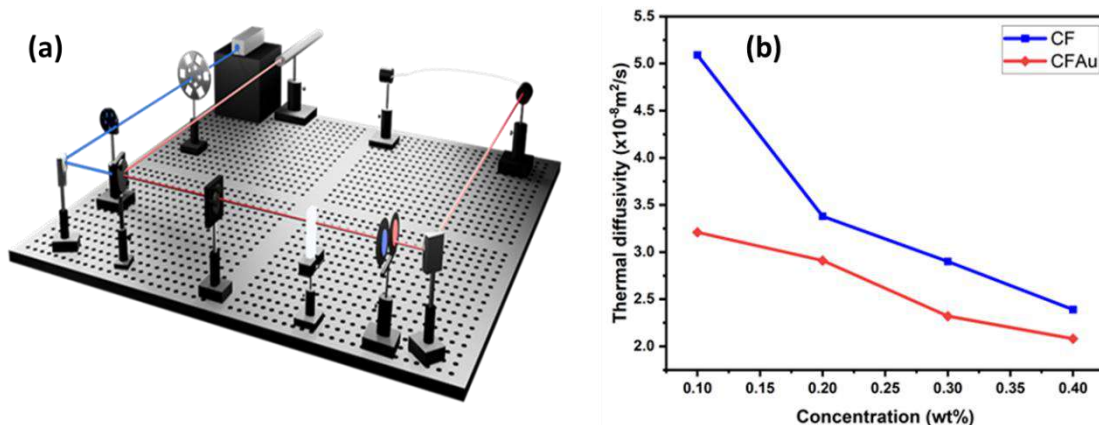


Fig. 1 (a) Experiment setup of dual beam thermal lens technique (b) Comparison of thermal diffusivity of CF and CF-Au NPs.

From the Fig. 1, it is evident that, as compared to CF NPs, the thermal diffusivity is decreased when we introduce a plasmonic particle into it. The variation in the values is attributed to the interaction between gold nanoparticles and CF NPs. Since it measures the characteristic time for transferring heat to the surroundings, we can use it for magnetic hyperthermia applications.

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Perturbation Induced Mode Conversion in a Few Mode Fiber

Veeresh K¹, Naveenkumar M.^{1,2}, Amal Jani³, and Shivaleela E S¹

1. Electrical Communication Engineering, Indian Institute of Science, Bengaluru, Karnataka 560012, India

2. Department of Electronics and Telecommunication Engineering, Siddaganga Institute of Technology, Tumakuru, Karnataka 572103, India

3. International School of Photonics, Cochin University of Science and Technology, Kochi, Kerala 682022, India

We propose a novel, cost-effective method for mode conversion in a 1550 nm single-mode fiber (SMF-28), which operates as a few-mode fiber at 633 nm when excited with a He-Ne laser ($V \approx 4.88$). By bending the fiber at angles of 0° – 10° , we induce mode conversion from the LP_{11} mode, dominant at $\theta = 0^\circ$, to LP_{02} and LP_{21} modes. The optical carrier has several degrees of freedom such as amplitude, frequency, phase and polarization. In addition to these, by adding space division multiplexing in few mode fibers, the data carrying capacity of the fiber can be enhanced several folds, in optical communication systems, similar to wavelength-division multiplexing (WDM) [1] in SMF.

In our experimental setup, a 633 nm He-Ne laser beam is launched into an SMF-28 fiber. Bending of SMF induces mode conversion, observed in far-field patterns projected on a screen. The patterns at different bending angles are shown in the Fig. 1. At $\theta = 0^\circ$, the two-lobe pattern indicates LP_{11} as in Fig.1 (a). Between 5° to 10° , multi-lobe patterns confirm conversion to LP_{21} , LP_{02} and combinations of modes as in Fig.1 (b), (c) and (d) respectively. This simple bending of SMF technique offers a practical alternative to complex mode converters [3].

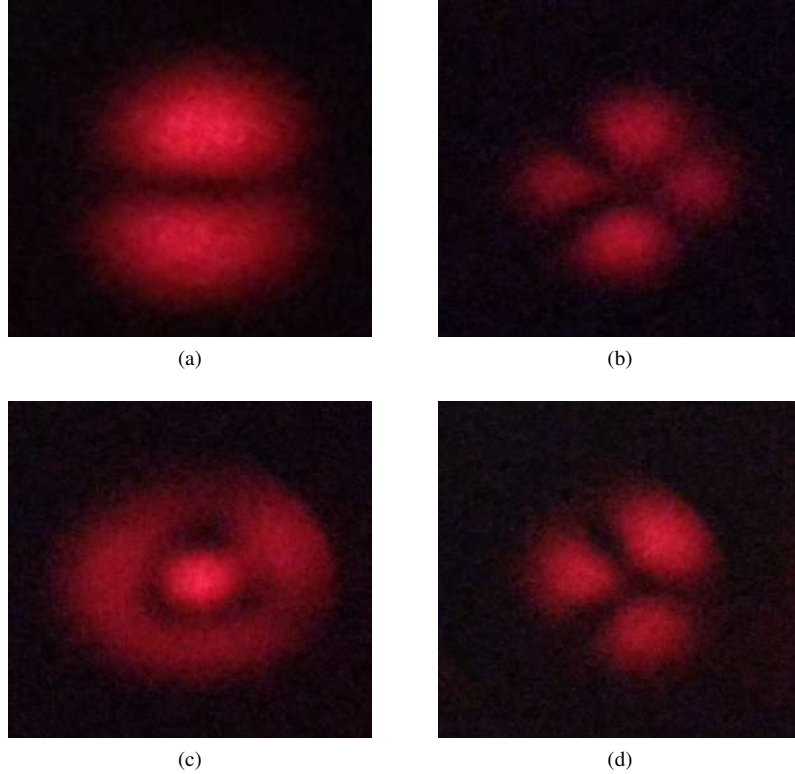


Fig. 1: Far-field patterns of SMF-28 at 633 nm for different bend angles, showing mode conversion from (a) LP_{11} , (b) LP_{21} , (c) LP_{02} , and (d) Combined mode

This approach is innovative due to its simplicity, mode conversion realized using minimal components, with physical bending of plain patch chord for Mode Division Multiplexing applications. Future work will explore dynamic bending and quantitative mode power measurements to optimize performance for optical sensing and high-capacity communication systems [1, 3].

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Laser Wavelength Calibration Using Sagnac Interferometer

Harikrishnan P, Dinesh N Naik

Applied and Adaptive Optics Laboratory, Department of Physics,
Indian Institute of Space Science and Technology, Thiruvananthapuram, Kerala
Corresponding author: harikrishnanp.21@res.iist.ac.in

Atomic spectrum absorptions are possible with tunable laser sources, which may find use in Doppler shifting and laser cooling. They can also be used for interferometric measurements and ranging and depth-sensing applications in Lidars [1,2]. Motorised feedback systems introduce nonlinearity and hysteresis for tens of nanometres of adjustable capability. Conventional spectrometers with nanometer resolution cannot accurately measure wavelength shift due to sharp line widths and tuning steps of 0.05nm. We propose wavelength change-induced phase difference delays in a common-path Sagnac interferometer to detect sub-nanometer tuning process alterations. The calibration of wavelength with tilted interference is studied.

The instantaneous difference of the phase difference with path delay d provides the slope at that pixel for a particular wavelength, given by,

$$S(n) = \frac{\partial \phi(x, y, n)}{\partial d} \quad (1)$$

Where n is the tuning step; $\phi(x, y, n)$ is the phase variation. Assuming the initial wavelength, the shift in the wavelength corresponding to each interferogram can be obtained by

$$\lambda_{\text{obtained}}(n+1) = W(n) * \lambda_{\text{obtained}}(n) \quad (2)$$

Where, $W(n) = \frac{s(n-1)}{s(n)}$ gives the slope ratios between the recorded interferograms.

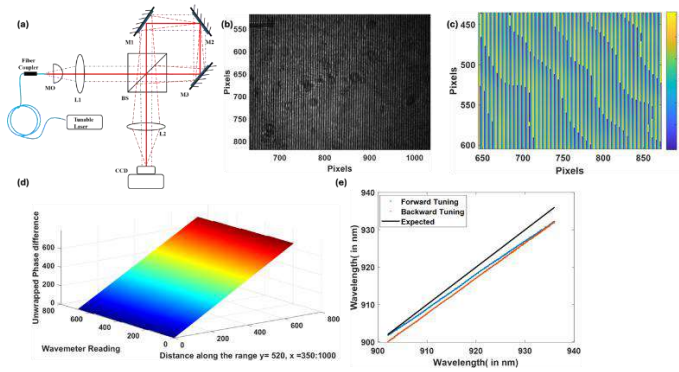


Fig 1 (a): Experimental Setup, (b) Enlarged portion of the recorded interferogram and (c) phase difference values corresponding to the recorded interferogram for laser system wavemeter reading 902 nm (b) unwrapped phase difference values obtained as a function of recorded interferogram number and distance along the pixel range $y=520$ and $x=350:1000$ and (c) Obtained wavelength values as a function expected wavelength.

Fig 1(a) shows the experiment setup where the light from the tunable laser diode (**Sacher Laser Technik TEC-520-0920-100-M**) is collimated using lens L1 and then fed to a Sagnac interferometer consisting of 3 mirrors: M1, M2 and M3. The mirror M3 is imaged onto the CCD camera (**PCO Pixelfly**) using a lens L2. (b) shows an enlarged region of the recorded interferogram obtained for a particularly unknown wavelength. (c) shows the enlarged view of the phase difference obtained after selecting one of the side lobes using the Fourier transform method of fringe analysis. (d) shows the unwrapped phase difference obtained along the pixel range $y=520$ and $x=350:1000$ obtained by tuning the laser system wavemeter reading 902 nm to 936nm. By obtaining the slopes as defined in Eq.1 and using Eq. 2, the shift in wavelengths in the process of tuning is shown in Fig. 2 (e). The plot with blue dots shows the experimentally obtained wavelength shift values when the wavelength is tuned from 902nm to 936nm, the plot with red dots shows the experimentally obtained wavelength values when the wavelength is tuned from 936nm to 902nm, and the black line shows the wavelength readings provided by the laser system using in-built calibration [3]. We experimentally investigated the wavelength tuning characteristics of the laser in forward and backwards directions using a Sagnac interferometer. The variation, though linear, has a maximum deviation of 3.90nm from the system wavemeter for a wavelength range of 33nm. This difference in measurement using interferometry can be due to the residual/uncompensated dispersion in the interferometer system or due to the motorised system used in the system for providing feedback, which needs to be further investigated. At the same time, our investigations do reveal a hysteresis for the forward and backwards tuning that can be attributed to mechanical motorised tuning.

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Electron Confinement-induced Plasmonic Breakdown in Metals

Prasanna Das¹, Sourav Rudra¹, Dheemahi Rao¹, Souvik Banerjee¹, A.I.K. Pillai², Magnus Garbrecht², Alexandra Boltasseva³, Igor V. Bondarev⁴, Vladimir M. Shalaev³, and Bivas Saha^{1,5}

1. Chemistry and Physics of Materials Unit and International Centre for Materials Science, Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 560064, India
2. Sydney Microscopy and Microanalysis, The University of Sydney, Camperdown, NSW 2006, Australia
3. Elmore Family School of Electrical and Computer Engineering, Purdue Quantum Science and Engineering Institute, and Birck Nanotechnology Center, Purdue University, West Lafayette, IN 47907, USA
4. Department of Mathematics & Physics, North Carolina Central University, Durham, NC 27707, USA
5. School of Advanced Materials and Sheikh Saqr Laboratory, Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 560064, India

Plasmons, quasiparticles of collective free-electron oscillations, enable nanoscale light confinement, strong absorption, and local field enhancement, supporting applications from photocatalysis to optical communications [1]. The classical Drude model describes plasmonic behavior in metals and other conductors, with the screened plasma frequency (ω_p) determined by carrier concentration, effective mass, and dielectric constant, but lacking spatial dispersion. This limits resonance tuning, especially for visible-range plasmonic metals. A recent nonlocal Drude theory incorporating the Keldysh–Rytova (KR) potential predicts that ultrathin plasmonic films with higher core dielectric constants than their surroundings experience strong electron confinement [2,3], inducing spatial dispersion of ω_p , increasing losses, and potentially suppressing plasmon oscillations. This “plasmonic breakdown” is accompanied by a metal–insulator transition (MIT). Thick films retain metallic Drude responses, but reducing thickness enhances Coulomb interactions, localizes states near the Fermi level, and drives a transition from a transdimensional (TD) plasmonic regime to a KR-insulating state, offering pathways for tunable transparent optics and novel electromagnetic effects.

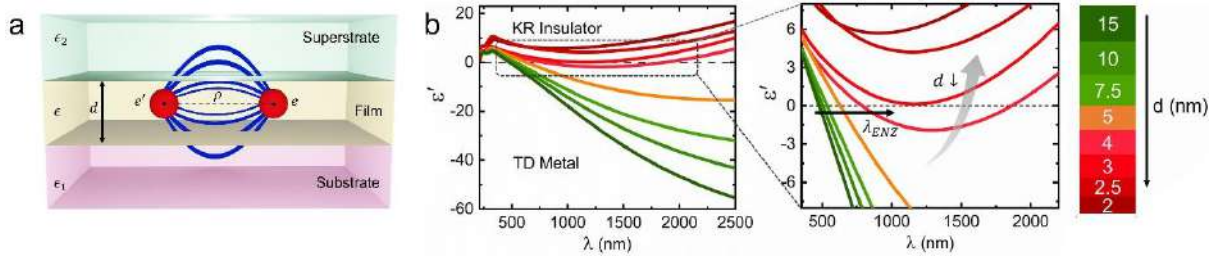


Fig. 1 (a) Schematic of a plasmonic metal sandwiched between a substrate and a superstrate. (b) the ϵ' of HfN films as a function of thickness.

In this work, we investigate hafnium nitride (HfN), a refractory, corrosion-resistant transition metal nitride, as a platform to observe electron-confinement-induced plasmonic breakdown and the associated metal–insulator transition (MIT). Epitaxial HfN films - bulk (150 nm) and ultrathin (2–15 nm) - were grown on MgO(001) via ultrahigh-vacuum magnetron sputtering at 900 °C. Spectroscopic ellipsometry (210–2500 nm) shows that thick films exhibit a Drude-like plasmonic response with an epsilon-near-zero (ENZ) wavelength at 415 nm, highly negative ϵ' at long wavelengths, and low losses near λ_{ENZ} . Reducing thickness decreases $|\epsilon'|$ and redshifts λ_{ENZ} from 478 nm (15 nm) to 787 nm (4 nm), consistent with confinement-induced spatial dispersion. Below 4 nm, ϵ' remains positive, indicating plasmonic breakdown. Optical spectra confirm the transition, and temperature-dependent resistivity reveals a TCR sign change near 5 nm and an eight-order resistivity increase in 2 nm films. Combined optical and electrical results confirm a progression from Drude metal to transdimensional plasmonic medium to Keldysh–Rytova insulator.

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Effects of strong magnetic field on Two-Electron Quantum Dots in a Quartic Anharmonic Potential

Soumen Das^{1*}, Swapan Mandal¹

1. Visva Bharati, Department of Physics, Santiniketan, Bolpur, India

E.mail – soumen.bondul@gmail.com

We investigate the analytical solutions of two-electron quantum dot (TEQD) confined through a quartic anharmonic potential under the influence of a strong, uniform magnetic field. While most prior research relies heavily on numerical methods due to the complexity of electron-electron interactions, this work aims to develop an analytical framework to understand such a system. The approach involves the separation of variables using center-of-mass and relative coordinates, simplifying the Hamiltonian and making it more tractable. The total Hamiltonian accounts for kinetic energy in the presence of a magnetic field, harmonic confinement, quartic anharmonicity, Coulomb interactions, and spin effects. After coordinate transformation, the Hamiltonian splits into two parts: one describing the center-of-mass motion and the other the relative motion. Analytical solutions are derived for the center-of-mass component, particularly in cylindrical coordinates.

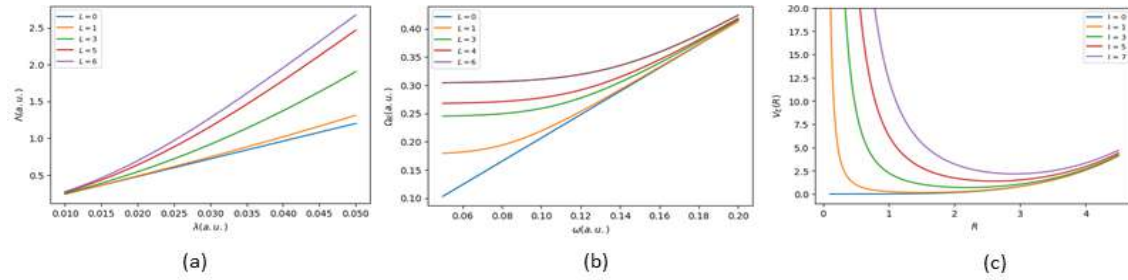


Fig. 1 (a) The renormalized anharmonic parameter Δ involving the centre of mass of two electron quantum dot is plotted as a function of the anharmonic constant λ for various angular momentum quantum number L (Given in the inset) with fixed $\omega_R = 1.0$ (b) The renormalized frequency Ω_R involving the centre of mass of two electron quantum dot is plotted as a function of the frequency of the harmonic potential ω for various angular momentum quantum number L (Given in the inset) with fixed $\lambda = 0.0001$. (c) The effective potential $V_E(R)$ between the two electrons quantum dot in centre of mass coordinate R is plotted against R for various angular momentum quantum number L with fixed $\lambda = 0.01$ and $\omega = 1.0$.

In the XY-plane, the Schrödinger equation becomes a central potential problem, where solutions are found using perturbation theory. The unperturbed system exhibits characteristics of a 2D isotropic harmonic oscillator with modified frequencies, and the eigenfunctions involve associated Laguerre polynomials. The first-order energy corrections due to the anharmonic term are also computed. Along the Z-axis, the system behaves as a 1D harmonic oscillator, and perturbative corrections are again calculated to refine energy estimates. An effective potential analysis is also presented, showing how quartic terms influence the potential landscape. A sextic equation is solved to find the minimum of the effective potential, further aiding in estimating the corrected energy eigenvalues. The total energy is then expressed, including both magnetic and anharmonic contributions.

This work provides an analytical understanding of quantum confinement in anharmonic quantum dots, especially under magnetic fields, and may offer insight into designing nanoscale quantum systems with tailored energy structures.

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Optical Image Encryption using Non-linear Fractional Fourier Transformation

Shirsendu Sarkar¹ and Shouvik Sadhukhan²

1. Department of Physics, Bhairab Ganguly College, Feeder Road, Belgharia, Kolkata-700055, India

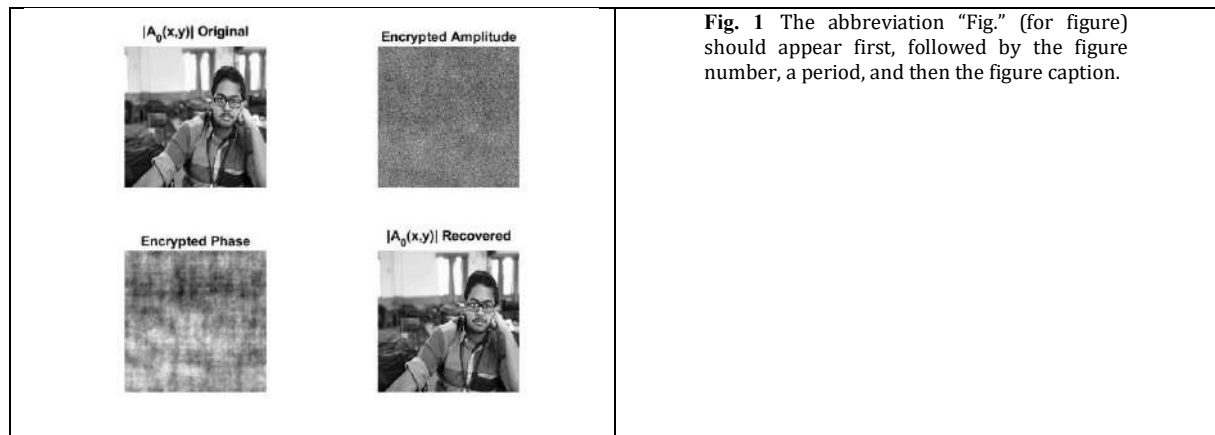
2. Applied and Adaptive Optics Laboratory, Department of Physics, Indian Institute of Space Science and Technology (IIST), P.O.: Valiamala, Trivandrum - 695547, State: Kerala; India

Corresponding Author Email: shirs.pp@gmail.com

Abstract: We propose a novel image encryption method based on the Generalized Fractional Fourier Transform (GFrFT), which extends conventional fractional transforms by incorporating nonlinear phase modulation through an anharmonic potential. This approach generates highly complex encrypted representations of images, offering enhanced security and strong sensitivity to secret keys such as the transform order and nonlinear strength. Unlike traditional linear FrFT-based encryption, the GFrFT produces non-Gaussian, unpredictable spectral outputs that are resistant to analytical decryption. Numerical experiments on grayscale images demonstrate that the method achieves secure scrambling and accurate decryption when all parameters are correctly matched, ensuring robust protection for optical and digital encryption systems.

Introduction: Image encryption methods using fractional Fourier transforms (FrFT) have attracted considerable interest due to their tunable domain rotation and sensitivity to the transform order, which naturally serves as a secret key. However, traditional FrFT is inherently linear, relying on harmonic dynamics, and produces outputs with predictable Gaussian-like characteristics. These properties may limit resistance to advanced cryptanalytic attacks, as the transformation lacks additional complexity in its phase evolution. To enhance encryption strength, we introduce the Generalized Fractional Fourier Transform (GFrFT), which incorporates nonlinear dynamics through an anharmonic potential. This modification fundamentally alters the transformation behavior, producing encrypted images with irregular, non-Gaussian features and highly sensitive dependence on system parameters. The resulting transform behaves as a controllable scrambling mechanism that is invertible only with the exact fractional order and nonlinear strength, both acting as secure keys. This approach merges the flexibility of fractional-domain processing with the unpredictability introduced by nonlinear phase distortion, creating a more secure encryption framework. Numerical demonstrations on grayscale images confirm that the GFrFT generates significantly more complex encrypted domains while maintaining reliable decryption, highlighting its potential for secure data transmission in optical and digital platforms.

Results analysis and Conclusion: Simulations using a 512×512 grayscale image demonstrate that the GFrFT generates strongly deformed encrypted spectra, with visual randomness surpassing standard FrFT. The encryption is highly sensitive to both fractional order α and anharmonic strength g even minimal deviations prevent accurate decryption, strengthening key security. The inverse GFrFT achieves near-lossless recovery of the original image when parameters are correct. These results confirm that the GFrFT framework, by combining nonlinear phase evolution with fractional domain rotation, provides a secure and reversible encryption scheme. Its compatibility with optical and digital implementations positions it as a versatile tool for next-generation image security systems.



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Experimental Demonstration of Plug and Play BB84 Quantum Key Distribution with Polarization Stability Compensation

Saravana Vilashini M^{1,2}, Anil Prabhakar^{1,2}

1. Department of Electrical Engineering, Indian Institute of Technology Madras, Chennai, Tamil Nadu 600036, India

2. Centre for Quantum Information, Communication and Computing (CQuICC), IIT Madras, Chennai, Tamil Nadu 600036, India

We demonstrated a phase-encoded quantum key distribution (QKD) system with polarization stability, which was deployed in a plug and play configuration to enable secure long-distance communication via optical fibre. Maintaining interferometer stability is a significant difficulty in phase encoded QKD because environmental perturbations can cause phase fluctuations that reduce interference visibility. Laser pulses are generated at the receiver (Bob) and sent to the transmitter (Alice), where they are significantly attenuated, phase-modulated, and reflected by a Faraday mirror. The bidirectional propagation compensates for phase irregularities, while the Faraday mirror ensures that returning pulses receive orthogonal polarization, allowing for polarization drift compensation [1,2]. Recent research shows that real-time polarization adjustment may maintain stability over tens of kilometers of fiber without requiring extra human intervention [3].

As illustrated in Fig. 1, the experimental setup generates 4 ns laser pulses separated by 36 ns, which are split at Bob into two paths, one with a phase modulator and other path is directly passed through a polarizing beam splitter. Recombined pulses travel through fibre and reaches Alice, where the reflected signals are returned to Bob for interference detection using a single-photon detector, with arrival timings recorded by a time tagger. System performance was measured using Quantum Bit Error Rate (QBER), Visibility, and Secure Key Rate (SKR). We achieved a QBER of 8.5%, which is less than the 11% criterion for secure key generation, and a Visibility of 0.8, over 50 km. The SKR, estimated as, $SKR = r [1 - f h(e) - h(e)]$, where r is the sifted key rate, $h(e)$ is the binary entropy function with an error correction efficiency factor of $f = 1.16$ [4], which was 5 kbps over 50 km as shown in Fig.2 (b).

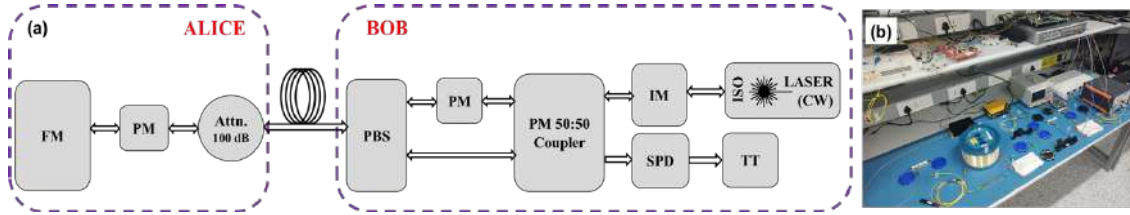


Fig. 1 (a). Schematic diagram IM: Intensity Modulator, TT: Time Tagger, SPD: Single Photon Detector, PM: Phase Modulator, PM 50:50: Polarization Maintaining 50:50, FM: Faraday Mirror, and (b). Experimental setup of Plug and Play BB84.

The stability comparison between the BB84 and the Plug-and-Play BB84 is shown in Fig. 2 (c). From the stability analysis over 25 seconds, it was found that conventional phase encoded QKD had QBER fluctuations ranging from 8% to 22%, but the Plug and Play BB84 has polarization compensated system which kept QBER between 7% and 8.5%. These findings indicate that polarization control in a phase encoded QKD architecture provides secure, stable key generation across extended fibre lengths.

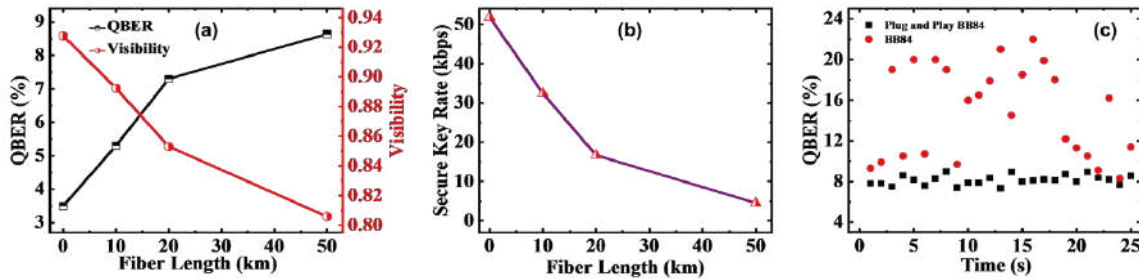


Fig. 2 (a) QBER and Visibility at different fiber lengths, (b) The SKR, (c) Stability Analysis of BB84 and Plug and Play BB84 Protocols

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Prism-Coupled SPR Sensing of Cyanide ions in Wastewater with Malononitrile Appended Free Base Porphyrin

Rohit Kumar Vishwakarma¹, Sandip Kumar², Muniappan Sankar², Sachin Kumar Srivastava^{1,3}

1. Centre for Photonics and Quantum Communication Technology, Indian Institute of Technology Roorkee, 247667, India

2. Department of Chemistry, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India

3. Department of Physics, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India

Abstract: We report a highly selective and sensitive SPR sensor for the detection of cyanide ions in wastewater using malononitrile appended free base porphyrin with estimated sensitivity of $6.1 \text{ nm}\cdot\text{mM}^{-1}$ and figure of merit 0.084 mM^{-1} .

Introduction: Cyanide is a toxic pollutant often found in industrial discharge, which affect nervous system, respiratory system, cardiovascular system leading to human death. The existing sensors for cyanide ions (CN^-) for low concentration require sophisticated instrumentation, rigorous sample preparation and skilled manpower. These problems can be overcome by employing surface plasmon resonance (SPR) technique along with malononitrile free base porphyrin (MAFBP). MAFBP provides selective and reversible binding toward cyanide ions making it a suitable recognition element for CN^- [1]. Surface plasmons are the collective oscillations of free electrons at metal-dielectric interface under time varying electromagnetic field. The SPR occurs when the wavevector of incident p-polarized light matches to the wavevector of surface plasmons. This resonance is highly sensitive towards a slight change in dielectric constant of the analyte medium. Thus, it can be used for highly sensitive and selective sensing applications.

Results and Discussion:

In the present study, a prism coupled custom-made SPR setup was used to perform spectral interrogation. Schematic of the sensor platform consists of a SF-11 right angle prism, a sensor chip, and flow cell. The sensor chip was placed beneath a flow cell as shown in Fig. 1(b), so that there is no aqueous leakage. To carry out the spectral interrogation analysis of the CN^- ions in aqueous solutions, a p-polarized collimated beam of polychromatic light was incident on one face of the prism. The reflected light with change in spectral behaviour was recorded at the other end and guided to a spectrometer via fiber optic cable. The SPR spectra for aqueous CN^- samples were recorded from concentration 1 mM to 10 mM. In Fig. 1(c) it is observed that the SPR response curves show as blue shift for the increasing concentrations. The extracted resonance wavelengths (λ_{res}) values from Fig. 1(c) have been plotted corresponding to their concentrations in Fig. 1(d), and a linear response is observed in the sensor's behaviour. The sensitivity of the sensor has been estimated to be $6.1 \text{ nm}\cdot\text{mM}^{-1}$ from the slope of linear response curve in Fig. 1(d). The other performance parameters such as detection accuracy ($\text{DA}=1/\text{FWHM}$) estimated from Fig. 1(c), and figure of merit ($\text{DA}\times\text{S}$) have been calculated to be 0.014 nm^{-1} and 0.084 mM^{-1} respectively. Fig. 1(e) shows the selectivity test response of the sensor for 10 mM aqueous solutions of other anions: Br^- , Cl^- , and F^- . It is clearly visible that for increasing concentration of CN^- , the λ_{res} value decreases. However, no significant change was observed in case of other anions. Also, real wastewater has been collected as shown in Fig. 1(a). The SPR responses of the wastewater samples was analyzed and found to be in good agreements with the λ_{res} values of standard CN^- samples.

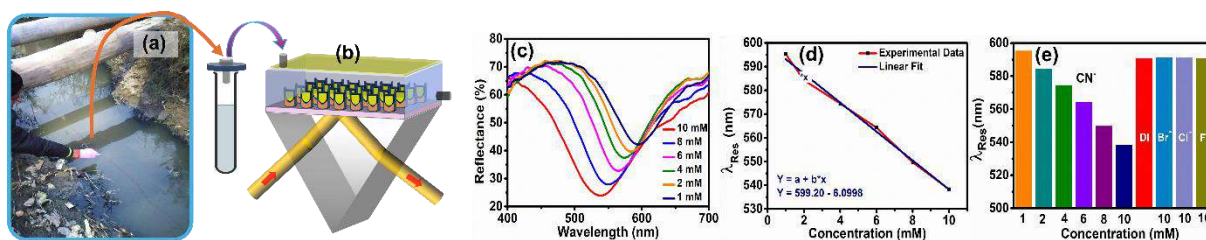


Fig. 1 (a) Wastewater collection (b) schematic of prism-coupled sensing platform (c) SPR spectra for varying concentrations of CN^- (d) corresponding sensors response curve (e) sensors selectivity tests with (Br^- , Cl^- , and F^-)

Conclusions: A prism based highly sensitive and selective SPR sensor was developed using MA-FBP to detect cyanide ions effectively in the wastewater. The S, DA and FOM were estimated to be $6.1 \text{ nm}\cdot\text{mM}^{-1}$, 0.014 nm^{-1} , and 0.084 mM^{-1} , respectively.

Acknowledgement: Funding from MoE-STARS (STARS/APR2019/NS/713), SERB (SRG/2020/ 002518) grants is thankfully acknowledged. Rohit Kumar Vishwakarma thanks MoE and IIT Roorkee for a research fellowship.

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Optical Skyrmion-Enhanced Vector Beam Magnetometry Using Electromagnetically Induced Transparency

Naincy Shrivastava

Indian Institute of Technology Patna, Bihta, Patna 801106, India

Optical skyrmions—topologically protected quasi-particle-like field structures—have recently emerged as a promising platform for precision magnetic sensing and advanced photonic engineering [1,4]. This work presents a comprehensive study of vector beam magnetometry augmented by optical skyrmion beams within the framework of electromagnetically induced transparency (EIT) [2,3]. We review the theoretical foundations of optical skyrmions, including their classification, topological invariants, and generation via paraxial vector beams [4], and highlight their unique spatial-polarization structures [1]. The EIT-based vector magnetometry protocol is analyzed using density matrix formalism [2] to model the interaction of spatially structured beams with atomic ensembles subjected to both static and time-varying magnetic fields. Our results reveal that the absorption spectra encode precise information on the magnetic field's vector components, with the EIT peak amplitude and frequency position being tunable through beam polarization, topology, and field orientation [3]. Experimental and theoretical comparisons demonstrate that integrating optical skyrmion beams enhances spatial resolution, enables multidimensional field mapping, and improves robustness at room temperature compared to conventional schemes. This synergy opens avenues for high-precision sensing, quantum information storage, and topological photonics-based communication systems [1–4].

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Speciality Fiber Interferometric Sensor for Selective Detection of Melamine

Binod Kumar Patra¹, Avijit Kumar² and Rajan Jha¹

¹Nanophotonics and Plasmonics Laboratory, Indian Institute of Technology Bhubaneswar, Odisha 752050, India

²Atoms+ Laboratory, Indian Institute of Technology Bhubaneswar, Odisha 752050, India

Email: *rjha@iitbbs.ac.in

Introduction: The detection of toxic chemicals in food has gained significant research attention in recent years [1]. The adulteration of food items with harmful chemicals is gradually increasing in an uncontrolled manner. Among them, melamine is widely misused in foodstuffs due to its low cost and high nitrogen content, which poses serious health risks when consumed beyond safe limits [2]. Therefore, monitoring of melamine into foodstuffs is very important. Although conventional detection methods are available [3], but they are often bulky, costly, and lack in sensitivity. Thus, there is a strong need for a compact, cost-effective, and sensitive biosensor. This need can be fulfilled by fiber optic interferometry integrated with suitable molecular receptors [4]. Molecular Imprinted Polymer (MIP) is an example of frequently used synthetic molecular receptor, providing highly stable, selective detection facility. Therefore, in this work a biosensor is fabricated using speciality fiber-based interferometry combining MIP for detection of melamine.

Working Principle: The specialty fiber-based interferometer consists of a hybrid SMF-PCF-SMF structure (as shown in Fig. 1(a)) that serves as a fiber transducer. When powered by an SLED source, this setup produces an interference pattern. The detector unit receives this interference pattern, which is produced from the superposition of core and higher-order cladding modes. The intensity of the interference pattern can be expressed using the following relation,

$$I = I_{core} + I_{clad} + 2\sqrt{I_{core}I_{clad}} \cos\left(\frac{2\pi\Delta n_{eff}L}{\lambda}\right) \quad (1)$$

Where, I_{core} and I_{clad} are the spectral intensities of the core and cladding modes in the PCF, and Δn_{eff} denotes the effective RI difference between core and cladding modes.

Results: The sensing probe is characterized through wavelength interrogation method by using the melamine solutions (10^{-9} M - 10^{-3} M) and corresponding interference patterns are recorded in Optical Spectrum Analyzer (OSA) as shown in Fig. 1(a). The calibration curve of the sensor is shown in Fig.1(b), indicating that the shift increases with the concentration of melamine and starts to saturate at higher concentrations of the sample. This saturation occurs due to the presence of a limited number of binding sites on the MIP layer. The sensitivity of this sensor is calculated from the polynomial equation of the curve. The maximum sensitivity of the sensor is 0.1×10^9 nm/M at the lowest concentration (10^{-9} M) of the melamine sample. The selective detection performance of this sensor is analyzed using different analytes with equal concentrations (10^{-3} M). This property has been shown in Fig. 1(c), which confirms that the wavelength shifts produced by the sensor for all these samples shows relatively lower wavelength shift as compared to melamine, thus confirming its selective property.

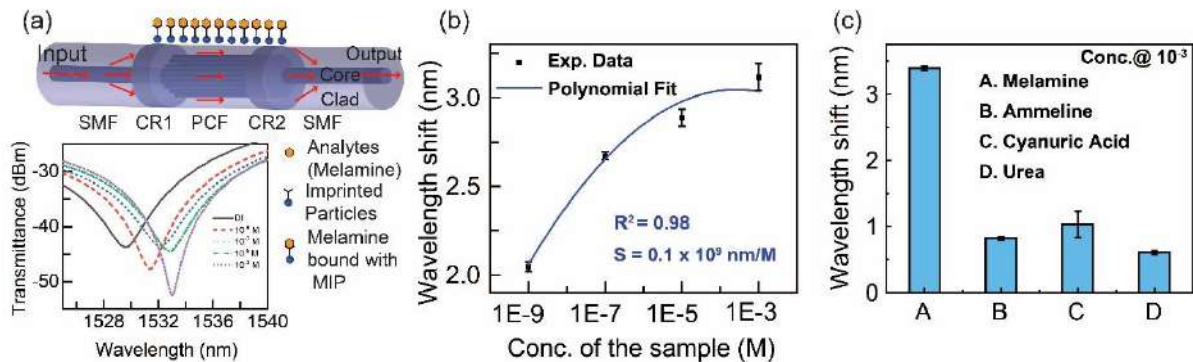


Fig. 1 (a) The schematic illustration of the sensing mechanism of the proposed sensor and corresponding OSA spectra (10^{-9} M - 10^{-3} M) (b) Calibration of the dip-wavelength shift with the concentration of melamine samples. (c) Selectivity performance of the sensor for different compounds with equal concentrations (10^{-3} M).

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Double Hanle resonance dependence on light polarization angle and transverse magnetic field direction

Pooja Kumari¹, Shrey Mehta¹, Raghwinder Singh Grewal¹, R.P. Singh²

¹

School of Arts And Sciences, Ahmedabad University, Navrangpura, Gujarat 380009, India

²Physical Research Laboratory Ahmedabad, Navrangpura, Gujarat 380009, India

In our recent work, we have performed both experimental and theoretical investigations on the dependence of the double Hanle resonance spectrum on the light polarization angle and the direction of the applied transverse magnetic field (TMF) perpendicular to the scanning magnetic field. These studies were performed using a Gaussian beam. In contrast to the traditional ground-state Hanle resonance signal with a single peak or dip at the center, the presence of TMF can create two peaks or dips in the signal through population redistribution among the ground-state sublevels, resulting in a double Hanle resonance spectrum [1]. The experiments were carried out for the $F_g = 2 \rightarrow F_e = 1$ transition of the ^{87}Rb D₁ line using a rubidium vapor cell containing buffer gas. We showed that a small light-polarization component along the direction of TMF introduces asymmetry in the double Hanle resonance signal [2]. Both the magnitude and the sign of asymmetry in the signal are sensitive to the TMF orientation, suggesting a possible method for in situ measurement of the direction of the magnetic fields. The physical origin of this asymmetry is explained by considering the redistribution of population among the ground-state Zeeman sublevels in the presence of TMF. In addition, we systematically varied both the polarization angle and the TMF direction and studied their effect on the line profile of Hanle resonances. We demonstrate that a double Hanle resonance changes to a dark Hanle resonance by rotating the light polarization vector irrespective of the TMF direction. We have developed a simple theoretical model based on a degenerate two-level system to explain our experimental observations.

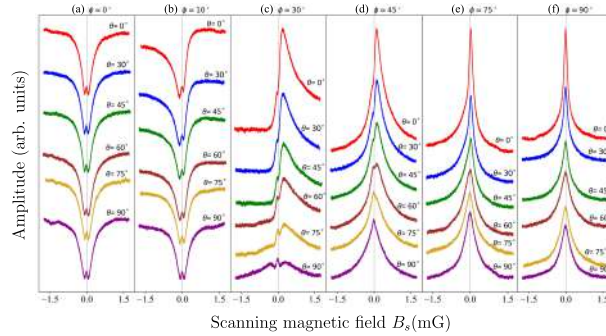


Figure 1: Experimentally measured Hanle resonance spectrum for the light polarization angle ϕ and the TMF angle θ ranging from 0° to 90° .

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Plasmon coupled optical modes of dye doped nematic liquid crystal microresonator

Sumant Pandey, G V Pavan Kumar

Department of Physics, Indian Institute of Science Education and Research Pune, Pune, Maharashtra 411008, India

Nematic liquid crystals exhibit both fluid-like and crystalline properties due to their anisotropic molecular alignment and the presence of topological defects. Liquid crystal micron-size droplets act like a cavity resonator. Their spherical symmetry and refractive index contrast with the surrounding medium enables light propagation to circulate inside a spherical cavity and return to its original position in phase after each round trip, leading to resonances called whispering gallery mode (WGM) [1]. The high-quality resonator and low whispering gallery mode volume enable strong light-matter interactions crucial for ultrasensitive optical detection through low input threshold pumps [2, 3]. Liquid crystal microdroplets are sensitive to changes in temperature, size, and external electric fields, making them pivotal in sensing applications [4]. In our work, we explore the enhanced optical modes of dye doped liquid crystal droplets due to their interaction with plasmonic structures. Microdroplets emit light through optical modes for different pump power. When these microdroplets are coupled with plasmonic nanoparticles an enhancement in the local electric field of the droplet observed. We systematically investigate the influence of various plasmonic structures, including nanospheres and microrods on the WGM mode enhancement, broadening, splitting, and shifting. In conclusion, this research provides an understanding of the optical modes in liquid crystal droplets, offering valuable insights for future innovations in the field of photonics, optoelectronics and sensors.

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High performance SPR detects Colorectal cancer with Au-franckeite and graphene nanoparticles

T.K. Lena Shree¹, R. Sakthi Maheswari¹, Amal M¹, K.B. Rajesh², M.Lavanya^{1*}

¹ Department of Physics, PSGR Krishnammal College for Women, Coimbatore, 641001.

² Department of Physics, Chikkanna Government Arts College, Thiruppur, 641602.

Colorectal cancer ranks as the third most prevalent cancer worldwide and remains a leading cause of cancer-related mortality. Traditional diagnostic techniques, including colonoscopy and CT imaging, primarily depend on tissue biopsy and visual inspection, which often fall short in detecting cancer at early stages due to limited sensitivity. In response to this clinical challenge, we propose an advanced Surface Plasmon Resonance (SPR) sensor designed for early-stage cancer diagnosis at the femto- to attometer scale. The sensor is structured using the Kretschmann configuration, incorporating an SiO₂ prism layered with gold (Au), franckeite—a naturally occurring two-dimensional chalcogenide—and graphene. This multilayer architecture is tailored to exploit the unique optical and electronic properties of each material to maximize sensing performance. Optimization of the sensor's sensitivity, figure of merit (FoM), and detection accuracy is achieved through numerical simulations utilizing the Transfer Matrix Method (TMM) and Finite Element Method (FEM). These computational approaches enable precise tuning of the structural parameters, ensuring enhanced responsiveness to minute refractive index changes associated with early cancer biomarkers. Our findings indicate the potential of this SPR configuration for integration into real-time, high-sensitivity biosensing platforms for colorectal cancer diagnostics.

Keywords: Colorectal cancer, Surface Plasmon Resonance (SPR), Kretschmann configuration, Franckeite, Graphene, FEM, TMM, Early diagnosis

Numerical Analysis of On-chip Leaky Waveguide for Cancer Cell Detection

Akshita Bansal*, Neena Jaggi, Than Singh Saini

*Corresponding email: 28akshitabansal@gmail.com

Department of Physics, National Institute of Technology Kurukshetra, Kurukshetra-136119,
Haryana, India

The need for an early cancer diagnosis is major concern as this disease become the first or second leading cause of casualties worldwide. Optical biosensing is an inventive method for early identification of cancer cells. This work presents a leaky waveguide-based biosensor for identification of two types of cancer cells Basal (skin cancer), and PC-12 (adrenal gland cancer). The proposed biosensor is characterized by a TeO_2 core having a trench on both sides on the SiO_2 substrate so that propagating modes become leaky. The finite element method (FEM) simulates the complex electromagnetic fields for precision modeling in optical waveguides. It has been used to determine the optical characteristics of light under variable refractive indices of cancerous cells, respectively. Applying numerical simulation, spectral variation of confinement loss has been calculated by using the Sellmeier equation in the wavelength range of $1.80\ \mu\text{m}$ to $2.0\ \mu\text{m}$ as shown in Fig. 1 [1]. The absorption fingerprint for most of the biomolecules is offered by the mid-IR spectral range material. The dip occurs for confinement loss at a particular wavelength for normal and cancerous cells when a mode is weakly coupled to the leaky mode. Its foundation is based on detecting variations in the light characteristics due to refractive index fluctuation for normal and suspicious cells that occur near or on the biosensor surface. When optical characteristics change, it affects the interaction of light and the sensing medium, wavelength shift occurs. To estimate the performance of the device, sensitivity and quality factor is calculated [2]. After numerical analysis of results, sensitivity was achieved for skin (Basal) cancer cells of $666.67\ \text{nm}/\text{RIU}$ with a 103.81 quality factor. Adrenal gland (PC-12) cancer cells were achieved sensitivity of $444.44\ \text{nm}/\text{RIU}$ with 97.6 quality factor. The proposed biosensor will open new possibilities for the diagnosis and detection of cancerous cells. This biosensor will open new possibilities for label-free, sensitive, and selective cancer cell detection.

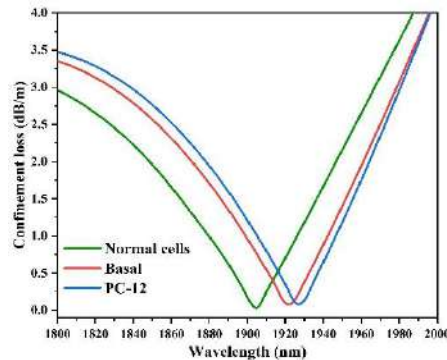


Figure 1. Spectral variation of confinement loss for normal cells and cancer cells in the wavelength range of $1.80\ \mu\text{m}$ to 2.0 .

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GUI Developed for Data Acquisition and Real-Time Display of Cerebral Blood Flow Images in an In-House Developed Small Animal Imaging Platform

Arghya Mondal¹, Reajmina Parvin¹, Ria Paul¹, Soumyajit Sarkar¹, Susweta Das¹, Sanyukta Pandey², Nixon M. Abraham², Hari M. Varma¹

1. Indian Institute of Technology Bombay, Department of Biosciences and Bioengineering, Mumbai, India

2. Indian Institute of Science Education and Research, Department of Biology, Pune, India

We report the development of a modular small animal imaging platform integrated with a robust Graphical User Interface (GUI) for high-resolution cerebral blood flow (CBF) imaging. The platform incorporates both Laser Speckle Contrast Imaging (LSCI) [1, 2] and Multi-speckle Diffuse Correlation Tomography (M-DCT) [1, 3], enabling multi-depth visualization of hemodynamic responses in rodents under intact scalp and skull conditions [1]. The in-house GUI serves as the command hub for all imaging operations—facilitating real-time switching between imaging modes with dynamic ROI selection, live video streaming, and automated multi-exposure acquisition. It integrates galvo-control for programmable raster scans across custom-defined ROIs, facilitating both superficial and deep tissue imaging without manual intervention. The interface also supports automatic time-stamped saving of image sequences, speckle contrast maps, and computed rCBF overlays. Designed with both modularity and scalability in mind, the GUI offers a user-friendly workflow that supports multi-modal experiments, efficient switching between stimulation protocols (olfactory or forepaw) [1, 4], and rapid configuration of scan parameters, demonstrating consistent rCBF activation in expected cortical and olfactory regions across multiple trials [1, 4]. This integrative software control significantly reduces procedural delays, enhances reproducibility, and optimizes the platform for functional neurovascular studies in rodents (rats and mice).

LSCI [2], and M-DCT [3, 5, 6], are used to measure the rCBF images of superficial and deep tissue. M-DCT [3, 5, 6], is the tomography counterpart of camera based high density diffuse correlation spectroscopy system.

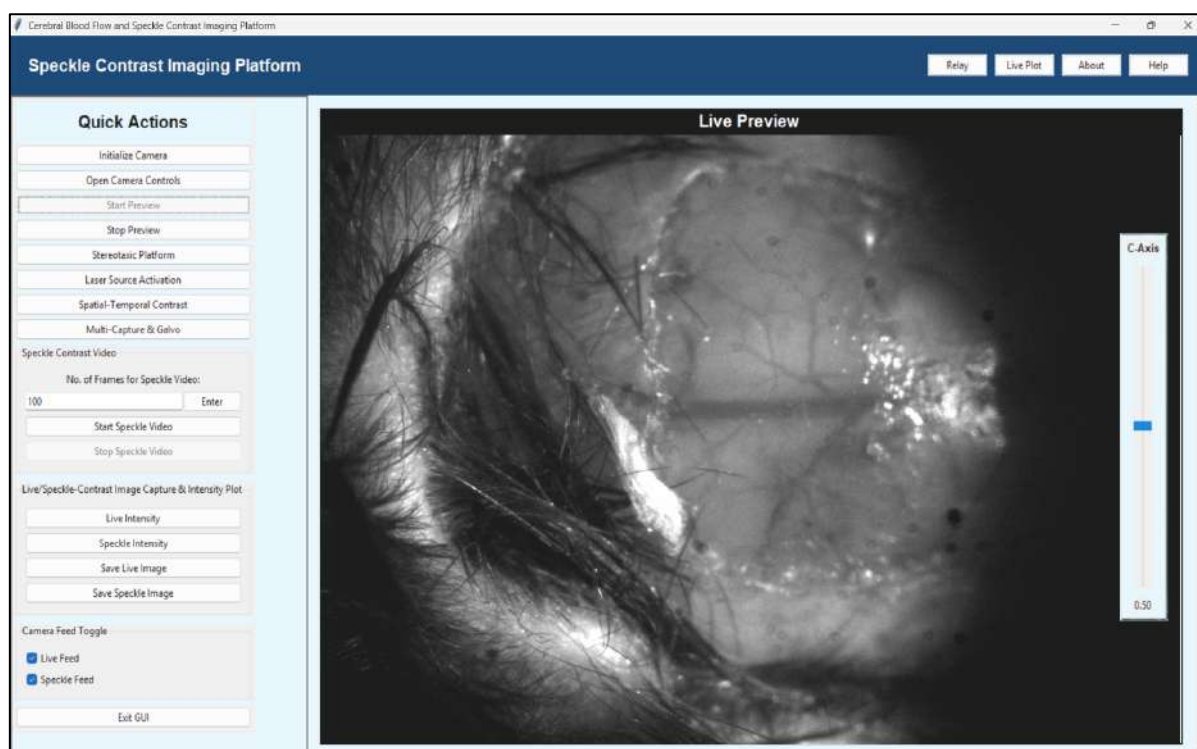


Fig. 1 GUI interface showing live video feed and various controls. The interface includes real-time imaging options, speckle contrast visualization, and customizable scanning parameters.

Figure 1 shows the GUI interface displaying a live image of a mouse brain with the skull removed. The left panel includes controls for camera parameters, a stereotaxic frame for adjusting the brain's height and XY position, as well as Multi-Capture and Galvo features. A live histogram plot is also available. All data acquisition processes can be managed through this GUI.

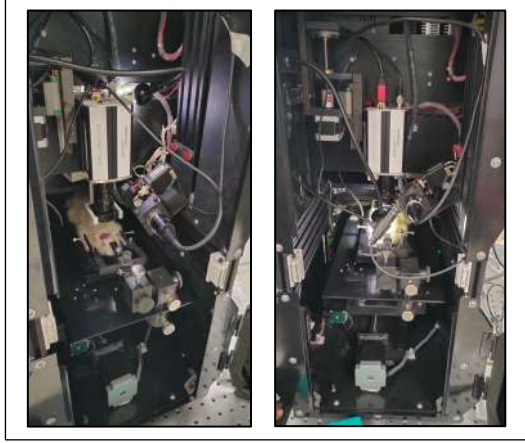


Fig. 2 Modular modular imaging setup showing small animal in stereotaxic frame and optics positioning.

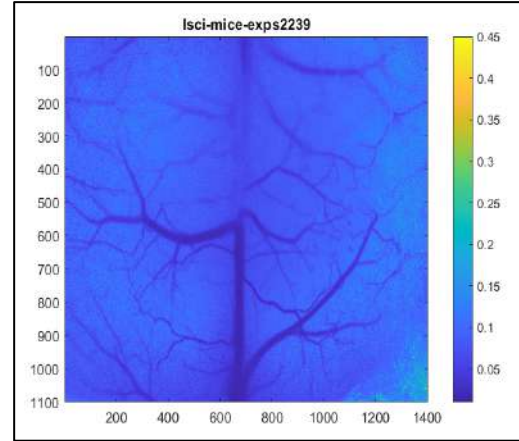


Fig. 3 The rCBF of Somatosensory cortex from LSCI, data is acquired using our GUI at an exposure of 2239 μ s.

Fig. 3 presents the experimental results of rCBF in the somatosensory region of the mouse brain during forepaw stimulation, captured using LSCI. The compact, multi-modular imaging setup enables repeatable imaging sessions and provides enhanced data acquisition control through a user-friendly GUI.

Ethical Approval

The experimental procedures used in this paper are approved by the Institutional Animal Ethics Committee (IAEC) at IISER Pune, and the Committee for the Control and Supervision of Experiments on Animals (CCSEA), Government of India (animal facility CCSEA registration number 1496/GO/ReBi/S/11/CCSEA). The usage of animals in this paper was approved under protocol number IISER-Pune/IAEC/2019-2/04.

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Fluorescence Features in Mung Bean-Derived Carbon Quantum Dots

Kiran John U.¹, Sharon Tomy², Pramod Gopinath¹

1. International School of Photonics, Cochin University of Science and Technology, Kochi, Kerala 682022, India

2. Department of Physics, Sacred Heart College Thevara, Kochi, Kerala 682013, India

Fluorescent carbon quantum dots (CQD) were synthesized by adopting one-step hydrothermal approach using cost-effective and eco-friendly natural precursor mung beans without using any other modifiers [1]. The spectroscopic characteristics of the synthesized carbon quantum dot sample were investigated using various characterization tools such as UV-Visible absorption spectroscopy, Photoluminescence spectroscopy, confocal laser Raman spectroscopy etc.

The carbon quantum dots exhibited absorption edge around 400 nm and sharp absorption in the UV region. The absorption spectrum showed a characteristic peak around 265 nm. The carbon quantum dot sample exhibited bright blue fluorescence under 365 nm UV excitation as given in Fig. 1 (a). Fig. 1 (b) illustrates the photoluminescence emission spectrum obtained under an excitation wavelength of 350 nm. The emission spectrum shows a broad nature and emission maximum centred at 428 nm. The photoluminescence emission for the sample studied by changing the excitation wavelength. The excitation-emission contour where plotted to analyze the intensity variation with excitation wavelength. The effect of concentration of the carbon quantum dot samples on the emission spectrum also studied. The chromaticity features of the sample were studied using CIE chromaticity color diagram.

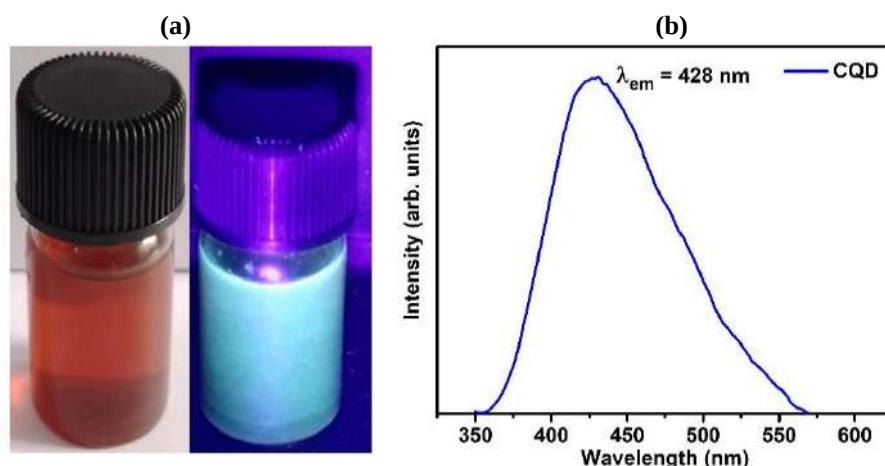


Fig. 1 (a) The carbon quantum dot sample viewed under normal light and 365 nm UV light **(b)** Photoluminescence emission spectra of the carbon quantum dots under an excitation wavelength of 350 nm.

The fluorescence features in the mung bean-derived carbon quantum dots indicates that they are very promising candidates as fluorescent probes for the efficient sensing and bioimaging applications. The fluorescent carbon quantum dot based fluorescent probes are eco-friendly, cost-effective and exhibits low toxicity which are highly recommended in the bioimaging and biosensing fields [2-3].

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Multipartite Entanglement Generation And Quantum Switch Based On Nonlinear Waveguide Arrays

Sugar Singh Meena¹, David Barral², Amit Rai¹

1. Jawaharlal Nehru University, New Delhi, 110067, India

2. Galicia Supercomputing Center (CESGA), Spain

We introduced an approach to generate continuous-variable (CV) multipartite entanglement that incorporates simultaneous nonlinearity and evanescent coupling in the array of $\chi^{(2)}$ -nonlinear waveguides (ANWs). Our technique is conceptually different from those that depend on bulk-optics-based schemes to generate CV-entangled states. The circular geometry of our system is interesting; it has two zero-supermodes that remain squeezed and phase-matched during propagation and improve the number of modes that are entangled compared to the planar ANWs, where only one zero-supermode is phase-matched. Using the properties of these zero-supermodes, we generate large CV-entangled states with application to quantum networks, as shown in Fig. 1.

We further show a source-based quantum switch (entanglement switch) that utilizes pump profile engineering to generate CV-multipartite entangled states locally and share them with the end nodes. We focus on a network with regular topology -- the nonlinear circular array -- where nodes are evenly spaced and connected over the same physical distance, each node having an equal number of physical neighbors. Our protocol creates a continuous distribution (CD) of entanglement, allowing nodes to continuously exchange links among them. Implementing a CD protocol could be a suitable approach to distribute entangled links at a high rate for large quantum networks and to solve routing problems. Physical ingredients, such as propagation eigenmodes, phase-matching, and analytical solutions based on symmetries, enable the generation of large and distributable entangled states within practical systems by going beyond the technical limitations of traditional bulk-optics-inspired schemes. Our protocol stands out for its simplicity and robustness, as the efficient build-up of the propagation eigenmodes is independent of the specific values of coupling and nonlinearity.

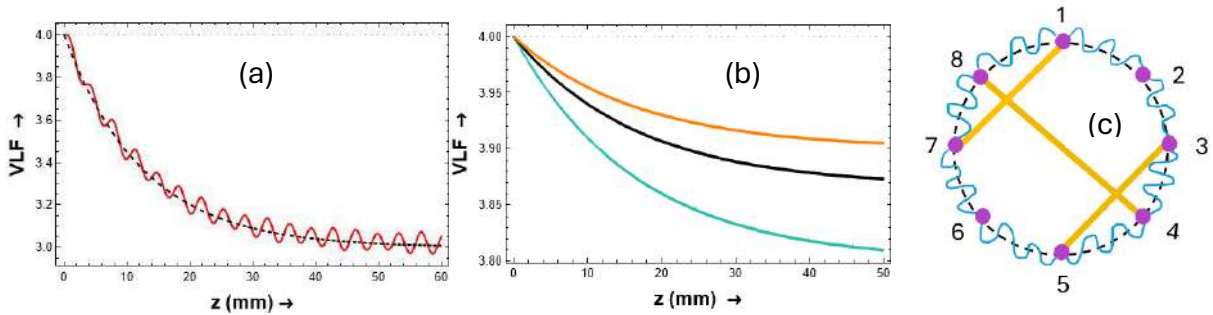


Fig. 1 Multipartite CV entanglement generation in the individual mode basis vs propagation distance (z) for a flat pump profile (all waveguides are pumped with the same power and phase). (a) van Loock-Furusawa inequalities (VLF) for eight waveguides circular ANWs (Red). We have two sets of multipartite entangled modes with identical results, 1-3-5-7 and 2-4-6-8, in the waveguide array with $N = 8$. (b) VLF inequalities for a large number of waveguides: $N = 40$ (Green), $N = 60$ (Black), and $N = 80$ (Orange). Simultaneous values under the threshold value (dotted), $VLF = 4$, imply CV multipartite entanglement. (c) If we pump waveguides with alternate $\pi/2$ phase, the multipartite entanglement present between individual modes 1-3-5-7 switches to bipartite entanglement between modes 1-7, 3-5, and 4-8. In the limits of large coupling, VLF are shown in dashed black. Linear coupling parameter $J = 0.45 \text{ mm}^{-1}$, Nonlinear coupling parameter $\eta = 0.020 \text{ mm}^{-1}$.

Example References

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Axial Structured Illumination Tomography (ASIT): 3D Label-free Phase Imaging technique

Nishant Goyal¹ and Kedar Khare^{1,2}

1. Department of Physics, Indian Institute of Technology Delhi, New Delhi 110016 India

2. Optics and Photonics Centre, Indian Institute of Technology Delhi, New Delhi 110016 India

Holographic Tomography or slice-by-slice 3D phase imaging provides detailed information about the internal structure of transparent specimens. Unlike the regular multi-angled illuminations configuration, originated by Wolf's early treatment [1], that is often linked to stability and calibration issues due to the angled hardware, we present ASIT configuration [2], shown in Fig. 1(a), in which the sample is illuminated using multiple axial randomly phase structured illumination(s) simplifying the system design and making it leaner and more stable. The recorded exit fields using digital holography emerging out from the sample are then used in the iterative sparse optimization framework for slice-by-slice phase or refractive index reconstruction [2]. The forward model is chosen as multi-slice beam propagation (MSBP) that is suitable for thicker samples that incorporates multiple scattering effects. In addition, we propose a design curve, shown in Fig. 1(b), to predict when the sparsity effectively removes crosstalk between the slices for true 3D reconstruction.

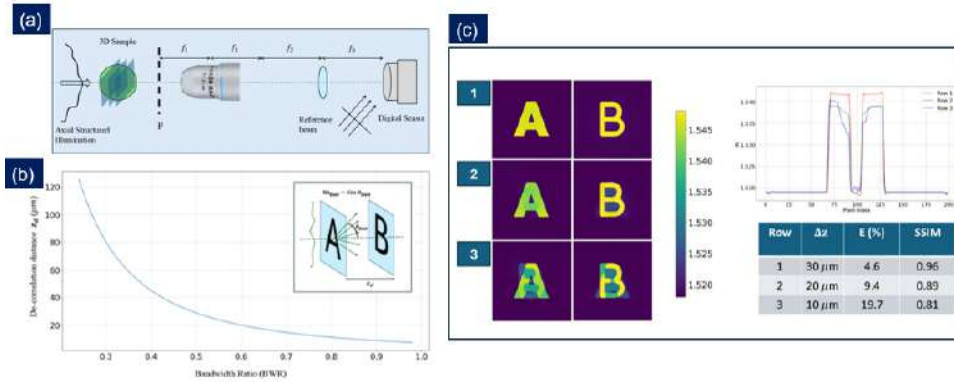


Fig. 1 (a) Schematic setup of the ASIT configuration, (b) Design curve based on bandwidth ratio of the exit field from typical slice, and (c) refractive index reconstruction results of 2-slice object with 3 interslice distances between them.

The design curve demonstrates what is the nominal inter-slice distance (also known as de-correlation distance) required based on the bandwidth ratio (BWR) of the exit-field emerging out of a typical slice of the 3D object under consideration. The de-correlation distance follows relation, $z_d \sim \lambda/(NA_{BWR})^2$, after which the field from first slice is expected to be adequately de-correlated with itself due to Fresnel propagation till the next slice and NA_{BWR} corresponds to the structural complexity of the exit wave for a given axial structured illumination. The sparsity penalty such as 3D TV in the reconstruction suitably mitigates the crosstalk between the slices when the interslice distance ensures a sufficient decorrelation and hence providing a true 3D phase or refractive index information. In Fig. 1(c), we show typical results of slice-by-slice reconstruction using single axial structured illumination with BWR = 0.6 corresponding to $z_d \sim 20 \mu\text{m}$. The reconstructions for the three inter-slice distances are shown where larger distance (than predicted z_d) promotes crosstalk free high-quality reconstruction. Furthermore, multiple slice problem can also be solved using the design curve and the reconstruction framework in ASIT configuration that may require more than one illumination as described well in [2]. We emphasize that for a given tomographic configuration and nature of 3D object, a combination of both the design curve and sparsity penalty is important in designing an ASIT system. An ASIT configuration can be retrofitted in the standard digital holographic microscopic (DHM) systems in regular labs with marginal changes and a simple and leaner coherent tomography system can be achieved that provides crosstalk free high-quality slice-by-slice phase or refractive index reconstruction of transparent biological specimens. In future work, we will provide preliminary experimental results on ASIT methodology.

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Aggregation Induced Emission Studies and Thermo-optical Properties of Carbazole diethyl thiobarbituric acid Conjugates

Devika Raja¹, Lakshmi R¹, Meema Rasheed², Narayanapillai Manoj², Pramod Gopinath^{1*}

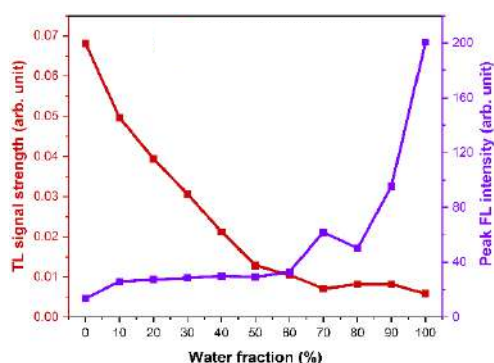
1. International School of Photonics, Cochin University of Science and Technology, Kochi-682022, Kerala, India

2. Department of Applied Chemistry, Cochin University of Science and Technology, Kochi-682022, Kerala, India

*E-mail: pramod@cusat.ac.in

Aggregation Caused Quenching (ACQ) is a classic phenomenon which restricts the use of majority of conventional luminophores with their full potential. But Aggregation Induced Emission (AIE), a complete contrary to this mechanism turns aggregation into a positive process by making non-emissive luminogens emissive as they aggregate. Because of their unique twisted structures, AIE dyes prevent π - π stacking when they aggregate. The primary mechanism underlying this phenomenon is Restriction of Intramolecular Motion (RIM). By restricting intramolecular vibrations and rotations non-radiative decay processes are reduced [1-3].

Here, we have studied the photophysical properties of different alkyl chain lengths of Carbazole diethyl thiobarbituric acid (CzTBA) D- π -A system. The AIE effect upon aggregation was studied using UV-Vis absorption spectroscopy, steady state and time resolved fluorescence spectroscopy by varying the water to THF binary solvent ratios. Aggregate size was determined using DLS measurements and morphological changes upon aggregation has observed. We have examined the role of hydrophobic interaction in AIE effect by varying the alkyl chain length. We have also investigated the variation in radiative and non-radiative decays on aggregation using dual beam thermal lens technique. The influence of hydrophobic interaction in thermal lens signal while changing alkyl chain length was also observed.



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Palladium Coated Gold Triangular Nanoprism U-bent Fiber Probes for Hydrogen Detection

Payel Ghosh¹, Akanksha Sharma², VV Raghavendra Sai³, Arup Lal Chakraborty¹, Saumyakanti Khatua²

1. Department of Electrical Engineering, Indian Institute of Technology Gandhinagar, Gujarat 382055, India

2. Department of Chemistry, Indian Institute of Technology Gandhinagar, Gujarat 382055, India

3. Department of Applied Mechanics and Biomedical Engineering, IIT Madras, Chennai-600 036, India

In the current shift towards clean and sustainable fuels, hydrogen production research has taken an enormous leap. With the advantage of producing limited emissions, hydrogen also comes with high flammability and potential for explosions. This calls for implementing robust detection systems and protocols for detecting hydrogen leakage for safety in hydrogen production, storage, and transportation [1]. In this study, we present u-bent optical fiber probes decorated with palladium (Pd)-coated gold triangular nanoprisms that can be easily installed to detect hydrogen, by monitoring the spectral shift of the nanoprisms due to hydrogen adsorption.

The u-bent optical fiber probe is first coated with chemically synthesized gold triangular nanoprism (AuTNP) as reported elsewhere [2]. Then the probe was stabilized in water after UV-ozone treatment and immersed in 10 mM Chloropalladic acid solution with 10 mM Ascorbic acid for 1 h to deposit palladium (Pd) on the AuTNP. The spectral red shift from 738 nm to 749 nm observed (Fig 1(a)) indicates Pd deposition on AuTNP, which was further confirmed with STEM mapping (Fig 1(b)) of AuTNP deposited TEM grid replicating the same procedure as on the AuTNP probe. Once the Pd deposition was complete, the probe was installed in a double-neck flask and connected to a broadband source and spectrometer for in situ spectra monitoring as hydrogen was injected into the flask using a balloon.

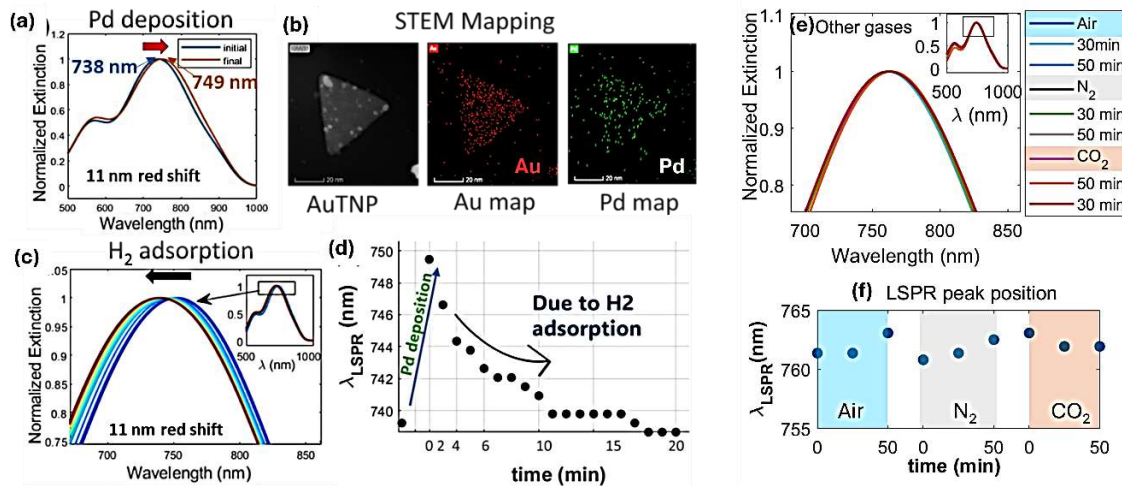


Fig. 1 (a) AuTNP probe spectra before and after Pd deposition, (b) Au and Pd mapping on a AuTNP after Pd deposition, (c) Probe spectra blue shifting due to hydrogen adsorption (inset shows the complete normalized spectra), (d) Spectral peak positions showing redshift upon Pd deposition and blue shift on hydrogen adsorption. (e) Pd-deposited AuTNP probe spectra in air, nitrogen, and carbon dioxide over time. (f) Localized surface plasmon resonance (LSPR) peak position showing negligible spectral shift (2nm) as compared to the 15 nm blueshift in Hydrogen, in all the cases.

With high concentration Hydrogen injection, we immediately observed spectral blue shift for 10 minutes before saturation with the peak shifting from 749 nm to 740 nm (Fig 1(c,d)). We noted the LSPR spectral positions for 20 minutes and observed only a 1 nm blue shift after 15 minutes (Fig 1(d)). We observed negligible spectral shift in air, nitrogen and carbon dioxide (Fig 1(e, f)). The spectral blue shift observed specific to hydrogen can be utilized to develop an alarm-based system to warn of hydrogen leakage in any suspected region. Moreover, probe sensor being completely fiber coupled is robust, compact, and can easily be installed in the field and monitored remotely. Preliminary results demonstrated the concept and concentration-based quantification and calibrations are to be done for translating into commercial hydrogen leakage detection device.

I acknowledge Dr Gaytri Joshi for AuTNP Synthesis and Mayank Dotial and CIF instruments IIT Gandhinagar for STEM mapping.

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Design and development of polarizing cubic beam splitter for 532nm laser

A S Upadhyaya, Anil Kumar, Suman Awasthi, L M Pant

IRDE, Raipur, Dehradun - 248008
asu.irde@gov.in

A polarizing beam splitter is an optical device that separates s and p polarization component of an unpolarized light into two perpendicular directions. In this reported work we have designed and developed polarizing cube beam splitter for 532nm laser wavelength. SF14 optical glass with refractive index 1.74 has been taken as substrate and prisms of very high angular accuracies were fabricated for cube formation.

For designing polarization sensitive coating at wavelength of interest, Macleod optical coating design software was used. The 9 layer design was synthesized using SiO_2 and Ta_2O_5 coating spices and finally refined by simplex refinement method. The two faces of cube were AR coated at 532nm at normal incidence while hypotenuse of one of the prism was designed for polarization sensitive coating with an incidence angle of 45° . The design has been depicted in fig. 1 and theoretical performance of the design is shown in fig. 2.

Beam splitter was fabricated by physical vapour deposition in a high vacuum coating plant with EBG source.

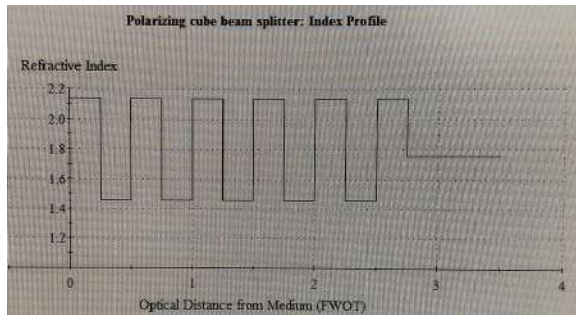


Fig.1 Index profile of polarizing beam splitter

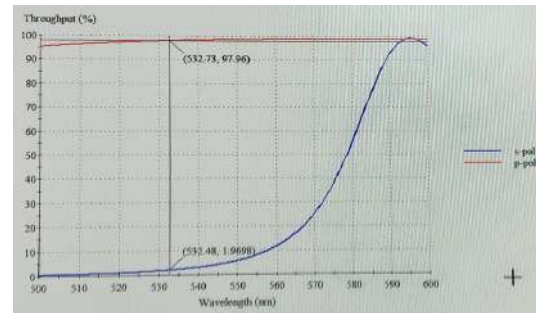


Fig. 2 Transmission characteristics of designed coating

The glass substrate was held in a dome shape substrate callot, which rotates on its axis ensuring thickness uniformity of deposited thin film. The chamber has been evacuated initially to a pressure of 1×10^{-6} mbar. Pre heating of the chamber was done by raising the temperature to 250°C to remove the water vapours in the high vacuum chamber. At this elevated temperature oxide materials were evaporated using EBG as per optimized process parameters as shown in table 1.

Table 1.- Process parameters of deposition

S. No.	Material	Pressure	Substrate Temp ($^\circ\text{C}$)	Deposition Rate ($\text{\AA}/\text{s}$)
1	SiO_2	2×10^{-4}	250	5.0
2	Ta_2O_5	3×10^{-4}	250	2.5
3	HfO_2	2×10^{-4}	250	2.0

Result and Discussion:

A setup was crafted to measure throughput of cemented cubic beam splitter at 532 nm wavelength for both s and p polarized components. 96.0 % and 97.0% throughput is achieved for s and p components respectively in orthogonal directions. The coating is environmental stable as per MIL-C-48497.

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Fluorescence and random lasing studies in Core shell $\text{Fe}_2\text{O}_3@\text{TiO}_2$ Nanoparticles dispersed Rhodamine- B solution

Aneesh Ayyappan¹, Ashok Vudayagiri¹

¹. School of Physics, University of Hyderabad, Gachibowli, Telangana, India-500046

We investigate the regulation of random lasing and fluorescence in Rhodamine-B dye solutions using $\text{Fe}_2\text{O}_3@\text{TiO}_2$ core-shell magnetic nanoparticles (MNPs) as scattering centers[1]. Samples were characterized via field emission scanning electron microscopy and UV-Vis absorption spectroscopy. Random lasing was excited by the 532 nm second harmonic of an Nd:YAG laser, and emission spectra were recorded for various MNP concentrations. The 10^{-4} M sample exhibited maximum emission intensity, indicating optimal scattering for enhanced lasing. Measurements performed under magnetic fields from 0 to 100 Gauss revealed that the TiO_2 shell enhanced scattering efficiency and fluorescence[2]. Furthermore, a magnetic-field-induced shift in the emission spectra demonstrated the tunability of the system's optical properties[3].

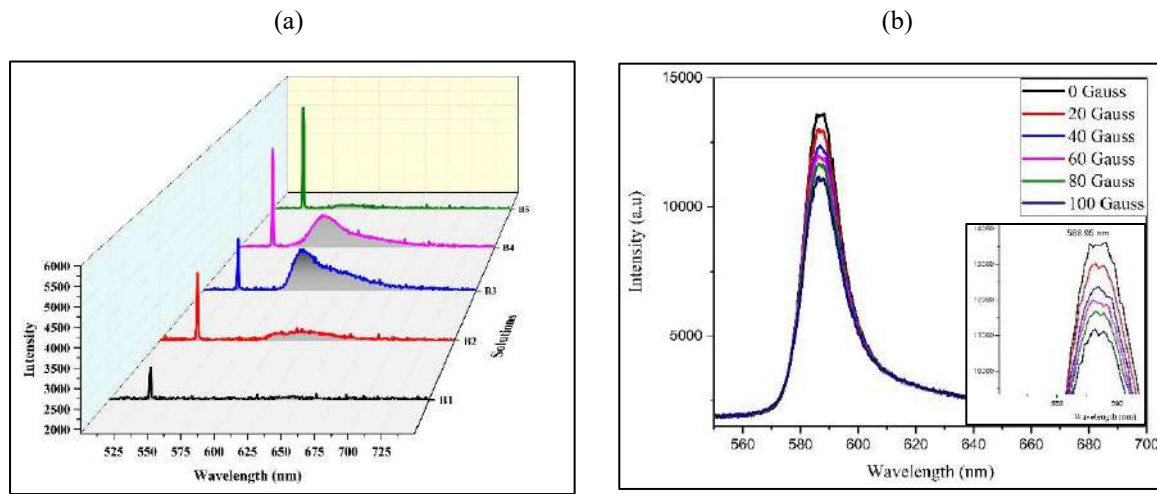


Fig. 1 a) Emission spectra of Rhodamine-B dissolved in B1- 10^{-6} M, B2- 10^{-5} M, B3- 10^{-4} M, B4- 10^{-3} M, B5- 10^{-2} M b) Emission spectra of $\text{Fe}_2\text{O}_3@\text{TiO}_2$ 10^{-3} M at (0-100 Gauss) magnetic field

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Fast evaluation of wavefront errors in multi-layered samples using the discrete Fourier transforms

Paresh Kumar Sahoo¹, Vyas Akondi²

Department of Physical Sciences, Indian Institute of Science Education and Research (IISER) Berhampur, Berhampur, Odisha 760003, India

Adaptive optics has become a vital tool to improve optical resolution in optical microscopy and ophthalmoscopy. In these applications, multiple layers of the samples, such as thick biological tissues or retinas, reflect light with varying reflectivity values. Such multiply reflecting samples induce artifactual errors in Shack-Hartmann (SH), which is the most widely used wavefront sensor (WS) in adaptive optics[1]. Prediction of these errors through simulations is useful to explore methods to mitigate them. Here, we used a fast method to evaluate SHWS images using the discrete Fourier transforms (DFT) while accounting for SHWS lenslet focal shift, achieving both speed and accuracy.

The Shack-Hartmann wavefront sensors (SHWSs) are widely used in astronomy, ophthalmoscopy, microscopy, free-space communications, and underwater imaging. Multiple layers are seen in samples such as ophthalmoscopic retinas, thick biological tissues in microscopy, and the sodium vapor layer in the atmosphere[2], [3]. Reflections from these multiple layers cause artifactual errors in SHWS images. In a previous work[1], it was shown that by using traditional integral calculation along with a larger centroiding box to capture the intensity from a dual-layer human and mouse retina, it is possible to evaluate SHWS images with lower artifactual errors. However, using traditional integral calculation to evaluate SHWS is computationally intensive even for dual-layer samples. In this work, we developed a rapid method to evaluate SHWS images using the discrete Fourier transforms (DFT), allowing us to simulate multiple layers. Our proposed DFT method accounts for the low Fresnel number of the SHWS lenslets, which is a critical factor in SHWS imaging. The DFT method increases the speed of simulation of SHWS images by over two orders of magnitude, enabling us to simulate samples having more than two layers with substantially reduced computational time while preserving greater accuracy compared to traditional integral calculation. With the DFT method, we first simulate a dual-layer human retina and later extend our model to simulate a 75-layer sample. The reflectivity values were obtained from the literature[4]. The centroid error between 1 Airy Disk Diameter (ADD) and the optimal centroiding box is illustrated in the figure shown below for 75-layer and 2-layer layers using DFT-based simulation. Additionally, a comparison of the intensity line profiles for the dual and 75-layer samples is presented.

It is found that, for the lenslet coordinate $(-12,0)$ with full circular illumination, DFT analysis shows that a 75-layer sample yields a centroid error of 0.0783 ADD units between a 1ADD and the optimal search box, whereas a dual-layer sample with a reflectivity ratio of 1:10 yields an error of 0.0188 ADD units.

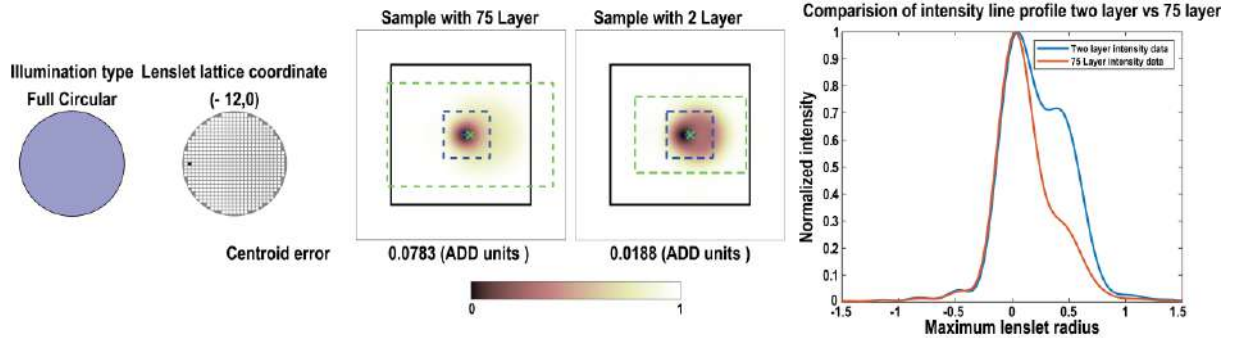


Fig. 1: DFT-based simulation of SHWS images for the lenslet lattice coordinate $(-12,0)$ with a full circular illumination pupil, for a sample with 75 layers and 2 layers. The centroid error between 1ADD and the optimal search box is calculated for both samples. A comparison of the intensity line profile for a 75-layer and a two-layer sample is also shown.

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Bend-Compensated Large Mode Area Fiber Designs for Single-Mode High-Power Laser Applications

Soorej Thekkeyil, and Deepak Jain

Optics and Photonics Centre, Indian Institute of Technology Delhi, New Delhi, India

Fiber lasers have emerged as a prominent technology in various high-power applications such as material processing, directed energy systems, particle accelerators, and nuclear fusion etc., due to their exceptional beam quality, efficiency, and scalability [1]. However, the further power scaling of fiber laser systems is constrained by several undesirable non-linear effects, including Stimulated Raman Scattering (SRS), Self-Phase Modulation (SPM), and Stimulated Brillouin Scattering (SBS). These effects become increasingly prominent as power levels rise in fiber's core, leading to performance degradation and modal instabilities. To mitigate these limitations, large-core diameter fibers that provide a large effective area (A_{eff}) for the fundamental mode (FM) are typically employed. A larger A_{eff} in optical fibers directly helps in reducing power density (intensity) for a given optical power, which effectively raises the total power handling. However, ensuring an effective single-mode (ESM) operation in such large-diameter multimode fibers is challenging, as higher-order modes (HOMs) tend to contribute to transverse modal instability (TMI), particularly at elevated power levels. On the other hand, rod-type fibers provide an A_{eff} exceeding $5000 \mu\text{m}^2$ for high-power extraction. However, their inability to coil and their length of 1-2 m restricts the laser system's compactness and thermal management. Therefore, advanced fiber designs with largest A_{eff} and high-loss HOM suppression are critical for achieving stable high-power performance.

In this paper, we present the results of our bend-compensated ARC, Triangular, and Multi-Trench Fiber designs that significantly scale the A_{eff} , achieving values more than $5000 \mu\text{m}^2$ while maintaining low FM loss ($<0.1 \text{ dB/m}$) and high HOM suppression ($>10 \text{ dB/m}$). The bend-compensated fiber design essentially has a negative tilt in the inner cladding to couple out the unwanted HOMs at the specific coil diameters [2]. Effective bend-induced refractive index of the fiber is calculated by applying the conformal mapping equation to the index of straight fiber. All simulations are done in the FEM based COMSOL Multiphysics software. This work explores the influence of key parameters, including the refractive index profile of core (Δn_{core}) and cladding (Δn_{clad}), and solving the trade-off between modal area and coilability. We have also investigated the impact of imperfections during the fiber fabrication process by incorporating ripples with an order of 10^{-4} . A more detailed study on the power overlap fraction within the core and its discrimination in this fiber is done in [3]. These significant discriminations ensure the FM dominates, operates effectively in a single-mode, and the delocalisation of HOMs inside the fiber core. This fiber can effectively address both modal instabilities and nonlinear effects at high-power levels.

Our studies show that these bend-compensated fiber designs can push high-power fiber laser systems to create more resilient and scalable solutions for demanding applications. Additionally, longer fibers provide an extended surface area for heat dissipation. Further optimisation opportunities include doping strategies on material composition. Specifically, Al_2O_3 doping in the core has been found to decrease the acoustic refractive index and thereby reduce the spatial overlap between optical and acoustic modes [5], which will effectively increase SBS threshold, allowing for higher power propagation and narrower linewidth laser operation. Table. 1 summarises the maximum effective area and required bend diameter for various classes of our bend-compensated fiber designs.

Fiber Class	Key Structure	Maximum A_{eff}	Bend Diameter
ARC Fiber [3]	Parabolic-index core	$\sim 5100 \mu\text{m}^2$	$\sim 100 \text{ cm}$
Triangular Fiber [4]	Triangle-index core	$\sim 3500 \mu\text{m}^2$	$\sim 30 \text{ cm}$
Triangular Multi-Trench Fiber [4]	Multiple trenches cladding	$\sim 4050 \mu\text{m}^2$	$\sim 57 \text{ cm}$

Table. 1 The maximum effective area and bend diameter comparison between different bend-compensated fiber designs.

We have achieved an ESM operation with an effective area of up to $5000 \mu\text{m}^2$ in a coiling configuration employing bend-compensated low-NA fibers which are comparable with the rod-type fiber performances. These fabrication-ready fiber designs have a cylindrical symmetric and all-solid structure, which offers suitability for mass-scale fabrication, decreased complexity for fiber handling and can be used in any orientation of bend while coiling. A longer fiber length is advantageous for the management of heat in comparison to rod-type fibers, and it is particularly beneficial for the production of high-power outputs in multi-kW class fiber laser systems.

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Controlled Vortex–Antivortex Lattice Melting through Core Size and Spacing

Rajneesh Fulara¹, Vishwa Pal¹

Department of Physics, Indian Institute of Technology Ropar, Rupnagar, Punjab, 140001, India

Vortex–antivortex (VAV) lattices are structured optical fields in which vortices of opposite topological charge are arranged in periodic patterns [1]. Such configurations have potential applications in higher dimensional information processing, multiparticle manipulations, optical communications, and fundamental studies in physics [2–4]. While the formation and free-space propagation of VAV lattices have been studied, their stability and melting dynamics are far less explored. In particular, because vortices of opposite charge tend to annihilate and the annihilation depends on the amplitude shape of vortex and separation between them [5], understanding the role of these parameters on melting of lattice is crucial for achieving better control and enabling practical applications.

In this work, we investigated the melting dynamics of a square 7×7 VAV lattice embedded in a Gaussian beam, focusing on the influence of lattice spacing and vortex core size. The vortices are modelled with tanh type cores, whose size and shape are controlled by the parameters of the tanh function. For small cores above a particular separation, the lattice remains stable over long propagation distances (Fig.1(a)). As the core size increases or the separation decreases, melting initiates at the outer layer and progresses inward (Fig. 1(b)). For sufficiently large cores and small separation, annihilation occurs through optical vortex turbulence, where numerous transient vortex–antivortex pairs form, destabilizing the phase before it gradually re-stabilizes from the edges inward (Fig. 1(c)). These results identify three distinct dynamical regimes, governed by vortex core size and lattice spacing.

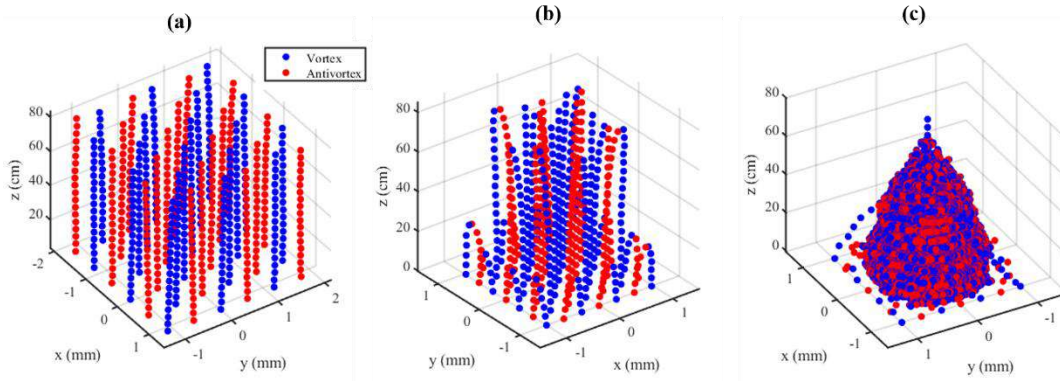


Fig. 1 Fig. 1 — Vortex–antivortex (VAV) lattice dynamics in different regimes of the parameter space. (a) **Stable regime** – lattice structure and vortex number remain unchanged during propagation. (b) **Layer-wise melting** – annihilation begins at the outer layers and progresses inward. (c) **Turbulent melting** – rapid creation and annihilation of multiple VAV pairs, leading to transient disorder before gradual re-stabilization

Our results demonstrate that the stability and melting of VAV lattices are strongly governed by their amplitude structure and lattice spacing. By tuning the vortex core size, we can access different melting pathways. These findings are relevant for controlling vortex lattices in optical systems and may serve as optical analogues for simulating ionic crystals, superfluid vortices, and Bose–Einstein condensate lattices.

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Abstract:

In this work, we investigate the controlled melting of optical vortex–antivortex (VAV) lattices by tailoring their amplitude core structure and lattice spacing. A square 7×7 VAV lattice embedded in a Gaussian beam is modelled using tanh-type vortex cores with tunable size. By varying core size and lattice spacing, we identify three distinct dynamical regimes during free-space propagation: (i) stable lattices with unchanged vortex arrangement, (ii) layer-wise melting starting from the edges, and (iii) turbulent melting with rapid creation–annihilation of transient pairs. These results demonstrate that amplitude engineering enables precise control of lattice stability, offering insights for optical analogues of crystal melting and vortex dynamics in superfluids and BECs.

Imaging Beyond the Working Distance of Microscope Objectives

Dinesh Saini¹, Manish Kumar²

¹. Optics and Photonics Centre, Indian Institute of Technology Delhi, New Delhi 110016, India

². Centre for Sensors, Instrumentation and Cyber Physical System Engineering, Indian Institute of Technology Delhi, New Delhi -110016.

Corresponding author: ²kmanish@iitd.ac.in, ¹dineshsaini00786@gmail.com

Microscope objectives are designed to follow the sine condition to provide a large field-of-view (fov) in the lateral direction. The plane lying at the working distance of the objective is imaged without any aberrations. In case of thick samples, sometimes the plane of interest lies beyond the working distance (WD) of the objective due to the thickness constraint. This can be avoided by using expensive long WD objectives. One way of imaging an offset plane, beyond the working distance, requires shifting the imaging plane by a distance proportional to the axial magnification of the conventional microscopy system (as shown in Fig. 1-a). However, this introduces spherical aberration, which remains diffraction-limited for lower NA objectives but becomes higher for high NA objectives.

In this paper, we use the concept of remote focusing (RF) to image an offset plane beyond the WD of a 10x microscope objective and compare it with the traditional method. RF microscopy system (shown in Fig. 1-b) can nullify spherical aberration introduced from offset planes [1-3]. So, we use this system to image a sample plane beyond WD (offset = 0.7 mm). We simulated both the traditional and the RF microscopy systems in *Ansys OpticStudio*. For simulation, we used a 10x objective (TL10X-2P, Thorlabs, blackbox file) having a WD of 7.7 mm and a fov of 2.4 mm (radius = 1.2 mm). For the tube lens, we used 200mm focal length lens (TTL200-A, Thorlabs). We simulated the image formation of a 1-D grating of period 2 μm placed at two different planes - native WD plane ($z = 0.0$ mm) and an offset plane ($z = 0.7$ mm). Figure 1-c shows a cropped portion of simulated image centred at 0.4 mm field point. We also calculated spherical aberration for both the planes (Fig 1-d), for traditional (TM) and RF microscopy (RFM) systems.

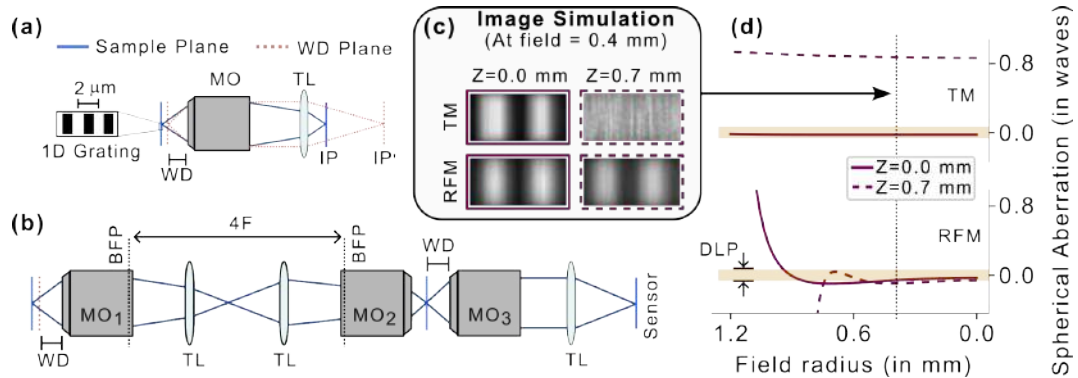


Fig. 1 Traditional Microscopy (TM) vs. Remote Focusing Microscopy (RFM) for imaging a plane beyond WD (a), Schematic of traditional microscopy system. For sample placed at WD ($z = 0.0$ mm), the dotted line shows image formation at plane IP' whereas the solid line shows shift in image plane at IP due to sample placed at offset plane ($z = 0.7$ mm). (b), Schematic of RF microscopy system. The back focal plane (BFP) of MO1 and MO2 are matched with 4F system formed by pair of tube lens TL, and together all of them constitutes RF unit. A third objective MO3 forms magnified image of offset sample plane. (c), Cropped region of simulated image of 1D grating centred at field = 0.4 mm. (d), Spherical aberration across fov for TM (a) and RFM (b) at both planes. Shaded region shows bound for diffraction-limited performance (DLP). Vertical dashed line marks the position of field wrt aberration at which image simulation in (c) was carried out.

The simulated image (Fig. 1-c) shows better performance of RFM. In RFM, for half of the native fov, the spherical aberration remains within the diffraction-limited region (DLP). Beyond this, the aberration increases sharply. In conclusion, we have shown aberration-free imaging in a 0.7 mm offset plane. This is around 10% increase in effective working distance at the cost of 50% loss in fov. This method is not limited to 10x objectives, and it can be easily extended to long WD objectives [4] to obtain ultra long working distance microscopy.

Acknowledgement: We thank IIT Delhi and ANRF for supporting and funding this research.

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Evolution of Squeezed Vacuum in Disordered and Next-Nearest-Neighbor Coupled Waveguide Arrays

Sunita Meena, Amit Rai

Jawaharlal Nehru University, New Delhi, 110067.

Squeezed states enable us to reduce quantum noise, suppressing uncertainty in one field quadrature while expanding it in its conjugate, exactly as the Heisenberg uncertainty principle allows [1]. Preserving such nonclassical states over integrated platforms requires controlling their evolution in realistic environments where fabrication imperfections introduce disorder. In our model [Fig. 1(a)], we investigate the combined role of Next-Nearest-Neighbor coupling (NNNC) and disorders- both On-Site Disorder (OSD) and Hopping Disorder (HoD).

$$i \frac{\partial \hat{a}_j}{\partial z} = (\epsilon_1)_j \hat{a}_j + \sum_{\delta=\pm 1} (J + (\epsilon_2)_{j,j+\delta}) \hat{a}_{j+\delta} + \sum_{\delta=\pm 2} (\alpha J + (\epsilon_3)_{j,j+\delta}) \hat{a}_{j+\delta}$$

here J and αJ is nearest-neighbour-coupling (NNC) and NNNC strengths respectively. ϵ_1 , ϵ_2 , and ϵ_3 are OSD, nearest-neighbor HoD, and next-nearest-neighbor HoD respectively. Above equation of motion is solved via the Green-function propagator formalism [2] to obtain mode evolution and the squeezing factor (SF) in the generalized ϕ -rotated quadrature [3], while $J = 1$, squeezing parameter (r) ≈ 0.89 throughout the article.

For a minimal three-waveguide system, NNNC alone produces periodic squeezing revivals and complete $Q \leftrightarrow P$ quadrature swapping [Fig. 1(b), $j=1$] while $\alpha=0.36$ is accessible and yield constructive interference of supermodes, facilitating on-chip quadrature control.

In extended arrays ($N=45$), even modest NNNC ($\alpha=0.36$) localizes noise near the input site, enhances revival patterns, and enables sustained quadrature swapping. OSD in extended array localize the noise to few modes and degrade the squeezing [Fig. 1(c), $j=23$, $SF(Q)$, $\alpha=0.36$]. On contrast HoD induces non-uniform distribution of noise and quadrature swapping [Fig. 1(d), $j=23$, $SF(P)$, $\alpha=0.36$]. NNNC mitigates OSD-induced loss by dynamically separating minimal SF from original quadrature, suggesting design routes for disorder-resilient quantum photonic links.

Our results establish NNNC- disorder interplay as a tunable mechanism for squeezing management, offering a pathway toward reconfigurable, noise-resilient integrated quantum photonic networks. Disorder studies reveal that OSD induces noise localization and degrades squeezing while HoD and NNNC enable within-quadrature noise transfer and minimal-SF splitting, offering partial squeezing preservation.

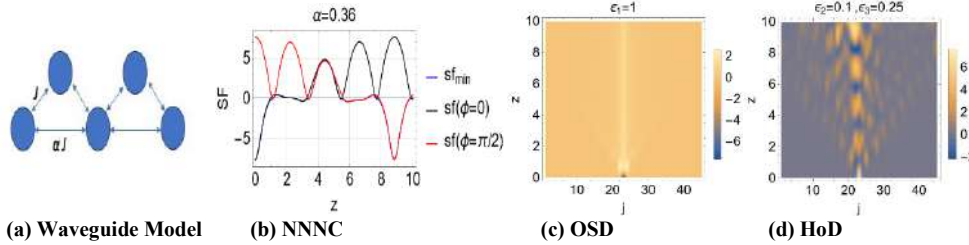


Fig. 1 (a) Waveguide model (b) Squeezing factor with distance for three waveguide case, here $\phi=0[\pi/2]$ is Q[P] (c) Density plot $j=23$, $SF(Q)$, $\alpha=0.36$, $\epsilon_1 = 1$ (d) Density plot $j=23$, $SF(P)$, $\alpha=0.36$, $\epsilon_2 = 0.1$, $\epsilon_3 = 0.25$

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Non-recursive approach of phase retrieval for TEM images using transport of intensity and phase equations

Ram Kumar, Shilpa Kanjilal, and Naveen K. Nishchal*

Department of Physics, Indian Institute of Technology Patna, Bihta, Patna 801106, India

* nkn@iitp.ac.in

Direct phase retrieval from measured intensities is enabled by the transport of intensity equation (TIE) [1] and the transport of phase equation (TPE) [2] are given as Eqs. (1) and (2), both derived from the paraxial Helmholtz equation. In practice, the TIE is solved numerically using intensity derivatives estimated via finite differences. Among various approaches, the fast Fourier transform (FFT)-based TIE (FFT-TIE) method is preferred for its speed and accuracy [3,4] but it assumes uniform intensity in the focused plane an assumption often violated, causing phase errors. Zhou *et al.* addressed this by combining TIE and TPE (FFT-TIE-TPE), introducing a non-recursive correction method [5]. They proposed modifying the propagation constant $k(x,y) = k_0 n(x,y)$ so that TIE retains its Poisson form even for non-uniform intensities, as shown in Eqs. (3) and (4). The resulting expression for $n(x,y)$ in Eq. (5) includes correction terms. The TPE equation is used to derive the second error term while the phase gradient dependent first error term is determined solely by solving the TIE. This study applies the FFT-TIE-TPE method to enhance phase resolution in TEM intensity images [6].

$$-\kappa_0 \frac{\partial I}{\partial z} = \nabla_{\perp} \cdot (I \nabla_{\perp} \Phi) \quad \dots(1) \quad \nabla_{\perp}^2 \sqrt{I} = \sqrt{I} \left[\nabla_{\perp} \Phi \cdot \nabla_{\perp} \Phi + 2\kappa_0 \frac{\partial \Phi}{\partial z} \right] \quad \dots(2) \quad -\kappa_0 n \frac{\partial I}{\partial z} = I (\nabla_{\perp}^2 \Phi) \quad \dots(3)$$

$$\nabla_{\perp}^2 \Phi = -\kappa_0 \frac{1}{I} \frac{\partial I}{\partial z} \quad \dots(4) \quad n = 1 + \frac{1}{\kappa_0 \left(\frac{\partial I}{\partial z} \right)} \nabla_{\perp} \cdot I \nabla_{\perp} \Phi + \frac{1}{\kappa_0} \frac{\partial \Phi}{\partial z} \quad \dots(5)$$

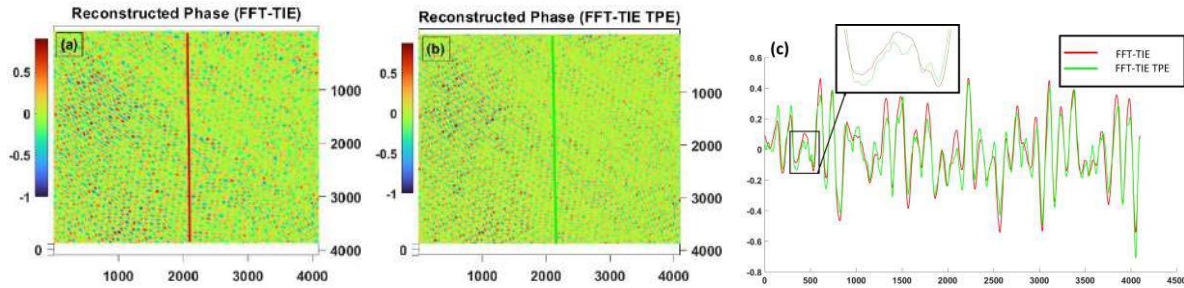


Fig. 1 Reconstructed phase with (a) TIE and (b) non-recursive TIE-TPE method, and (c) vertical cross-sectional plot from (a) and (b).

Figures 1(a,b) show phase images retrieved from HR-TEM intensity images of the MoS₂-CuO composite sample recorded using a JEM-F200 TEM, via FFT-TIE and FFT-TIE-TPE methods, respectively. The results show the normalized quantitative phase values. The vertical cross-section plot from Fig. 1(a) and (b) is plotted in (c) which reveals that FFT-TIE-TPE (green) captures finer structural variations than FFT-TIE (red). The results confirm that FFT-TIE-TPE provides enhanced phase resolution for TEM phase retrieval of non-transparent samples.

Acknowledgments

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Propagation properties of Bessel-Beams and Laguerre-Gauss beams with a high-order radial index: Comparison study

Velagala Ganeash^{1†}, MD. Haider Ansari^{1†}, Ravi Kumar¹, Shashi Prabhakar², Salla Gangi Reddy^{1*}, R. P. Singh²

1. Department of Physics, School of Engineering and Sciences, SRM University AP, Amaravati, 522240, India

2. Quantum Science and Technology Laboratory, Physics Research Laboratory, Ahmedabad, 380009, India

Structured light beams with a helical phase structure are characterized by an azimuthal phase term and carry orbital angular momentum. These beams exhibit a unique intensity distribution and distinctive propagation properties, such as self-healing and quasi-diffracting transmission. These properties have established them as valuable tools in high-capacity free-space optical communications, optical manipulation, and imaging. Among the most studied OAM beams are Bessel beams (BBs), Bessel-Gauss beams (BGBs), and Laguerre-Gauss beams (LGBs), each exhibiting unique modal structures and propagation characteristics. In this work, we experimentally generate BBs, BGBs, and LG beams using a computer-generated hologram with identical beam parameters. We observe that all three beams exhibit nearly identical central intensity distributions. Furthermore, we obstructed these beams with an annular object to examine their self-healing properties. We found that LGBs with a high radial index possess self-healing abilities and are more robust, propagating further than BBs and BGBs under similar conditions. Additionally, we scattered these beams through a ground glass plate and recorded the resulting speckles at different propagation distances. All three beams display similar autocorrelation intensity profiles, indicating equivalent spatial coherence after scattering. These results confirm the functional equivalence of BBs, BGBs, and high-order radial index LGBs in both free-space and scattering environments, providing practical guidance for selecting structured beam types in OAM-based communications and imaging systems.

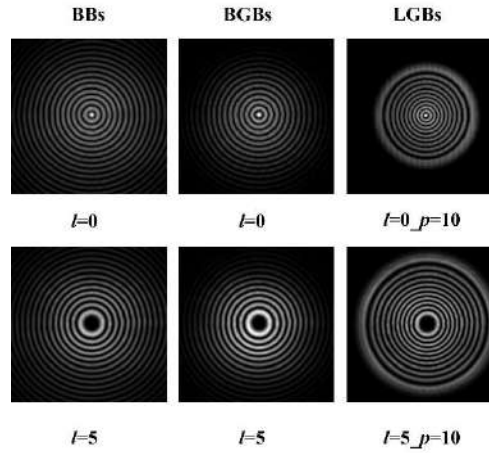


Fig. 1 Experimentally realised intensity profiles of Bessel, Bessel-Gauss, and Laguerre-Gauss beams

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Enhancing Phase Estimation Precision in Mach-Zehnder Interferometry Using Non-Gaussian Operations

K. Amrutha¹, C. Sudheesh¹

1. Indian Institute of Space science and Technology, Thiruvananthapuram 695547, India

Phase estimation lies at the core of quantum metrology and interferometric measurements. It refers to the indirect determination of a phase shift parameter, typically introduced by an optical path difference, and is fundamental to applications that require high-precision measurement. However, the sensitivity of conventional phase estimation is fundamentally constrained by the Standard Quantum Limit (SQL), also known as the Shot Noise Limit (SNL), arising from vacuum fluctuations inherent to the quantized electromagnetic field.

Optical interferometry, particularly the Mach-Zehnder Interferometer (MZI), serves as a central platform for realizing precision measurements in quantum technologies. Accurate phase estimation is essential in diverse areas such as gravitational-wave detection, time and frequency standardization, quantum imaging, atomic clock development, and magnetometry. To surpass the SQL, quantum-enhanced strategies involving non-classical states of light and non-Gaussian operations are actively pursued.

In this study, we explore the use of non-Gaussian operations- specifically, photon addition (PA) and photon subtraction (PS) applied to a squeezed vacuum state (SVS), which is then combined with a coherent state (CS), as inputs to the MZI. The aim is to enhance the phase sensitivity beyond that achievable with traditional classical or Gaussian quantum inputs. We rigorously evaluate the performance of photon-added squeezed vacuum states (PA-SVS) and photon-subtracted squeezed vacuum states (PS-SVS), both mixed with coherent states, and compare them to conventional inputs such as pure CS and SVS.

Phase sensitivity is assessed using two complementary methods: the error propagation formula and the Quantum Cramér-Rao Bound (QCRB), the latter providing a fundamental lower bound on the variance of unbiased estimators. In particular, we analyse the phase uncertainty derived from the quantum Fisher information and demonstrate its consistency with results obtained via error propagation when parity detection is employed as the measurement observable.

Beyond PA-SVS and PS-SVS, we further investigate the metrological advantages of other quantum states, including photon-added coherent states and photon-added or subtracted thermal states. Our analysis reveals a strong correlation between the degree of non-classicality and the achievable measurement precision, highlighting the critical role of quantum resource engineering in enhancing interferometric sensitivity.

These findings contribute to advancing quantum metrology by offering experimentally accessible and theoretically sound pathways to exceed classical precision limits. By integrating non-Gaussian operations with squeezed and coherent states in realistic settings accounting for photon losses, this work provides valuable insights for developing next-generation quantum sensors and measurement protocols.

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Evolution of Intrinsic and Extrinsic OAM During Optical Vortex Self-Healing

Kiran Divakar,

Muruges S, C S Narayanamurthy, and Ashok Kumar

Department of Physics, Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram, 695547, Kerala, India

Optical beams carrying orbital angular momentum (OAM), commonly known as optical vortices, have attracted considerable attention for about three decades due to their applications in optical communication, micromanipulation, and quantum information [1]. These beams exhibit a remarkable property of self-healing upon propagation when partially obstructed. Such self-healing behaviour has been widely studied in different classes of beams with OAM [2]. While previous studies have primarily focused on the qualitative analysis of the OAM recovery, our work presents a quantitative analysis of the problem and investigates the intrinsic and extrinsic OAM in the vortex beam. In this study, we consider a Laguerre–Gaussian (ψ_p^l) beam with azimuthal index $l=1$ and radial index $p=0$. We demonstrate the evolution of the OAM of a clipped beam through both experimental measurements and numerical simulations. The study is conducted by clipping the beam with a wedge-shaped object and allowing it to propagate in free space for regeneration. The extrinsic and intrinsic OAM of the evolved beam are measured and compared with the simulated results.

An LG beam of charge $l=1$ at the beam waist is $\psi_0^1 = \frac{2}{\sqrt{\pi}} \frac{r}{\omega_0^2} e^{-r^2/\omega_0^2} e^{-i\phi}$, where $r^2 = x^2 + y^2$, $\phi = \tan^{-1} y/x$, ω_0 is the waist radius and $k = \frac{2\pi}{\lambda}$ with λ as the wavelength of the beam. We clip the beam using triangular wedges with adjustable shapes. Assuming the direction of propagation of the beam along the z-axis, the total OAM along the z-direction is defined as $\langle \hat{L}_z \rangle = \langle \hat{x} \hat{p}_y - \hat{y} \hat{p}_x \rangle$. The extrinsic OAM (EOAM), which depends on the origin, is defined as, $\langle \hat{L}_z^e \rangle = \langle \hat{r} \rangle \times \langle \hat{p} \rangle$, and the intrinsic OAM (IOAM) is defined as, $\langle \hat{L}_z^i \rangle = \langle \hat{L}_z \rangle - \langle \hat{L}_z^e \rangle$ [3]. The obstruction introduces an asymmetry in the beam, leading to the generation of the EOAM, which is otherwise zero. We calculated the IOAM and EOAM for a symmetric vortex beam with azimuthal index $l=1$ and found that the IOAM remains 1 and the EOAM remains 0 upon free space propagation. A beam with $\omega_0 = 0.1 \text{ mm}$ and a clipping of approximately 20.8% of its intensity acquires a non-zero EOAM of 0.081, while the IOAM remains unchanged. The OAM values remain unchanged during beam propagation, as shown in Fig. 1(a). The beam restores its shape during propagation, yet the EOAM and IOAM are preserved.

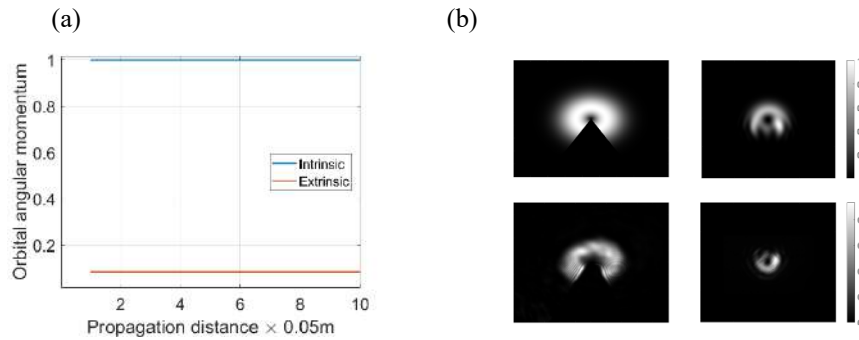


Fig. 1 (a) Numerical study of the evolution of IOAM ($\hat{L}_{int}^{sim} = 1$) and EOAM ($\hat{L}_{ext}^{sim} = 0.085$) with propagation. The beam parameters are $\omega_0 = 0.1 \text{ mm}$, azimuthal index $l=1$ and $\lambda = 633 \times 10^{-9} \text{ m}$. (b) Top row: simulated images; bottom row: experimental images of the clipped and regenerated beams.

The orbital angular momentum values are measured using a technique reported in [4]. In Fig. 1(b), the simulated (first row) and experimental (second row) beam images at the waist and after a propagation of 0.35 m are shown. The experimental result is in good agreement with the simulated result. Simulated EOAM $\hat{L}_{ext}^{sim} = 0.085$ and experimental EOAM $\hat{L}_{ext}^{ex} = 0.089$.

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Dipole Interaction Induced PMMA Waveguide based Compensation of Signal Noise in Free Space Optical Communication

Shouvik Sadhukhan¹ and C. S. Narayanamurthy¹

*1. Applied and Adaptive Optics Laboratory, Department of Physics, Indian Institute of Space Science and Technology (IIST), P.O: Valiamala, Trivandrum - 695547, State: Kerala; India
Email: shouvikphysics1996@gmail.com*

Abstract: We present an experimental study demonstrating the mitigation of signal degradation in free-space optical (FSO) communication channels using a PMMA (polymethyl methacrylate) rod incorporating dipole interaction-based compensation. The results measure the influence of atmospheric turbulence on the transmitted beam and the corrective effect of dipole-coupled PMMA rod. Performance is quantified via the scintillation index and probability density function (PDF) parameters, which show a substantial reduction in intensity fluctuations and improved signal stability when the waveguide is integrated.

Introduction: Free-space optical (FSO) communication systems offer high-bandwidth data transmission but suffer from atmospheric turbulence-induced signal distortions, including intensity scintillation and phase fluctuations. These effects, primarily caused by refractive index inhomogeneities, significantly degrade link reliability. Conventional mitigation methods, such as adaptive optics or aperture averaging, are complex and costly. In this work, we explore a novel compensation approach utilizing a PMMA waveguide whose internal dipole interactions induce field redistribution, mitigating scintillation effects. The PMMA structure acts as a passive stabilizing medium: microscopic dipoles, excited by the incident field, re-radiate coherently, effectively evening out local field variations before detection. The experimental configuration (Fig. 1a) examines the turbulence-distorted beam with and without the waveguide, quantifying improvements through two primary metrics: (i) the scintillation index, measuring normalized intensity variance, and (ii) the PDF parameters, assessing statistical intensity behaviour.

Results Analysis: Figures 1b and 1c reveal a marked reduction in the scintillation index across varying turbulence strengths when the dipole-compensating PMMA waveguide is employed. Without compensation, the scintillation index increases rapidly with turbulence strength, indicating severe beam fading. With the waveguide, this growth is suppressed, reducing normalized intensity variance by over 40% in moderate-to-strong turbulence regimes. Figures 1d highlight PDF shape parameters (fitted via log-normal and gamma-gamma models) to capture intensity distribution changes. The compensated channel exhibits narrower distributions with reduced skewness, confirming that dipole interaction redistributes localized hotspots into a more uniform profile. These results demonstrate that the PMMA waveguide not only mitigates intensity fluctuations but also stabilizes the statistical behaviour of the received optical field, offering a cost-effective and passive solution for FSO systems.

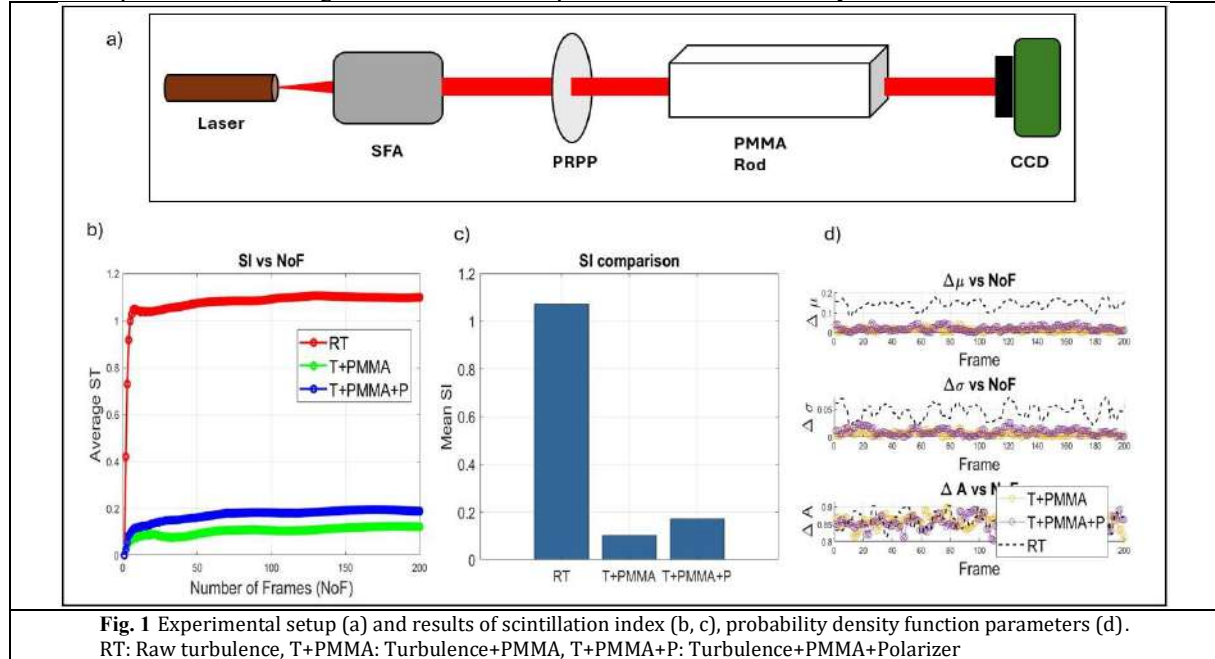


Fig. 1 Experimental setup (a) and results of scintillation index (b, c), probability density function parameters (d). RT: Raw turbulence, T+PMMA: Turbulence+PMMA, T+PMMA+P: Turbulence+PMMA+Polarizer

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Thermal lensing-induced nonlinear optical response in KMnO_4 under continuous-wave laser excitation

Rojalin Padhi,^{1,*} Himani Sharma,¹ Gopal Prasad Sahu,¹ Kavita Devi¹

¹Department of Physics, Indian Institute of Technology Dharwad, Dharwad, Karnataka 580011, India

*Author e-mail address: rojalinpadi@iitdh.ac.in

Nonlinear optical phenomena driven by continuous-wave (cw) laser excitation have gained increasing attention due to their relevance in practical photonic applications involving prolonged light and matter interactions. Among these phenomena, thermal lensing which results from localized heating caused by optical absorption plays a critical role in modulating the refractive index profile within a material. Unlike ultrafast electronic nonlinearities typically observed under pulsed laser excitation, thermal nonlinearities are dominant in the cw regime, where longer interaction times lead to cumulative thermal gradients [1]. Despite its importance, thermal lensing remains relatively underexplored, particularly in materials that exhibit both linear and nonlinear absorption mechanisms. Here we address the current gap by investigating cw laser induced thermal lensing in potassium permanganate (KMnO_4), a promising optical material known for its strong visible absorption, chemical stability, and potential for tunability in composite systems. Further, using the Z scan technique, we systematically examine how variations in laser parameters and KMnO_4 concentration influence the third order nonlinear optical response. The results obtained on thermally driven optical nonlinearities in KMnO_4 , with the analysis performed highlights its potential for use in photonic device applications such as optical limiters, and nonlinear sensors [2,3].

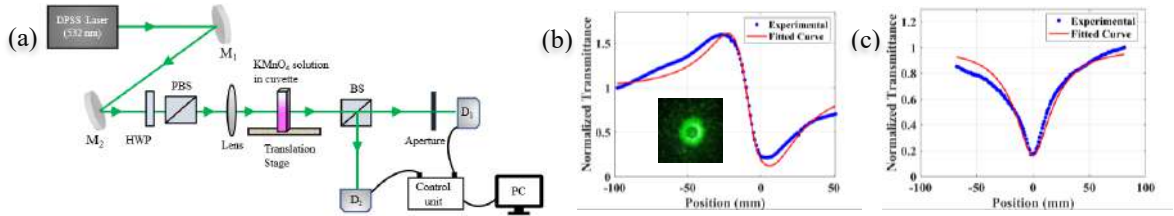


Fig. 1 Schematic of experimental setup. $M_{1,2}$: mirrors, HWP: half wave plate, PBS: polarizing beam splitter, BS: beam splitter, $D_{1,2}$: detectors. Experimentally obtained and theoretically fitted curve at input power of 100mW for (b) nonlinear refractive index (n_2), inset: Ring formation on spatial profile due to thermal lensing, and (c) nonlinear absorption coefficient (β) under thermal lensing for 100 μM concentration of KMnO_4 .

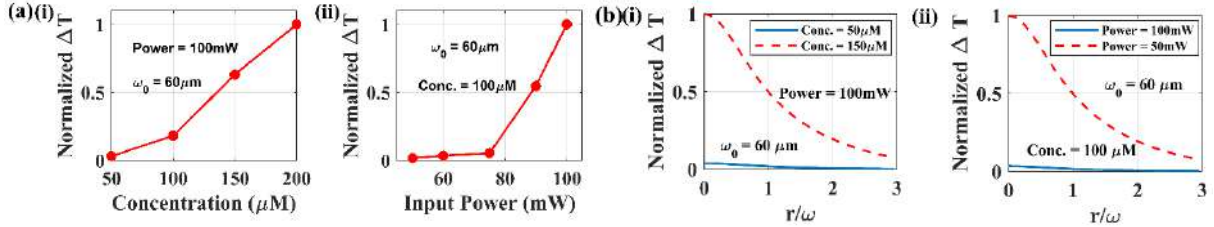


Fig. 2 (a) Temperature gradient at focus and (b) radial temperature distribution under nonlinear absorption for varying (i) concentration, and (ii) power.

The schematic in Fig. 1(a) outlines the experimental setup used to extract nonlinear refraction and absorption parameters. Figures 1(b) and 1(c) present the experimental transmittance curves in closed aperture (CA) and open aperture (OA) configurations, respectively. The CA plot exhibits a peak–valley signature characteristic of self-defocusing which is due to the thermal lensing contribution to the third order nonlinearity, while the OA curve indicates reverse saturable absorption. The inset in Fig. 1(b) shows the ring formation on spatial profile due to thermal lensing. Figures 2(a)(i–ii) show the variation of normalized temperature rise (ΔT) with sample concentration and input power respectively. As evident, ΔT increases with increasing concentration and input power. Figures 2(b)(i–ii) display the radial distribution of temperature within the sample under different conditions. The results indicate that the temperature rise is more significant near the beam axis and diminishes radially outward. The analysis at different concentrations and powers confirms that tighter focusing and higher absorption enhance localized heating, thereby amplifying the thermal lensing effect. The detailed analysis of the results obtained on thermal lensing evidence and confirmation, optical nonlinearity in presence of linear absorption, nonlinear absorption and temperature rise, and optical limiting in KMnO_4 will be presented.

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Thermoluminescence Investigation of Dy(III) Doped BaAl₂O₄ Aluminate Based Phosphor

Elison Macwan¹, Naresh Degda¹

¹ Department of Physics, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodra-390002, India.

The objective of this research is to study the application of BaAl₂O₄-Aluminate based phosphor doped with rare earths [Dy (III)] in the use for Thermoluminescence dosimetry. BaAl₂O₄ is a stuffed tridymite with hexagonal structure at room temperature. BaAl₂O₄ was selected as a host because of its distinctive features such as high chemical stability and a wide band gap [1,2]. The phosphor was prepared via solid-state reaction route at high temperature. At first stoichiometry of all the raw chemicals was done and their weights were calculated, then the raw chemicals which included Ba(NO₃)₂ [Loba chemicals, 99%], Al(NO₃)₃·9H₂O [Loba chemicals, 99%] and Dy₂O₃ [Loba chemicals, 99.9%] of AR grade were weighed using a digital weighing balance. Then the weighed raw chemicals were grinded separately at first and together afterwards for 30 minutes each using an agate mortar and pestle. Then the combined material was transferred to an alumina crucible which was then heated in a muffle furnace for 12 hours at 1200°C.

Characterisation was done by Powder X-ray Diffraction method to find the crystal structure and phase of BaAl₂O₄: Dy. It was done using a D8-bruker advance x-ray diffractometer with Cu-K α radiation (λ = 1.54Å) in the range of 20° to 70°. A hexagonal phase was discovered as shown in Fig.1(a). which confirmed the formation of desired phosphor.

Thermoluminescence studies were carried out and a high-quality TL was detected when the phosphor was irradiated using a radioactive ⁹⁰Sr/⁹⁰Y beta source at 10 Gy dose. The measurements were taken in range of 28°C (room temperature) to 250°C measured at 1°Cs⁻¹. The TL glow curve as shown in Fig.1(b) shows two major peaks at ~90°C and ~143°C. The TL intensity showcased a linear response to the applied dose range.

The TL results shows that the phosphor under study has the potential to be used in thermoluminescence dosimetry (TLD).

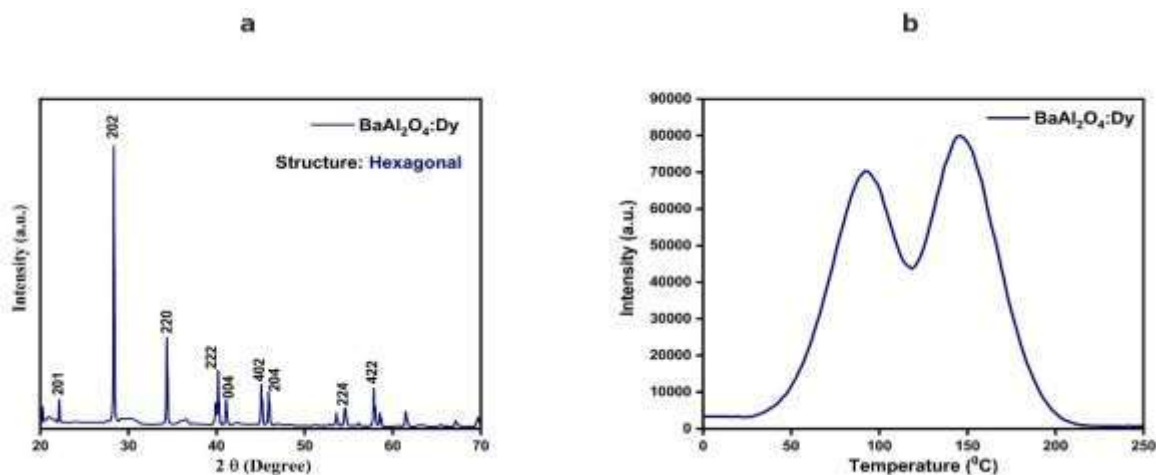


Fig. 1 (a) X-ray diffraction pattern of BaAl₂O₄: Dy & (b) TL Glow curve of BaAl₂O₄: Dy recorded after 10 Gy dose of beta rays.

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Multimode fiber speckle patterns of beam-scaled OAM modes

Nikhil Vangety^{1*}, and Shashi Prabhakar¹

Quantum Science and Technology Laboratory, Physical Research Laboratory Ahmedabad, Navrangpura, Gujarat 380009, India

Email: vnikhil@prl.res.in

The orbital angular momentum in light stems from its distinctive phase configuration. Specifically, when the phase of a light beam rotates or “twists” around its axis in steps of ℓ times 2π , described mathematically as $\exp(-i\ell\phi)$ with ϕ representing the azimuthal angle, each photon acquires an OAM value equal to $\ell\hbar$ [1,2]. This twisting creates a core of zero intensity at the beam’s center, an optical singularity which is characteristic of so-called vortex beams with a topological charge ℓ . There are numerous ways to generate light beams carrying OAM, but the most prevalent technique is to use Laguerre-Gaussian (LG) modes, which naturally possess such a helical phase structure. However, the size of the beams increases with ℓ , which makes an arduous task in communication applications, while launching these beams in single- or multi-mode fibers (SMF or MMF) possessing small core diameters. Recently in [3], the authors have proposed OAM with topologically controlled beam sizes, where they have applied different scaling factors to the beam waist for controlling the size of the beams. Particularly, when the beam waist (w_0) is scaled by a factor of $1/\sqrt{(|\ell|+1)}$, the beam size remains same for all ℓ values. In this work, we are particularly looking into the speckle patterns of such scaled LG beams that are formed by launching these beams into the input facet of the standard MMF with core diameter 200 μm , 0.22 N.A. Fig. 1 shows the different scaled LG modes ($p=0$) with ℓ values -5, -2, 0, 2, 5 (top) as well their speckle patterns (bottom), respectively.

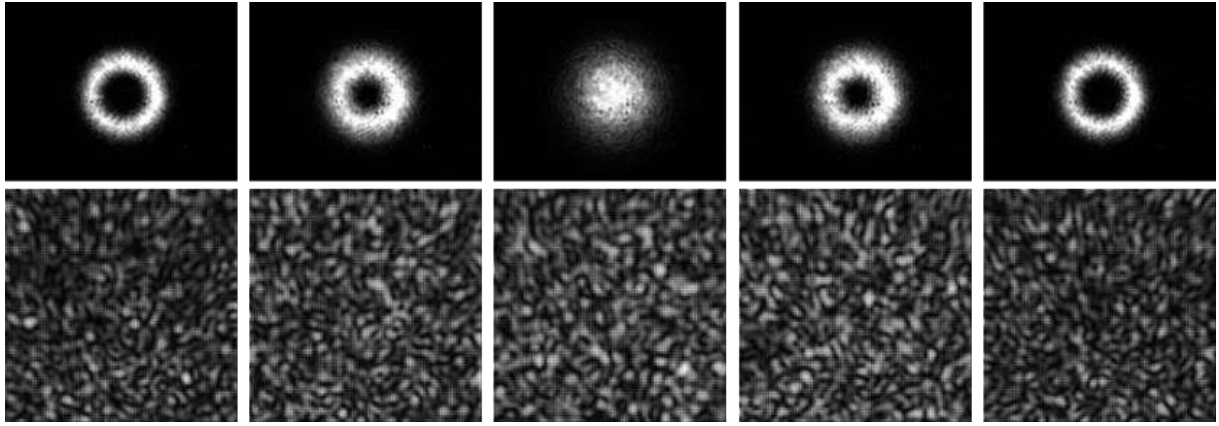


Fig. 1 Scaled LG modes ($p=0$) with $\ell = -5, -2, 0, 2, \text{ and } 5$ respectively, (top). The corresponding speckle patterns of $\ell = -5, -2, 0, 2, \text{ and } 5$ respectively (bottom).

The distinctive features in the speckles provide a promising basis for effectively classifying OAM states using machine learning methods such as convolutional neural networks due to their ability to capture subtle spatial intensity variations unique to each OAM mode. This approach is crucial for enhancing high-capacity optical communications by enabling efficient mode-division multiplexing, which significantly increases data transmission rates. It also advances quantum information processing by accurately identifying quantum states encoded in OAM modes. Moreover, it improves secure and precise optical sensing technologies by providing robust, real-time detection of environmental changes and enabling durable communication links in complex or turbulent conditions.

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Comparative Analysis of Interferometric and Non-Interferometric Quantitative Phase Imaging Techniques for Label-Free Characterization of Bovine Spermatozoa

Harpreet Kaur, Satish Kumar Dubey, Dalip Singh Mehta

Center for Sensors, Instrumentation and Cyber Physical System Engineering (SeNSE), Indian Institute of Technology Delhi, Hauz Khas, New Delhi-110016, India

Introduction: The phase of sperm cells contains significant information about the morphology and refractive index variation inside the cells [1]. Various quantitative phase imaging (QPI) techniques have been developed to find the phase shift in the light that has passed through a sperm cell. One of the methods is interferometric-based, and the other is a non-interferometric method. A label free QPI system, without any fluorescent dye, offers excellent phase resolution but requires a highly stable optical setup for interferometric system (such as Linnik or Mirau based partially spatially coherent (PSC) -QPI system). Non- interferometric such as transport of intensity equation (TIE) reconstruct phase map based on intensity variation at different focus level, offers simplicity and portability. This study compares these two different methods on fixed bovine sperm cells.

Results and discussion: Figure 1A shows the images acquired using interferometric based PSC-QPI method whose experimental setup is shown in [2], where (a) is the bright field image, (b) is the recorded interferogram, and (c) is the reconstructed phase map obtained using single shot Fourier transform method. Figure 1B shows the images acquired using non-interferometric based method, where (d-f) are the recorded intensity images at 0 μm , 6 μm and -6 μm , and (g) is the reconstructed phase map using TIE method. Interferometric QPI system produces high contrast phase maps, having phase sensitivity comes out to 20 mrad. TIE-QPI system recovered the shape of sperm cells but with poor phase sensitivity. However, TIE require standard bright field microscope, and no interferometric alignment.

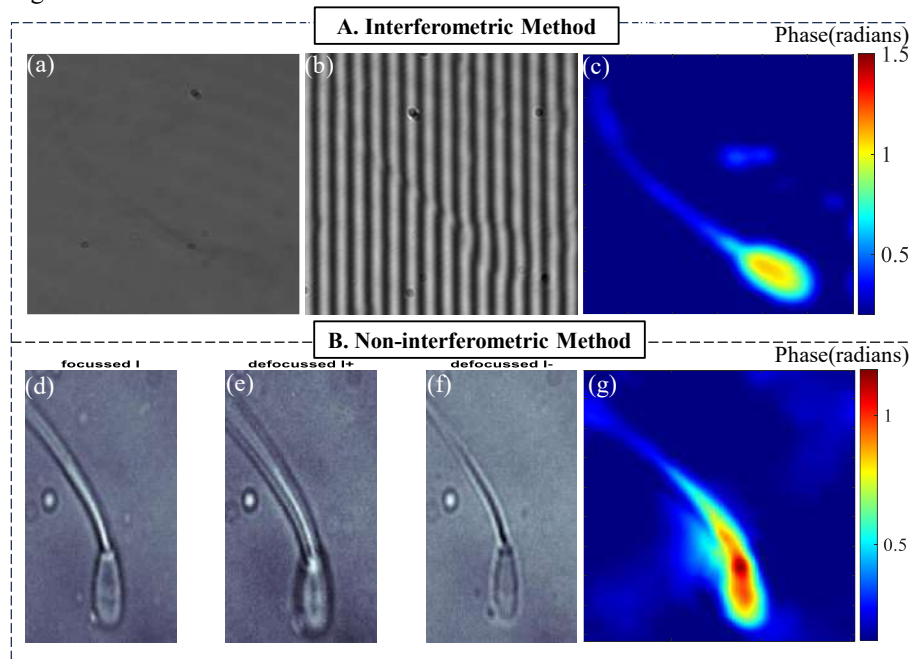


Fig. 1 (A). shows the acquired images using interferometric based method using PSC-QPM system where (a) is the bright field image (b) is the recorded interferogram and (c) is the reconstructed phase map obtained using Fourier transform method. (B). shows the image acquired using non-interferometric based method where (d-f) are the intensity images captured at 0 μm , 6 μm and -6 μm and (g) is the phase map obtained using TIE based method.

Conclusion: Accurate characterization of sperm morphology is important for assisted reproduction technology. Interferometric QPI remains a standard method for high precision sperm imaging, whereas non-interferometric TIE-QPI is a viable alternative where simplicity and accessibility are priorities. Future work will include machine learning based analysis to further enhance the label-free sperm diagnostics.

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Enhanced Spatial Mode Overlap and Nonlinear Interactions in Hollow Ring-Core Fibers

Shruti Jain *, Deepak Jain

Optics and Photonics Centre, Indian Institute of Technology Delhi, New Delhi, 110016, India

A central challenge in the development of nonlinear photonics platforms is achieving perfect phase-matching conditions. To gain flexibility in the properties of generated photons, researchers often employ combinations of different higher-order modes. While these modes can fulfill the required phase-matching conditions, they typically suffer from reduced spatial overlap. Maximizing the spatial mode overlap between interacting modes is therefore a crucial goal in advancing nonlinear photonic technologies, as it directly influences the efficiency of nonlinear processes such as photon-pair generation. The overlap is quantified by the f-factor, which serves as a key element of nonlinear efficiency. We initially explored the use of solid ring-core fibers (RCFs) as a means to enhance the overlap between fundamental (HE_{11}) and first higher-order mode (TE_{01}) modes compared to conventional step-index fibers (SIFs), resulting in moderately improved f-factor values. However, despite the enhanced overlap, solid RCFs still suffer from a relatively large effective mode area. A high effective area is undesirable because it reduces the intensity of the interacting fields and thus reduces nonlinear efficiency, even when mode overlap is improved.

In order to increase the efficiency, we introduce another fiber design featuring a ring-core structure with a central air hole. This hollow RCF structure is engineered to improve the spatial overlap between modes while simultaneously reducing the effective area. The central air hole helps confine the optical field more tightly around the ring, leading to a stronger overlap integral and reducing the effective area between the HE_{11} and TE_{01} modes. This dual benefit is due to the tailored refractive index profile and mode confinement characteristics specific to this geometry. Figure 1 schematically compares (a) a standard step-index fiber, (b) a solid ring-core fiber, and (c) the proposed ring-core fiber with a hollow central region.

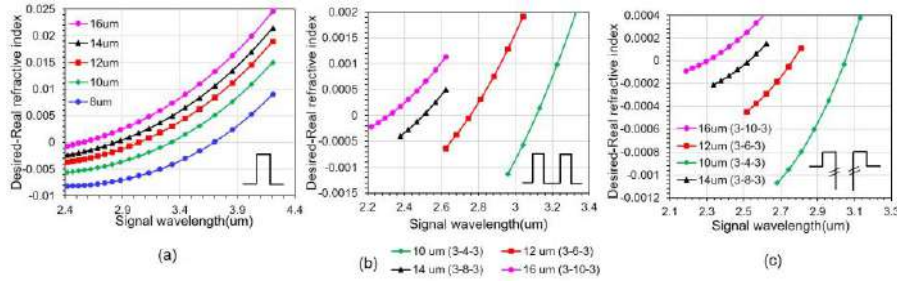


Fig. 1 The difference between the desired and real refractive index for a 1550 nm pump wavelength plotted signal wavelengths to meet the phase-matching condition, for the configurations $TE_{01}^p, TE_{01}^i, HE_{11}^s$ (a) SIF, (b) RCF, (c) hollow ring-core fiber.

The existing mixed-mode phase-matching has been used [2] for the mode combinations, where we fixed the TE_{01} mode as the pump and idler, and HE_{11} as the signal, and we calculated the difference between the desired and real effective refractive indices of the signal mode for a fixed pump wavelength of 1550 nm across varying signal wavelengths and fiber core diameters, as shown in fig.1. Here, we use different air hole diameter and fixed ring thickness (3 μm) with 10 mol% Germania and 90 mol% Silica core with 100 mol% Silica cladding fiber. The Sellmeier equation for SiO_2 and GeO_2 is employed to calculate the refractive index profile [3]. Figure 1 illustrates that the difference between the desired and real effective indices becomes zero, corresponding to the phase-matched signal wavelength, which varies with core diameter. The calculated f-factor value for different fiber geometries is summarized in Table 1.

Table 1. Calculated F-factor for Degenerate Pump Photons in a 10% GeO_2 doped Hollow Ring-core fiber

Ring size (μm)	SIF (unit of $F \cdot \mu m^{-2}$)	Solid ring-core fiber	Ring-core with central air hole
3-4-3	$F = 0.015$	$F = 0.016$	$F = 0.017$
3-6-3	$F = 0.010$	$F = 0.012$	$F = 0.014$
3-8-3	$F = 0.007$	$F = 0.008$	$F = 0.010$
3-10-3	$F = 0.005$	$F = 0.007$	$F = 0.009$

The comparison table shows that the hollow ring-core fiber containing a central air hole exhibits a higher f-factor than SIFs and solid RCFs. This improved f-factor translates directly into higher nonlinear interaction efficiency. Since the efficiency of nonlinear processes such as photon-pair generation in quantum photonic applications scales with the f-factor, our proposed design offers a significant performance advantage.

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Characterization of a free-flowing liquid sheet and plasma mirror at high repetition rate (kHz)

Mukesh Kumar¹, S. Sree Harsha¹, Prashant Kumar Singh¹

1. Tata Institute of Fundamental Research, Hyderabad 500046, India

We present a new approach for generating a free-flowing liquid sheet by impinging a continuous liquid jet on the sharp edge of a planar substrate at a controlled angle. The formation process is systematically optimized by varying jet parameters, impact geometry, and liquid composition to obtain a smooth, stable, and uniform sheet suitable for high-intensity laser–plasma applications. Thickness characterization, performed in air using both spectral and spatial interference methods [1], reveals a non-uniform thickness profile along the propagation axis, ranging from 4.8 μm to 1.1 μm .

This liquid sheet is employed as the active surface of a plasma mirror operating in vacuum at a base pressure of 9×10^{-1} mbar and a processing pressure of 1.10 mbar. A Pharos femtosecond laser at 1030 nm wavelength is used for plasma mirror experiments. Detailed optical characterization includes near-field and far-field beam profiles, as well as spectral measurements before and after reflection from the plasma mirror. At 500 Hz repetition rate, we measure intensity-dependent reflectivities [2] of 66.5% for S-polarized light and 49.1% for P-polarized light as shown in figure 1(a); at 1 kHz, S-polarized reflectivity is 59%. The pointing stability [3] of the liquid sheet, critical for long-term operation, is quantified as fluctuations of $5.4 \pm 0.2 \mu\text{rad}$ in the x-direction and $5.0 \pm 0.25 \mu\text{rad}$ in the y-direction.

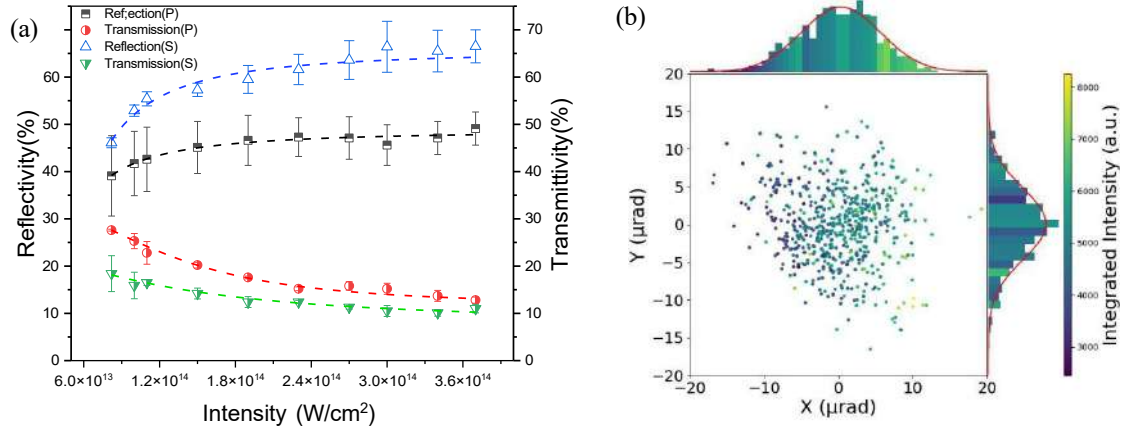


Figure 1 (a) shown intensity dependent reflection and transmission at 500Hz, (b) pointing stability of plasma mirror during interaction $5.4 \pm 0.2 \mu\text{rad}$ in the x-direction and $5.0 \pm 0.2 \mu\text{rad}$.

For sheet generation in air, we use a 50:50 mixture of ethylene glycol and deionized water, chosen for its balance between viscosity and evaporation resistance. For plasma mirror operation in vacuum, the composition is adjusted to a 60:40 ethylene glycol to deionized water ratio to enhance stability under reduced pressure. The results demonstrate that this liquid-sheet technique enables a compact, stable, and high-repetition-rate plasma mirror system with tunable optical and mechanical properties, offering significant potential for next-generation high-intensity laser experiments.

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Blue-pumped Femtosecond Photorefractive Optical Transient Detection

Sukeert¹, S. Chaitanya Kumar², P. G. Schunemann³, M. Ebrahim-Zadeh^{1,4}, A. Esteban-Martín⁵

1. ICFO—Institut de Ciències Fotòniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain

2. Tata Institute of Fundamental Research Hyderabad, 36/P Gopanpally, Hyderabad 500046, Telangana, India

3. BAE Systems Inc., MER15-1813, P.O. Box 868, Nashua, New Hampshire 03061-0868, USA

4. Institució Catalana de Recerca i Estudis Avançats (ICREA), Passeig Lluís Companys 23, Barcelona 08010, Spain

5. Departament d'Òptica i Optometria i Ciències de la Visió, Universitat de València, Dr. Moliner 50, 46100-Burjassot, Spain

Phase measurement plays a crucial role in optical systems, enabling the detection of minute changes in the properties of light, such as wavefront distortions, refractive index variations, or motion-induced shifts. Traditional interferometers are often susceptible to environmental perturbations, resulting in degraded measurement accuracy. Optical transient detection (OTD) is an adaptive interferometric technique, commonly based on two-wave mixing (TWM) in photorefractive crystals, for optical phase detection with enhanced background suppression, while compensating for slow environmental fluctuations, [1-3]. Here we report on femtosecond OTD in Barium Titanate, BaTiO₃ (BTO) photorefractive crystal using TWM pumped in the blue, to detect weak and fast phase fluctuations by injecting a phase-triggering signal, to set the system in quadrature condition, and enable enhanced signal-phase detection with SNR up to 40 dB. To the best of our knowledge, this is the first demonstration of OTD using up-converted visible femtosecond pulses in the blue.

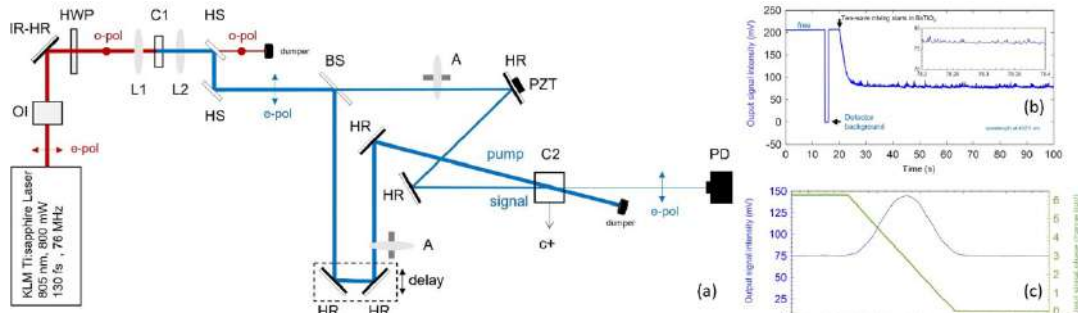


Fig. 1 (a) Experimental setup for femtosecond OTD in the blue. OI, optical isolator; HWP, half-wave plate; BS, beam splitter; IR-HR, IR high-reflector; HR, blue high-reflector; L1-L2, lenses; C1, BIBO crystal; HS, harmonic separator; A, attenuator; PZT: piezo-electric transducer. C2, BaTiO₃ crystal, PD: photodetector, (b) signal intensity suppression by TWM grating formation, and (c) transient output signal for applied signal phase changes.

The schematic of the experimental setup is shown in Fig. 1(a). The pump source is a Kerr lens-mode-locked Ti:sapphire laser emitting at 805 nm and providing ~ 150 fs pulses at 76 MHz repetition rate, which is externally frequency doubled in a 4.6-mm-long Bismuth Triborate, BiB₃O₆ (BIBO) crystal, cut for type-1($ee \rightarrow o$) critical phase matching ($\theta = 152.8^\circ$, $\phi = 90^\circ$). The blue light is split into a weak signal and strong pump beam, and both the beams intersect in the photorefractive BTO crystal of length 7 mm and an aperture of $5.23 \times 6.67 \text{ mm}^2$ [4]. The angle between pump and signal was set at 20° , resulting in grating period of the order of $0.5 \mu\text{m}$. The c^+ -axis of the crystal is oriented in order to get signal attenuation under steady-state operation, and the output signal is detected with a Si photodetector. The pump and the signal pulses are synchronized using a delay line to achieve temporal overlap in the crystal. The synchronization range for our mode-locked pulses is measured to be $\sim 150 \mu\text{m}$, corresponding to pulse durations of the order of 500 fs for the blue pulses. Figure 1(b) shows the temporal dynamics of grating formation in the BTO crystal for output suppression under illumination with blue femtosecond pulses. We were able to obtain a suppression contrast of up to 60% for a signal power of 1 mW, and a maximum pump power of 120 mW. In order to characterize the performance of our system for phase measurements, we arrange a set of intensity measurements for different values of phase changes by applying a ramp on the blue signal beam. The temporal measurements of the OTD output signal as well as the applied linear phase variations ranging from 0 to 2π is shown in Fig. 1(c) where the output signal intensity exhibits a symmetrical response to the 2π ramp within the 25 ms, and a maximum value for a signal-phase change of π . By pumping in blue, the achieved OTD signal is 10 times higher for a 100 times lower input signal power as compared to pumping in infrared [5]. Complete characterization of the OTD device, including OTD signal phase calibration, temporal behaviour of attenuation, noise equivalent phase sensitivity, and its use as an ultrasensitive sensor will be presented.

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Analysis of Quantum Dots as Fluorescence-based Sensors Considering Two-level Transitions with Monte Carlo Simulations

Ayush Bhatt¹, Charvin Jadhavan¹, Debjani Bagchi¹

1. Department of Physics, Faculty Of Science, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat - 390002

In recent years, nanoscale materials have gained attention for their unique properties compared to bulk forms. Among these, quantum dots (QDs) are notable in photonics. QDs are semiconductor nanoparticles with size-tunable emission, high photostability, and broad absorption with narrow emission spectra, arising from quantum confinement where restriction in all three dimensions produces discrete atomic-like energy levels.

QDs exhibit photoluminescence changes upon interaction with analytes, forming the basis for sensing. Sensitivity and specificity can be tuned via surface chemistry, enabling detection of ions, small molecules, and biomolecules. Their high surface-to-volume ratio, tunable emission, and stability further enhance detection capabilities [1]. In sensing, QDs act as fluorescent probes whose emission—intensity, wavelength, or lifetime—changes through mechanisms such as energy transfer, surface charge variation, or chemical bonding [2]. Optical detection uses light–material interactions, including fluorescence-based sensing for metal ions, bioimaging, and environmental monitoring, or UV-Visible spectroscopy for absorbance studies. Electronic detection relies on electrical property changes, as in electrochemical, field-effect transistor, or impedimetric sensors.

In this work, fluorescence and absorbance spectra were measured at varying concentrations to relate ion concentration to the optical response of boron-doped CQDs. Fluorescence change was quantified by ΔF (Eq. 1), with results for three ions in Figure 1.

$$\Delta F = \frac{I_{QD} - I_{QD+ion}}{I_{QD}} \times 100 \quad \text{.....Eq. 1}$$

Monte Carlo simulations were performed, modeling CQDs as two-level systems with Fermi-Dirac statistics, degeneracy, and electron transfer effects. Figure 2 shows the probability distributions for unexcited QD systems.

These simulations aid in developing detailed quantum dot sensor models, serve as predictive tools for sensing efficiency, enable rapid optimization, and provide insight into principles for QDs as single-photon or variable photon state emitters.

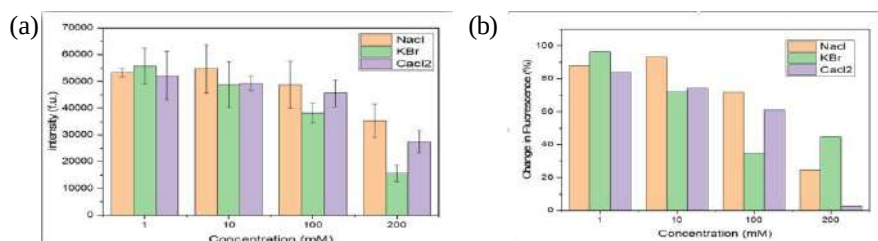


Fig. 1 (a) Fluorescence Intensity of CQDs as a function of the added salt for different concentrations, three different ions are shown. **(b)** Change in fluorescence intensity calculated using the formula given in Eq. 1.

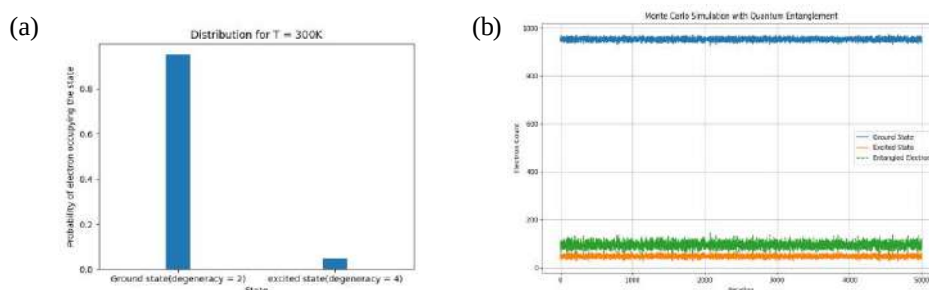


Fig. 2 (a) Probability distributions of ground state and excited state obtained with Monte Carlo simulations of Fermi-Dirac two level systems with degeneracy. **(b)** Monte Carlo simulations of Fermi-Dirac two level systems with degeneracy and entanglement.

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Optical Design of 30X Continuous Zoom Optical System under Paraxial Approximation and Short-Focus Real Lens Design Optimization

Asha B¹, Totan Chand^{2,3}, Shravana Kumar RR⁴, Sourabh Roy¹

1. Department of Physics, National Institute of Technology Warangal, Telangana 506004, India

2. Indian Institute of Astrophysics, II Block, Koramangala, Bengaluru 560033, India

3. Academy of Scientific & Innovative research (AcSIR)-CSIO, Sector-30C, Chandigarh 160030, India

4. CSIR-Central Scientific Instruments Organisation (CSIO), Sector 30C, Chandigarh 160030, India

The Zoom System is constructed using the four-group stable imaging principle under paraxial approximation [1]. The paraxial approximation simplifies the initial stage by focusing on the first-order system behavior. Using Paraxial Ray Tracing equations, the focal length and the inter lens group spacing were calculated to satisfy 30X zoom ratio within a total track length of 120mm. The focal length of the system ranges from 8mm to 240mm achieving a wide diagonal field of view of 52.48° and narrow diagonal field of view of 1.88°, the f/8 is maintained across all focal length so that the brightness stays constant while zooming and the diameter of the lens is maintained within 55mm. The system is designed to operate with a 1/2.3 type CMOS image sensor having a diagonal size of 7.9 mm.

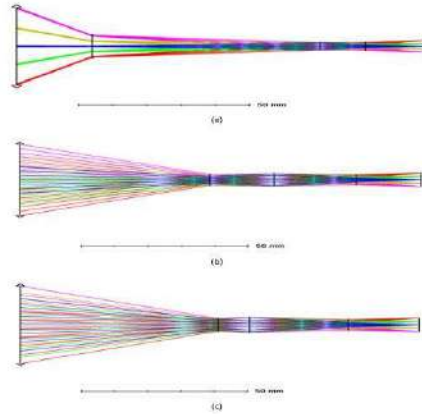


Fig. 1 Ideal configuration of Zoom Optical System at (a) Short, (b) Mid and (c) Long focus respectively

Based on paraxial calculations, a real lens system is constructed for short focus with an extended total track length of 150 mm to accommodate realistic optical components. During this conversion process, each paraxial lens surface is replaced by a combination of multiple real lens elements [2,3]. The short focus design was optimized using zemax software to control aberrations and maintain high image quality.

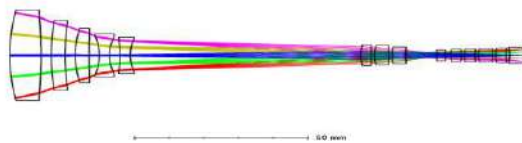


Fig. 2 Real Lens Design at Short Focus

Future work will focus on expanding the real lens design to cover the full zoom range while maintaining image quality, controlling aberrations, and accounting for mechanical tolerances and zoom group movement. Additionally, further optimization of the short-focus configuration is required to reduce the remaining distortion and achieve full optimization.

Keywords: Zoom lens, Paraxial Design, Four group system, Optimization design

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Correlation Signatures of Twisted Perfect Optical Vortices in Speckle Fields

Yukti Pandey¹, Raj Kumar², Nandan S. Bisht¹

¹Applied Optics & Spectroscopy Laboratory, Department of Physics, Soban Singh Jeena University, Campus, Almora (Uttarakhand)

²CSIR-Central Scientific Instruments Organization, Sector 30 C, Chandigarh 160030, India

Abstract: Speckle patterns from Twisted Perfect Optical Vortices (T-POV) exhibit distinct correlation features shaped by angular phase modulation, where ring deformation and lobe structures enable charge-specific recognition and indirect vortex characterization through scattering media.

Introduction: Structured light beams carrying orbital angular momentum have enabled advanced control over optical fields. In scattering media, such beams produce speckle patterns rich in information about phase structure and topological order [1-4].

Methodology: The experimental setup uses a phase only Spatial Light Modulator (GAEA-2.1) to generate a twisted [3] Bessel gaussian vortex beam [2], modeled as:

$$U_0(r, \theta) = J_\ell(k_r r) \cdot \exp(i\ell\theta) \cdot \exp\left(-\frac{r^2}{v^2}\right) \quad (1)$$

Where, J_ℓ is the Bessel function of order ℓ , k_r is the radial wavenumber, and v defines the Gaussian envelope width. The term $\exp(i\ell\theta)$ represents the spiral phase, imparting topological charge(tc) ℓ . To introduce angular distortion the phase is modified to $\theta' = \arctan(my/x)$, with m being a tunable twist parameter. The resulting twisted beam becomes:

$$U_m(r, \theta') = J_\ell(k_r r) \cdot \exp(i\ell\theta') \cdot \exp\left(-\frac{r^2}{v^2}\right) \quad (2)$$

exhibiting controllable spiral asymmetry. A blazed grating $\exp(ik_g x)$ can be added to diffract the beam spatially. A 2f imaging system converts the twisted Bessel Gaussian beam into a T-POV at the Fourier plane. A ground glass diffuser is placed at this T-POV plane to introduce random scattering. A second 2f system relays the speckle field onto the CCD. Speckles are recorded at various axial distances beyond the second lens to study propagation dynamics [4].

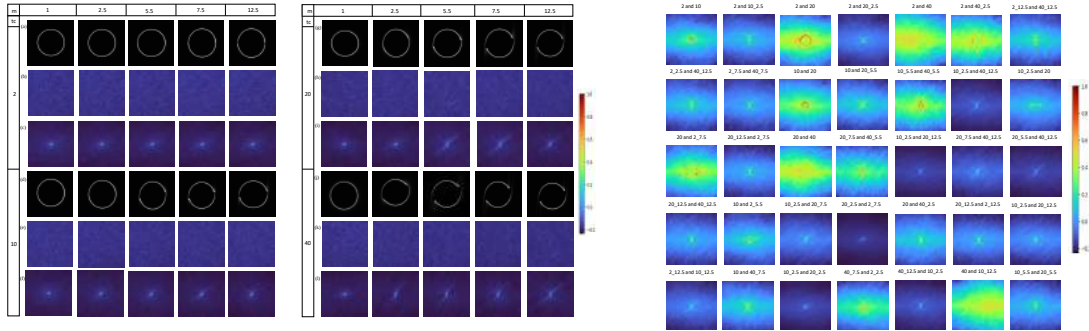


Figure 1: Left – T-POV fields, speckle patterns, and their autocorrelations for varying tc's and m . Rows (a,d,g,j) show POVs; (b,e,h,k) show speckles; (c,f,i,l) show autocorrelations; Right – cross-correlations between twisted beams labeled as ℓ_1 and ℓ_2 combinations.

Results and Discussion: Autocorrelation of T-POV speckles shows clear structural evolution with topological charge ℓ and modulation parameter m . At low ℓ , patterns remain circular with minimal distortion, while increasing ℓ and m leads to ring deformation and multi-lobed structures, indicating angular segmentation of the vortex field. Cross-correlation between different charges ($\ell_1 \neq \ell_2$) exhibits distinct rings when the charge difference is small, but the pattern blurs as the difference increases. Introducing angular phase modulation m restores pronounced features such as rings, lobes, and symmetric structures. This reveals structural resonance induced by angular phase twisting. These correlation features provide a unique, mode-specific signature that supports applications in vortex mode tagging, cryptographic optical encoding, and correlation-based ghost imaging, where phase retrieval from indirect speckle observations is required. Figure 1 illustrate these observations.

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Far-field Coherence of Phase Modulated Partially Coherent Beam

Haneen V N, Dinesh N Naik

Applied and Adaptive Optics Laboratory, Department of Physics, Indian Institute of Space Science and Technology, Thiruvananthapuram, Kerala, 695547, India.

The distinct diffraction peaks produced by diffractive optical elements under coherent illumination become obscured as light becomes less coherent. For phase-only diffractive optical elements, the classical VCZ theorem predicts the presence of a central peak in the coherence domain due to the uniform intensity of the source. Despite this, when the illumination is not completely incoherent, it has been shown that even phase gratings can produce a multiple-peak far-zone degree of coherence [1,2]. Here, we are investigating a sinusoidal phase grating under the illumination of partially coherent light and verifying the behaviour of far-field coherence with different source parameters, especially the phase modulation depth of the source. To the best of our knowledge, nobody has explored the freedom to vary the phase modulation of the source to get specific coherence patterns in the far-field.

A Gaussian field is simulated and allowed to pass through a sinusoidal phase grating represented by the following equation. $H(x, y) = \exp [j \frac{m}{2} \sin(2\pi f_0 x)]$, where m is peak to peak excursion of the phase delay and f_0 is the spatial frequency of the grating [3]. For the study, f_0 is taken as $1/60 \mu m^{-1}$

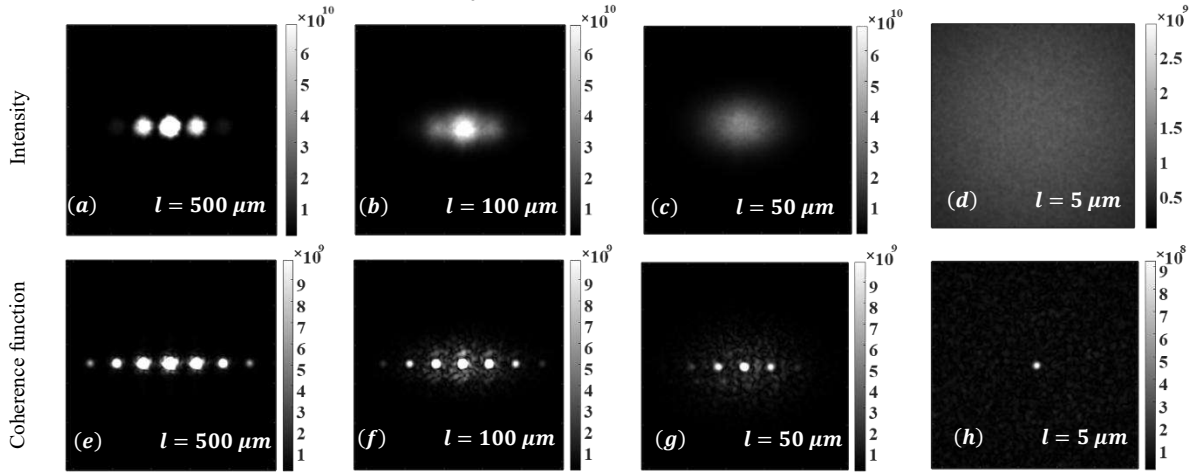


Fig.1: Far-field intensity and Far-field Coherence function (both in arbitrary units) of sources simulated for different correlation lengths l .

From the simulation results given in Fig.1, it is clear that, a range of source correlation lengths (l) exists for which diffraction orders of grating disappear entirely into a single intensity lobe while the presence of periodic structure can still be detected from the peaks of the degree of coherence. To study, how these coherence peaks vary with source parameters, the phase modulation depth of grating is varied by changing the value of m as in Figure 2.

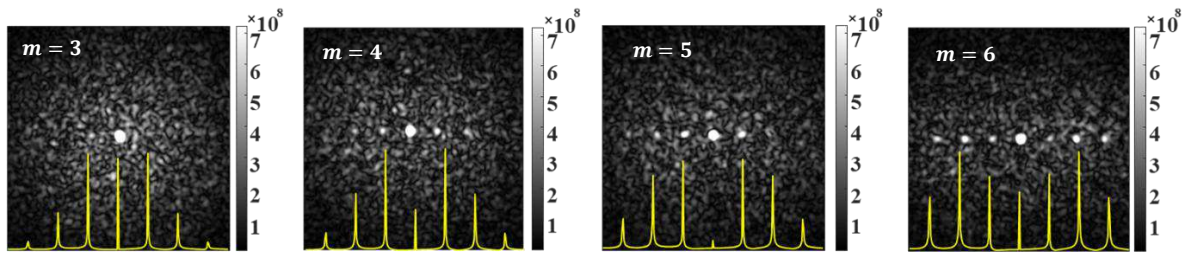


Fig.2: Coherence peaks under partially coherent illumination of grating ($l = 15 \mu m$), for different phase-modulation depth of the source. Corresponding diffraction peaks of grating under coherent illumination are given as yellow lines inset.

Phase modulation significantly influences the structure of far-field coherence, even when the source has the same correlation length. Since only the appropriate phase structure can generate corresponding coherence peaks in the system, it introduces possibilities of information coding where randomness may prevent direct information retrieval, but correlation analysis allows for successful decoding.

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Femtosecond pulse generation and spectral broadening in a SESAM-driven continuous-wave optical parametric oscillator

Himani Sharma,^{1,*} Rojalin Padhi,¹ Alfredo Daniel Sanchez,^{2,3} Gopal Prasad Sahu,¹

Majid Ebrahim-Zadeh,^{2,4} and Kavita Devi¹

¹Department of Physics, Indian Institute of Technology Dharwad, Dharwad, Karnataka 580011, India

²ICFO-Institut de Ciències Fòniques, Mediterranean Technology Park, 08860 Castelldefels, Barcelona, Spain

³FunGlass, Alexander Dubček University of Trenčín, Študentská 2, 911 50 Trenčín, Slovakia

⁴Institució Catalana de Recerca i Estudis Avançats (ICREA), Passeig Lluís Companys 23, Barcelona 08010, Spain

*Author e-mail address: HimaniSharma@iitdh.ac.in

Continuous-wave (cw) mode-locked optical parametric oscillators (OPOs) offer a simpler and cost-effective approach for pulse generation with the added advantage of wide spectral coverage. However, although active mode locking in cw OPOs has enabled the pulse generation in picosecond time scale, the generated pulses are far from transform limited bandwidth. Recent advances in intracavity dispersion compensation have demonstrated a simple, effective, and promising route to overcome this limitation, enabling broadband multi-axial-mode output and improved temporal coherence [1-5]. Despite the progress with active mode locking in dispersion-controlled cavity, there remains a critical need for a fully passive solution that enables stable ultrashort pulse generation with flexible repetition rate. Here we present the first generic and passive technique generating stable femtosecond pulses at high repetition rate which is attained by integrating semiconductor saturable absorber mirrors (SESAM) into a dispersion-compensated cw-pumped OPO. SESAMs are widely used in mode-locked lasers and synchronously-pumped OPOs, however their application in cw OPOs till date remains largely unexplored [6]. This study presents the first comprehensive numerical investigation of the temporal, spectral, and phase dynamics of a SESAM driven dispersion-compensated cw-pumped OPO. This analysis introduces a promising architecture for passive femtosecond pulse generation in cw OPOs, with potential applications in ultrafast seed sources for chirped pulse amplification, broadband spectral output generation, multi-species detection, and high-speed optical data sampling.

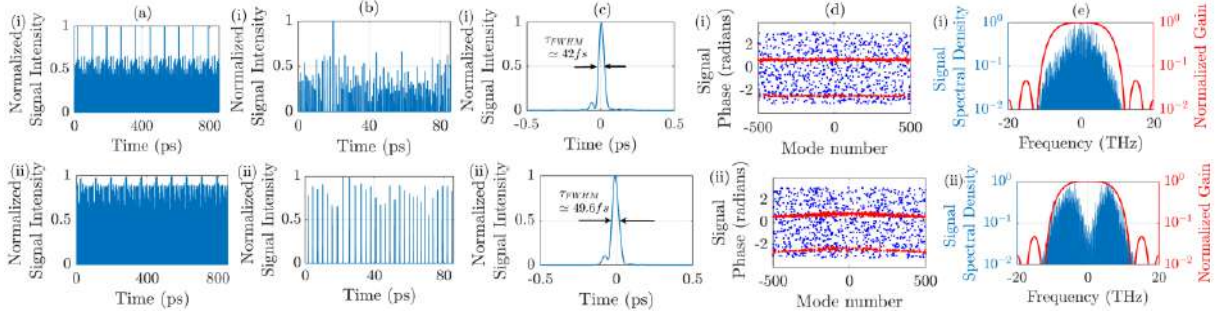


Fig. 1 In steady state with 5-mm-long MgO:sPPLT crystal with 7.97 μm grating period, the plots for (a) normalized signal intensity variation with time for last 10 round-trips, (b) zoomed-in last round-trip, (c) extracted single pulse from the pulse train, (d) steady state offset phase (blue) and symmetric average phase (red) as a function of mode number and (e) Fourier transform (blue) of temporal characteristics with normalized gain (red), for SESAM parameters (i) $I_{\text{sat}}=0.5 \text{ W}/\mu\text{m}^2$, $\Delta R=1\%$, $q_{\text{ns}}=0.05\%$, $P_{\text{in}}=1.42\text{W}$, and (ii) $I_{\text{sat}}=2.5 \text{ W}/\mu\text{m}^2$, $\Delta R=10\%$, $q_{\text{ns}}=1\%$, $P_{\text{in}}=6\text{W}$.

The system dynamics are modelled using coupled-wave equations and are numerically solved via the Split-Step Fourier method. Figure 1 summarizes the steady-state dynamics for two sets of SESAM parameters considering modulation depth (ΔR), saturation intensity (I_{sat}), and non-saturable loss (q_{ns}) under different input pump power (P_{in}) depending upon the system threshold, demonstrating the transition from weak modulation to strong passive mode-locking. Figure 1(a-i) and 1(a-ii) show stable pulse train formation for last 10 round trips. The zoomed-in views of the last round-trip is shown in Fig. 1(b-i) and 1(b-ii). As evident, the second set of SESAM parameter results into clear pulse train at repetition rate of $\sim 350 \text{ GHz}$, while dense and strong amplitude modulated profile has been observed with the first set of SESAM parameters. A single extracted pulse (Figs. 1(c-i), 1(c-ii)) shows femtosecond pulse generation (FWHM duration $< 50 \text{ fs}$). The signal phase profile across modes (Figs. 1(d-i), 1(d-ii)) illustrates phase coherence and spectral profile (Figs. 1(e-i), 1(e-ii)) shows significant spectral broadening with distinct features across various set of SESAM parameters. Further analysis on the role of third-order dispersion, SESAM parameters, nonlinear medium, and crystal lengths variation at and away from the degeneracy will be presented.

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Wavelength and Numerical Aperture Dependent Properties of Spatiotemporal Solitons in a Graded-Index Multimode Fiber (GRIN-MMF)

Love Kumar Sharma¹, Vishwa Pal¹

¹Dept. of Physics, Indian Institute of Technology Ropar, Rupnagar 140001, Punjab, India

We investigate the unique properties of femtosecond spatiotemporal solitons in a parabolic graded-index multimode fiber (GRIN-MMF) with varying input pulse wavelengths, and in multimode fibers of different numerical apertures (NAs). At very low input pulse energy, pulses in each of the individual modes disperse due to chromatic dispersion and separate from each other due to intermodal dispersion [1]. As the input energy increases, a single multimode soliton comprising of many lower-order modes emerges. The pulses in each mode synchronize due to the wavelength shifts caused by the interplay of various nonlinear effects. It has also been shown recently that multimode soliton exhibits some peculiar properties in terms of their pulsewidth and energies [2], and the multimode soliton condenses into a fundamental soliton with increasing input energy after propagation through long spans of GRIN-MMF [3]. Our results indicate to the fact that the optimal energy required for multimode soliton formation increases with the increase in central wavelength of the launched input pulse. The minimum achievable output soliton pulsewidth is independent of the input pulsewidth, but is strongly dependent on the input pulse wavelength. Additionally, a higher numerical aperture of the MMF reduces the optimal energy required for multimode soliton formation in GRIN fibers, and multimode solitons propagating through such fibers of high NA experience enhanced Raman-induced spectral red-shifting. Our findings concerning the properties of spatiotemporal solitons in MMFs may pave the way for an improved understanding and better control of novel spatiotemporal phenomena in multimode platforms, and in applications where specific soliton properties are desired.

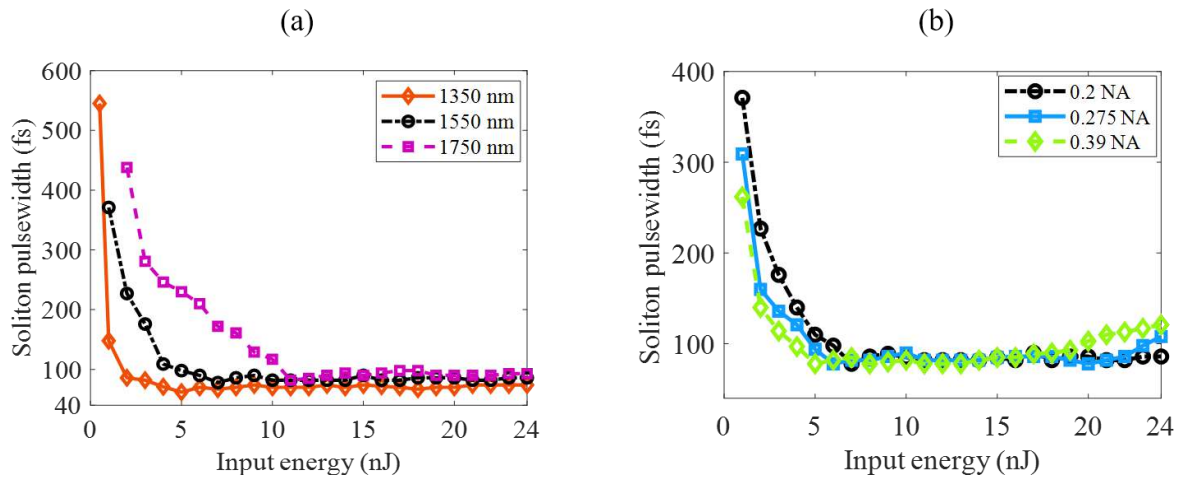


Fig.1- Evolution of the soliton pulsewidth with input energy at the output of a GRIN-MMF: (a) for input pulses of different central wavelengths of 1350 nm, 1550 nm, and 1750 nm, and (b) in MMF of different NA at a fixed input wavelength of 1550 nm, and initial pulsewidth of 500 fs.

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Optimization of Heat Generation and Transfer from Single Dielectric Core-Metal Nanoshells for Photothermal Therapy

Pranabjyoti Patar* and Venkata Ramanaiah Dantham

Department of Physics, Indian Institute of Technology Patna, Patna, Bihar 801106, India

*Presenting author: pranabjyoti_2121ph20@iitp.ac.in

Photothermal therapy (PTT) has emerged as a promising, minimally invasive cancer treatment technique that utilizes the localized heat generated by light absorption to selectively destroy cancer or tumor cells [1]. The photothermal effect is primarily driven by localized surface plasmon resonance (LSPR), wherein conduction electrons in noble metal nanostructures, such as gold or silver, collectively oscillate in response to incident light. When these plasmonic oscillations decay non-radiatively, they generate significant heat in the surrounding medium that can destroy targeted cancer or tumor cells selectively, while minimizing harm to nearby healthy tissues [2]. Therefore, optimizing light absorption and significantly improving nanoparticle heat conversion is essential for effective PTT.

Among various plasmonic configurations, dielectric core-metal nanoshells offer a versatile platform to tune the LSPR wavelength and relative absorption and scattering efficiencies of the nanoshells from ultraviolet to near infrared (NIR) by varying the size and composition of each layer of the nanoshells [3]. This tunability allows these nanoshells to be precisely engineered for strong absorption in the NIR region, where biological tissues exhibit maximal transparency, thereby enabling deep tissue penetration. Furthermore, nanoshells offer several advantages compared to solid nanoparticles in biological applications, including reduced cytotoxic effects, enhanced dispersibility in biological media, improved compatibility with cells and tissues, stronger binding capabilities with bioactive molecules, and greater thermal and chemical stability. Notably, the nanoshells have recently garnered significant attention as nano-sources of heat, making them useful for various PTT applications.

This study presents a comprehensive theoretical analysis of heat generation and transfer from dielectric core-metal shell nanoparticles under resonant optical excitation [4,5]. By strategically tailoring the physical dimensions and material compositions of the core, we aim to optimize the localized heating while ensuring optimal heat dissipation that is suitable for PTT applications. Initially, we studied the far-field optical properties, such as absorption and scattering efficiencies of single nanoshells surrounded by water/body tissues for different core radii (r_c), shell thicknesses (t), and wavelengths of incident light (λ). Later, the near-field optical properties of the single nanoshells at different hybridized modes are studied. Finally, the heat power generated in the vicinity of the nanoshells and the temperature rise in the surroundings are optimized due to the heat transfer from single nanoshells by varying the values of r_c , t , and λ .

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Study of Scattering Fields and Optical Forces for a Dielectric Sphere in Stratified Optical Tweezers System

Suvajit Dey¹, Sauvik Roy¹, Subhasish Duttagupta^{1,2}, Nirmalya Ghosh¹, and Ayan Banerjee¹

1. Indian Institute of Science Education and Research- Kolkata, Campus Rd, Mohanpur, Haringhata Farm, West Bengal 741246, India

2. Tata Institute of Fundamental Research, Hyderabad, Telangana 500046, India

Optical tweezers provide a powerful platform for studying optical forces in tightly focused, non-paraxial fields. Despite numerous studies, a complete description remains challenging due to two main factors: (a) the inhomogeneous field structure arising from vectorial superposition and optical aberrations, and (b) particle-specific properties such as size and refractive index contrast with respect to the surrounding media. Here, we present a generalised theoretical model that accurately predicts optical forces by computing the total (incident + scattered) field for spherical dielectric particles of any size, in spherically aberrated optical traps, unlike previous models limited to homogeneous media [1]. The aberrated traps, created by focusing light through refractive index-stratified media, offer unique advantages such as multiple axial and off-axial trapping regions with a single beam – leading to simple routes towards developing holographic tweezers, increased coupling efficiency into micro-cavities, etc. Towards this, the most important hurdle in evaluating the scattered field from the particle is determining the beam-shape coefficient of the non-paraxial incident field in stratified media by employing the Generalised Lorentz-Mie theory. We have been able to represent the focused field in terms of vector spherical harmonics and derive the associated BSCs at different positions within the stratified medium. These BSC are then utilised to calculate the accurate scattered fields (at *both near and far locations*) for the spherical scatterer. The major advantage of the method is that BSCs are now independent of the radial coordinate, allowing the particle to be placed anywhere in the trapping region, as well as reducing a large amount of numerical calculation into

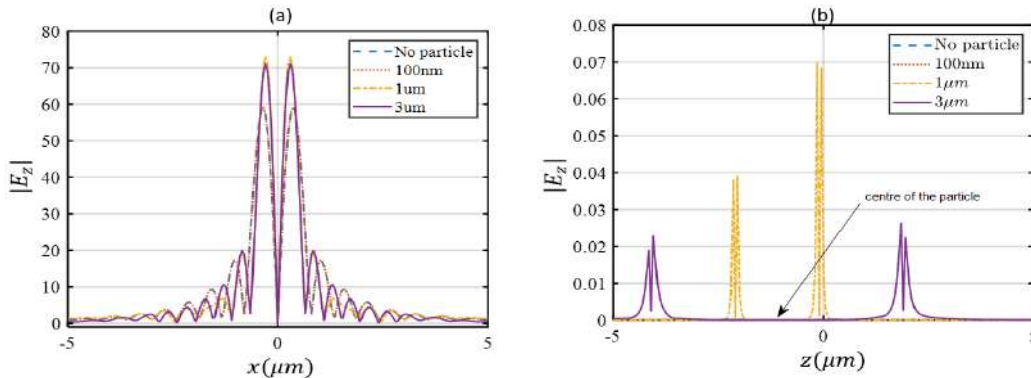


Fig.1 Longitudinal Component of total focal field with a variation in size of trapped particle. Due to aberration by the mismatch in refractive indices between immersion oil (R.I. = 1.518) and water (R.I = 1.33) in OT, focus shifts to $z = -1.1 \mu\text{m}$ plane from geometrical focus. We fixed the centre of the particle at $(x, y, z) = (0, 0, -1.1 \mu\text{m})$. (a) Variation of $|E_z|$ along the x axis at $(y = 0, z = -1.1 \mu\text{m})$ (b) Variation of $|E_z|$ along the z axis at $(x = 0, y = 0)$.

evaluating a single integral to determine the scattered field. In Figure 1, we present the longitudinal field enhancement, which is crucial for generating the transverse momentum. Although the longitudinal field component is generally negligible along the optical axis ($x=0, y=0, z$) of a tightly focused beam [2], it is enhanced due to scattering from a particle with radius comparable to the incident wavelength. We validate our theory through rigorous FDTD simulation of tightly focused fields. The total optical force has been calculated using the Maxwell-Stress tensor (MST) in the nearby space surrounding the scatterer [3]. Now, experiments usually assume a harmonic optical trap and calculate the trapping stiffness ($\mathbf{F} = -\mathbf{k} \cdot \mathbf{r}$). In the close neighbourhood region of focus, we calculate the trapping energy of a particle ($W \approx \frac{1}{2}k_x x^2 + \frac{1}{2}k_y y^2 + \frac{1}{2}k_z z^2$) [4], and observe that the stiffness of the approximated Harmonic trap is in good agreement with experiments. These accurate optical force calculations can enable precise biological trapping in complex media, advancing single-molecule studies.

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Development of Butcher Block Technique for Strip Filter Assembly

Anjali Kashyap, Swati Bisht, Rajesh Meshram

Space Applications Centre, Ahmedabad, Gujarat 380015, India

ABSTRACT

In several of our latest projects such as GISAT-1/2, RESOURCESAT-3/3A, we are utilizing strip-filter assemblies fabricated through BUTCHER-BLOCK technique to realise multispectral cameras. The advancement of the BUTCHER-BLOCK technique for the production of strip filter assemblies enables us to support our future endeavours by developing the necessary band-pass filters in-house.

Optical multi-spectral remote sensing of the Earth from both aerial and space platforms employs visible and infrared sensors located in space to gauge the radiation that is either reflected or emitted from the Earth and its atmosphere. Thin-film optical filters are utilized to select these specific channels. Standard configurations include filter wheels and discrete filters. To achieve compact and lightweight camera designs, multi-channel filter assemblies can be positioned close to the electronic detectors. Compact push-broom imaging systems generally utilize multispectral filter assemblies that are mounted directly above area arrays or multi-stage TDI sensors.

The multispectral filter assemblies are made up of stripe-shaped linear sliced filters, with each filter corresponding to a specific spectral band. These stripe filters can be joined side-by-side to create a strip filter assembly. The process of bonding filter strips together to create filter arrays is referred to as the BUTCHER-BLOCK technique.

The paper thoroughly outlines all the procedures involved in the development of the BUTCHER-BLOCK technique. Although the process could have been demonstrated using a mechanical model, the coating was introduced to enhance the dicing process for both sides multilayer coated substrates. A narrow band-pass filter is designed and developed and precisely diced into strips complying with the specifications detailed in this document. Gluing technique is then developed to fabricate filter arrays that are capable of enduring Thermovac cycling and vibration testing in accordance with the levels specified in the document.



Figure 1 Developed Strip Filter Assembly

Generation and Certification of pure phase entangled light

Rounak Chatterjee¹, Mayuresh S Kanagal¹, Saptak Mandal², Vikas S Bhat¹, Kiran Bajar¹, Sushil Mujumdar¹

1. Tata Institute of Fundamental Research(T.I.F.R), Mumbai- 400005, India

2.Indian Institute of Science Education and Research (IISER)Kolkata,, Mohanpur, Nadia - 741246, West Bengal, India

Spontaneous Parametric Down-Conversion (SPDC) is a non-linear optical process that spontaneously converts a photon of high energy into two lower-energy entangled (in polarization and space) photons following conservation of energy and momentum. It is well known in community that these pairs exhibit position (momentum) correlations at near (far) field. In our work, we aim study in the intermediate regimes, i.e. action of Fresnel propagation operator on the biphoton quantum state. For an in initial approximation of double Gaussian at near-field, at a distance z , the wavefunction can be written as:

$$\Psi(x_1, x_2; z) \propto \exp\left(-\frac{(x_1 - x_2)^2}{4\left(\frac{iz}{k} + \sigma_-^2\right)}\right) \exp\left(-\frac{(x_1 + x_2)^2}{4\left(\frac{iz}{k} + \sigma_+^2\right)}\right)$$

where $\sigma_{\pm}$, are the position-momentum correlation widths at near-field, while at z , $\sigma_{\pm}(z) = \sqrt{\sigma_{\pm}^2 + \left(\frac{z^2}{k^2\sigma_{\pm}^2}\right)}$. At particular distance $z = z_p = \pm k\sigma_+\sigma_-$, we observe $\sigma_+(z_p) = \sigma_-(z_p)$, and wavefunction modifies as:

$$\Psi(x_1, x_2; z_p) \propto \exp\left(-\frac{(x_1^2 + x_2^2)}{4(\sigma_+^2 + \sigma_-^2)}\right) \exp\left(\frac{i}{4(\sigma_+^2 + \sigma_-^2)}\left((x_1 - x_2)^2 \frac{\sigma_+}{\sigma_-} + (x_1 + x_2)^2 \frac{\sigma_-}{\sigma_+}\right)\right)$$

This wavefunction clearly indicates that the entangling terms are entirely transferred to the phase of the wavefunction, and the state is therefore referred to as a *phase-entangled state*. By re-arranging the equation and eliminating the quadratic term in the phase part, we obtain a *pure phase-entangled state*, whose wavefunction is given as $\Psi_{p^2}(x_1, x_2) \propto \exp(-A(x_1^2 + x_2^2)) - iBx_1x_2$, where the phase contains only correlation term.

Interestingly, performing a partial Fourier transform of $\Psi_{p^2}(x_1, x_2)$ results in state $\psi(p_1, x_2) =$

$\frac{1}{\hbar\sqrt{\pi}} \exp(-Ax_2^2) \exp(-(p_1/\hbar + Bx_2)^2/4A)$ in which the position of one photon is correlated with the

momentum of the other photon. This property for this state can be experimentally measured using a single lens Fourier transform using lens of focal length f_m for one photon and imaging the other with

magnification M_m yielding density: $\rho(x_k, x_p) = \frac{2}{\lambda f_m M_m} \exp\left(-2A' \frac{x_p^2}{M_m^2}\right) \exp\left(-\frac{\left(\frac{2\pi x_k}{\lambda f_m} + B' \frac{x_p}{M_m}\right)^2}{4A'}\right)$

where $A' = 4z_p^2 A/M^2 f^2$ and $B' = 4z_p^2 B/M^2 f^2$. For fixed A' , B' and f_m the functional form is generalised gaussian with a tilt angle and axis width as the function of M_m . The tilt angle is given by $\theta =$

$\frac{1}{2} \tan^{-1}\left(\frac{2b}{a-c}\right)$ where $a = \frac{2\pi^2}{\lambda^2 f_m^2 A}$, $b = \frac{\pi B'}{\lambda f_m M_m A'}$ and $c = \frac{2A'}{M_m^2} + \frac{B'^2}{2M_m^2 A'}$.

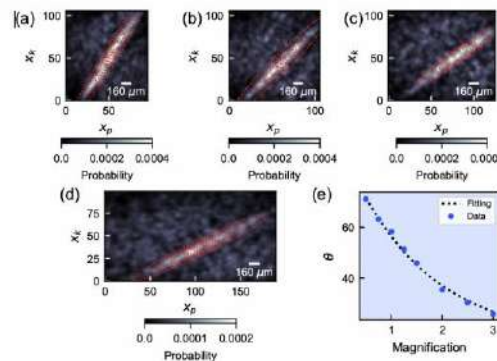


Fig. 1 plot shows the experimental data for variation of correlation for different M_m values (a) 1.0 (b) 1.5 (c) 2.0 (d) 2.5 red dotted line shows the fitted 2D gaussian (e) blue dots indicates the experimental value of θ and dotted line indicates the fit done using equation for θ

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Mid-IR Supercontinuum Generation using TeO₂-coated SiN On-chip Hybrid Waveguide

Kanika*, Neena Jaggi, Than Singh Saini

Department of Physics, National Institute of Technology Kurukshetra, Kurukshetra-136119, HR, India

*kanikapruthi003@gmail.com

The generation of mid-IR light sources attracts many researchers as it offers significant implications across various fields, including medical, defense, environmental monitoring, communication, and more. In the literature, broadband mid-IR supercontinuum (SC) light has been reported using different conventional fiber, waveguide, and photonic crystal fiber geometries in various materials, including silicon, tellurite, and chalcogenide glasses [1-6]. To generate efficient and stable SC spectra, the waveguide zero dispersion wavelength (ZDW) must match the operating wavelength of the input pulse laser sources. This reduces the power requirement needed for nonlinear interactions. Materials like chalcogenides, silicon, and germanium are highly transparent in mid-IR regions and have large linear and nonlinear refractive indices, making them important choices for mid-IR nonlinear photonics [5-6]. But ZDW of these materials are very high and lie in the mid-IR region, and such laser pulses operating at mid-IR wavelengths are not commercially available. Furthermore, using silica as a substrate limits mid-IR transmission upto around 2.5 μm because of its low transparency beyond this.

In this study, therefore, we have reported generation of SC spectra using tellurium-oxide (TeO₂) coated silicon nitride (SiN) hybrid waveguide design on sapphire substrate. This waveguide design exhibits ZDW at 2.05 μm and commercially available laser pulse is available at 2 μm . Our simulations predict a broad SC spectrum extending its range from 1250 nm to 6000 nm when injected with a commercially available hyperbolic secant pulse operating at 2 μm exhibits peak power of 3.5 kW, and pulse width of 50 fs. The 2.25-octave SC spectrum is generated using 10 mm long hybrid waveguide structure. This mid-IR SC spectrum is obtained using a low-power injecting pulse. Many molecules show their vibrational transitions in this region also known as molecular fingerprinting region. Also, earth atmosphere is transparent from 3 μm to 5 μm wavelength range. Hence, from an application perspective, such nonlinear hybrid waveguide presents significant potential including gas sensing, free space communication, biological tissue imaging, the development of stabilized optical frequency combs for precision spectroscopy, and explosive detection.

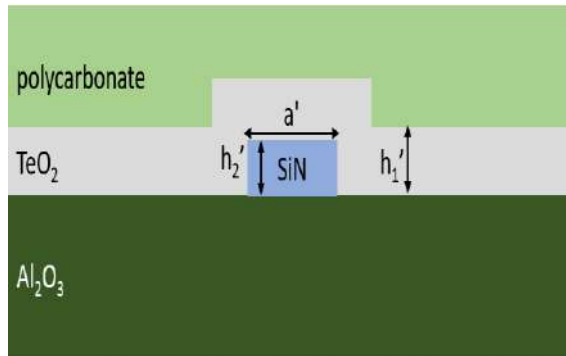


Fig.1 Transverse cross-sectional view of TeO₂-coated SiN hybrid waveguide.

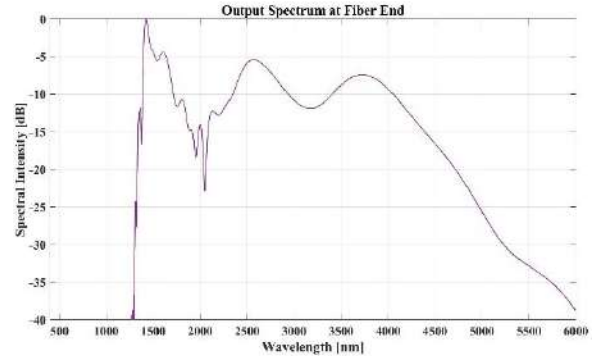


Fig.2 Output SC spectra of TeO₂-coated SiN hybrid waveguide.

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Simulation of the Conventional Polishing Process for Fused Silica Optical Glass

Aparajita Parashar^{1,*}, Raj Kumar Pal^{2,a}, Vinod Karar^{3,b}

Corresponding author: * aparajita.csio21j@acsir.res.in , parasharaparajita23@gmail.com , [0009-0000-7459-193X](tel:0009-0000-7459-193X)

^a rajkp.al.csio@csir.res.in , rajkp.al@gmail.com , [0000-0003-4608-9752](tel:0000-0003-4608-9752) ^b vinodkarar.crri@nic.in ,
vk.arar@rediffmail.com , [0000-0002-3760-9480](tel:0000-0002-3760-9480)

¹Academy of Scientific and Innovative Research (AcSIR), CSIR-Central Scientific Instruments Organisation (CSIR-CSIO) Campus, Sector 30 C, Chandigarh – 160030, India

² Advanced Engineering and Design, CSIR-CSIO, Sector 30 C, Chandigarh – 160030, India

³CSIR-Central Road Research Institute (CRRRI), Delhi - Mathura Road, New Delhi 110025

Abstract: The widely used method for the manufacturing and ultra-precision machining of glass or optical lenses is the conventional method of chemical mechanical polishing (CMP). This process of polishing is the effect of mechanical grinding and chemical etching, together, at the interface of workpiece-polisher. At the interface, various unseen components play a dominating role and need to be explored [1]. This study is done to observe the combined effect of machine parameters such as arm length and stroke angle, in addition to the effective pressure acting at the workpiece-polisher interface, during the polishing of fused silica optical glass [2]. The performance of the polishing process also depends upon the mode of contact at the interface, which is a highly complex subject and need to be explored [3]. For better understanding of the process, simulation/modeling of the polishing process parameters is done using software tools. It is observed that the effective pressure at the interface is being influenced by the various dynamic and static parameters and its cumulative effect can be seen on the Material Removal Rate (MRR) and Surface roughness Ra of the optical glass.

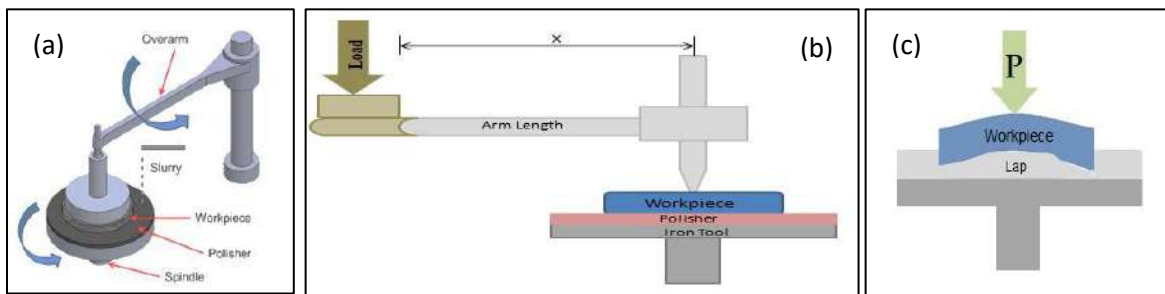


Fig. 1 Showing the schematic of Experimental setup and its workpiece-polisher interface

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Measuring of Rough Optical Surfaces by LWIR Deflectometry: System Modelling, Analysis and Initial Results

Nishchith Bhat, CHS Satyaprasad, J. John

Laboratory for Electro-Optics Systems(LEOS), Indian Space Research Organisation, Bengaluru 560058

Aspherical grinding is the process of shaping large optical surfaces to the required profile, often achieving sub-micron accuracy. However, accurately measuring these rough surfaces remains challenging, as visible-light interferometry fails due to low reflectivity, and alternatives like CO₂ laser interferometers and swing-arm profilometers face practical scalability and cost issues. As a result, undetected grinding errors can carry over to the much slower and expensive polishing phase. This emphasizes the need for a reliable and economical method to measure surfaces during grinding phase itself.

Building on principles of phase measuring deflectometry[1], we propose using long wave infrared (LWIR) deflectometry to measure rough optical surfaces. A heated wire, serving as a thermal source, is scanned horizontally and vertically, and its reflection from the test surface is captured by an LWIR camera. By analyzing the distortion of the reflected thermal line, local surface slopes are derived and subsequently integrated to reconstruct the surface profile[2]. In this paper, we present the developed system model, analyze the key parameters that influence measurement sensitivity, and share a set of preliminary test results that demonstrate the feasibility and performance of the proposed approach.

Precision of this measurement system depends on irradiance measured with respect to camera noise. We do a radiometric modelling of the system and arrive at optimal wire parameters, current and temperature for minimal centroiding error. Accuracy depends on geometric errors, wire straightness etc. We have developed a novel technique that eliminates errors due to wire straightness as well as fixed pattern noise and background noise to a large extent. Further we have introduced slit apertures in front of imaging lens that greatly reduce the unwanted rays hitting the detectors.

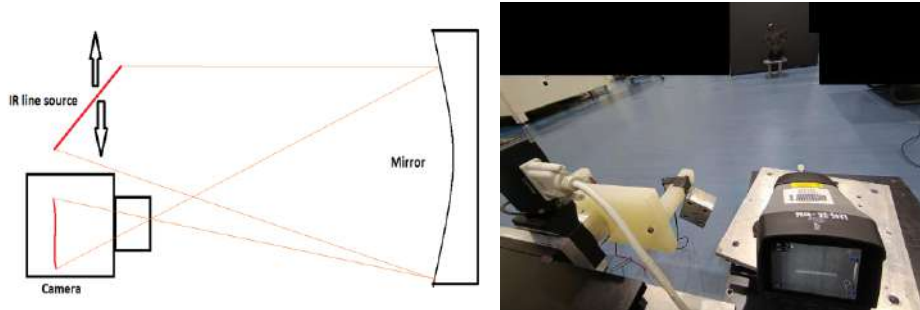


Fig 1: Schematic of IR deflectometry(left), and realised test setup comprising of heated wire, IR imaging camera and surface under test(right)

We present results for off-axis parabolic mirror under fabrication and on-axis ellipsoidal mirror. In both cases we are able to measure the overall surface profile and show that our system is sensitive to measure 1 μ m peak to valley surface features. Efforts to improve accuracy by eliminating sources of geometric errors are currently underway

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Unveiling coherent perfect absorption in composite films: a study on polarized beam interaction

Sauvik Roy,¹ Nirmalya Ghosh,¹ Ayan Banerjee,¹ and Subhasish Dutta Gupta^{1,2,3}

¹ Department of Physical Sciences, Indian Institute of Science Education and Research Kolkata, Mohanpur-741246, West Bengal, India

² Tata Institute of Fundamental Research, Hyderabad, Telangana 500046, India

³ Department of Physics, Indian Institute of Technology, Jodhpur 342030, India

*sdghyderabad@gmail.com

Coherent perfect absorption (CPA) [1–3], an advanced extension of the critical coupling (CC) mechanism, offers a compelling method to achieve complete suppression of scattered light. This phenomenon, a fascinating area in physics and optical engineering, involves two identical light waves incident on an absorptive material from opposite directions. The key to CPA lies in the destructive interference of the scattered light, effectively canceling it out on both sides. Numerous practical realizations of CPA have been reported, further validating the viability and potential applications of this concept. Several of these studies include metasurfaces, cylindrical structures, diverse heterogeneous metal-dielectric composite layers [3, 4], disordered medium, and exceptional points as absorbers to achieve CPA. However, all these scenarios suffer from serious drawbacks as these are based on the theory of complete destruction of two plane waves only. Since no light source is practically infinite in extent, i.e. plane wave in nature, the realization of CPA to date is an idealization of the true CPA. Notably, a ‘beam’ of finite extent consists of numerous partial plane waves, each traveling in different directions. Consequently, it is practically impossible to simultaneously satisfy the CPA conditions for all these individual plane waves. In this study, we address this issue by demonstrating that while true CPA is valid for plane waves, it does not hold perfectly for a coherent ‘beam’ with a finite spatial extent. Consequently, achieving perfect zero intensity out of a beam utilizing the CPA is impossible.

We invoke the vector angular spectrum method [5, 6] to explore the light-matter interactions of the individual plane waves incident on a heterogeneous metal-dielectric composite slab. The inherent dispersion of the slab leads to the CPA at a wavelength 562nm . The equal amplitude of the reflection and transmission coefficients, the required π phase difference, and the required dip in the $|r_f + t_b|$ in $\log$ scale are shown in Fig. 1. However, for a beam, the complete suppression can not be observed as seen in Fig 2

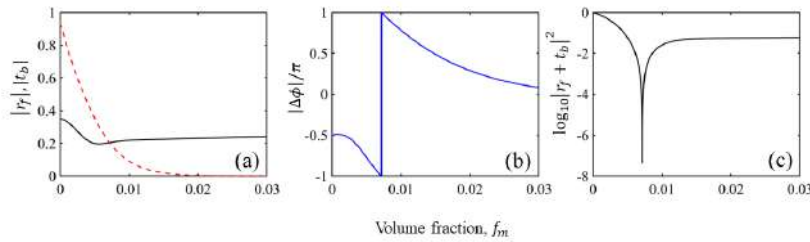


Fig. 1. (a) The absolute values and (b) the phases of the transmission and reflection coefficients of the forward (f) and backward (b) propagating plane waves. (c) The level of absorption in log scale.

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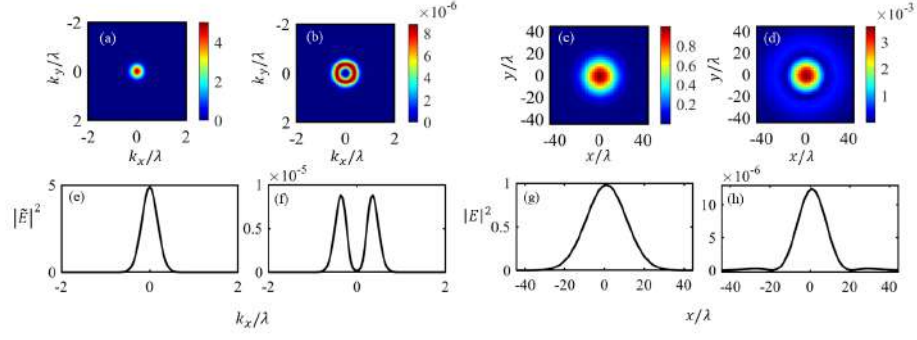


Fig. 2. (a) Incident and (b) scattered spectrum of a s-polarized Gaussian beam. (c) Incident and (d) scattered beam profile in real space. The line plots of the spectrum in (a) and (b) across $k_y = 0$ are plotted in (e) and (f) respectively. Similarly, the line plots of (c) and (d) across $y = 0$ are plotted in (g) and (h) respectively. Note that the scattered profile in (d) is contrast-enhanced to visualize better the side lobes that appeared due to the perfect absorption of the central k -vector as depicted in (b) or (f).

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All-Dielectric Chiral Metasurface for the Generation of Optical Skyrmions

Bharathy Jacob¹, Yogesh Natesan², Nithyanandan Kanagaraj^{1*}

1. Department of Physics, Indian Institute of Technology Hyderabad, Telangana, 502284, India

2. Department of Physics, National Institute of Technology Calicut, Kerala, 673601, India

Optical skyrmions are an emerging class of structured light fields, characterized by intricate particle-like topologies and significant potential to advance modern information technologies. Previous realizations using evanescent plasmonic fields [1] or free-space interferometric setups [2] required bulky, complex optics, limiting practicality. Here, we present a compact all-dielectric chiral metasurface capable of generating high-quality optical skyrmions. The generated skyrmions are characterized by their skyrmion number and demonstrate topological stability against variations in the incident polarization angle. This approach offers a pathway toward practical implementations of topologically enhanced remote super-resolution microscopy and robust optical information transfer.

Optical skyrmions are generated by the coherent superposition of two orthogonal scalar beams, with at least one carrying orbital angular momentum (OAM). While the choice of polarization basis—linear or circular—affects the polarization texture, it does not alter the topological charge or skyrmion number. In this work, we adopt a circular polarization basis, encoding a vortex phase profile with topological charge +1 on the RCP component and a plane-wave phase (charge 0) on the LCP component, producing the polarization field of a Stokes skyrmion (Fig. 2(b)). The Metaskyrmion Generator comprises two half-swastik Germanium chiral meta-atoms with high circular dichroism (CDT), functioning as a half-wave plates, enabling conversion from LCP to RCP, and enabling $0-2\pi$ geometric phase control via orientation (Fig.1). Unitcell A transmits only the LCP component, while Unitcell B, obtained by rotating Unitcell A by 90° about the x-axis, transmits only the RCP component. The vortex phase is encoded onto Unitcell A and the plane-wave phase onto Unitcell B, with the two interleaved to form the complete metasurface. When the metasurface is illuminated with the LP source, it generates optical Skyrmion (Fig.2(b)). The skyrmion number N_{sk} quantifies the topological nature of the polarization field by measuring how its vectors wrap around the Poincaré sphere [3]. The polarization vector fields in Fig. 2(c) shows an **saddle-type skyrmion** at polarization angle $\Phi_0=0^\circ$ whose texture rotates with Φ_0 , while preserving topology, while bottom row of Fig. 2(c) shows full Poincaré sphere coverage at all angles, confirming robust, tunable topological mapping. The proposed Metaskyrmion Generator is ideal for applications with limited polarization control.

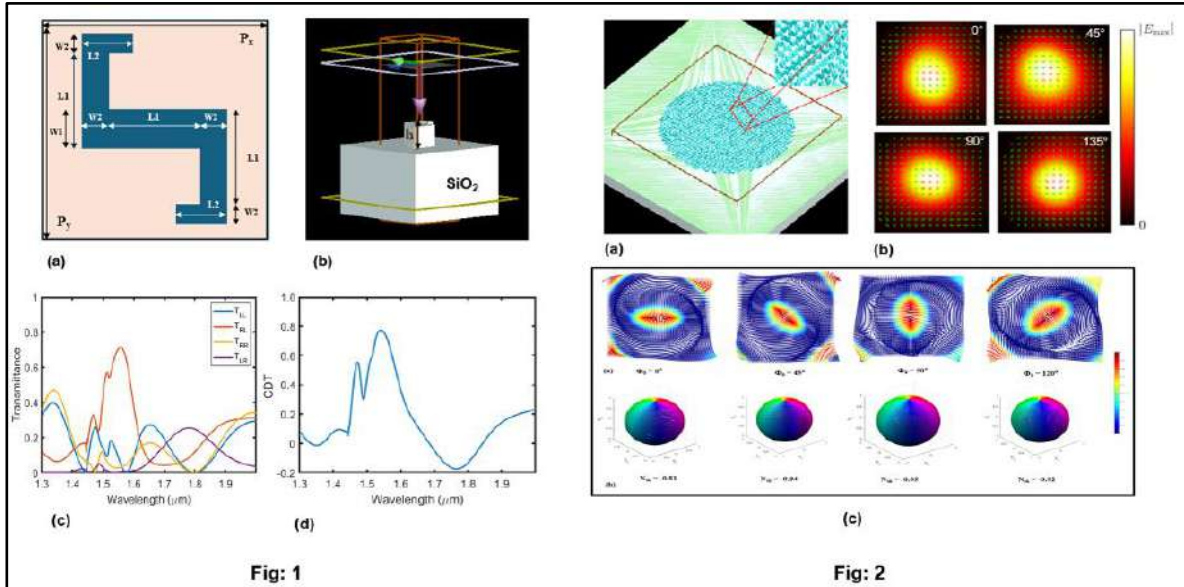


Figure 1: (a) and (b) shows the designed chiral unit cell with dimensions W1 = 205 nm, W2 = 102 nm, L1 = 400 nm, L2 = 200 nm, H = 500 nm, Px=Py = 1 μm. (c) and (d) shows the co and cross polarized transmittance and Circular Dichroism under CP illumination. Figure 2 : (a) Interleaved Metaskyrmion Generator (b), (c) represents the Topological polarization vector fields and its corresponding Poincaré sphere mappings under varying input polarization angles.

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Numerical Investigation of Electro-Optic Effect on Second Harmonic Generation Spectra in Segmented Quasi Phase Matching Devices

Ugrasen Singh¹, Abhinav Kumar², Prashant Povel Dwivedi^{2*}, Ajay Mishra³, Nimish Dixit³

¹Department of Physics, Manipal University Jaipur, Jaipur 303 007, Rajasthan India

²MUJ-NLO⁺ Research Lab, Department of Electronics and Communication Engineering, Manipal University Jaipur, Jaipur 303 007, Rajasthan India

³Instruments Research & Development Establishment (IRDE), DRDO, Dehradun- 248 008, Uttarakhand India

*prashant.dwivedi@jaipur.manipal.edu

Quasi-phase-matching (QPM) in periodically structured $\chi^{(2)}$ nonlinear crystals has become an essential technique for efficient frequency conversion in nonlinear optics, enabling applications such as high-performance optical parametric amplifiers and wavelength converters. However, one major limitation of conventional QPM devices lies in their fixed domain structure, which defines the phase-matching profile at the time of fabrication and cannot be altered thereafter. In previously developed QPM crystals, changing the temperature could shift the center wavelength of the phase-matching profile, but the overall spectral shape remained unchanged, limiting their tunability [1]. This restricts the adaptability of QPM devices in real-time applications. In contrast, segmented QPM structures, when combined with the electro-optic effect, offer a promising solution by enabling rapid, in situ modulation of the phase-matching profile shape not just its position during operation. Such controllable reshaping has significant potential for both narrow and broadband wavelength-conversion systems, expanding the functional versatility of QPM-based devices [1-3].

In this work, we conduct a theoretical investigation by introducing an electro-optically tunable three-segment QPM device. The structure includes two periodically poled outer segments and a central unpoled, single-domain region equipped with electrodes to apply an external electric field. This approach introduces a new method for modifying the form of a QPM intensity profile in situ using an external phase shift, while keeping the center wavelength constant. The QPM device is divided into three equal segments, where the middle portion is made of nonpatterned (single-domain) LiNbO₃ and is responsible for introducing the phase shift. The 1st and 3rd segments are periodically poled using conventional fabrication techniques. We simulate the SHG response using MATLAB for voltages of 0 V, +820 V, and -640 V. The results, shown in Fig. 1, clearly demonstrate a voltage-induced shift and reshaping of the SHG spectrum.

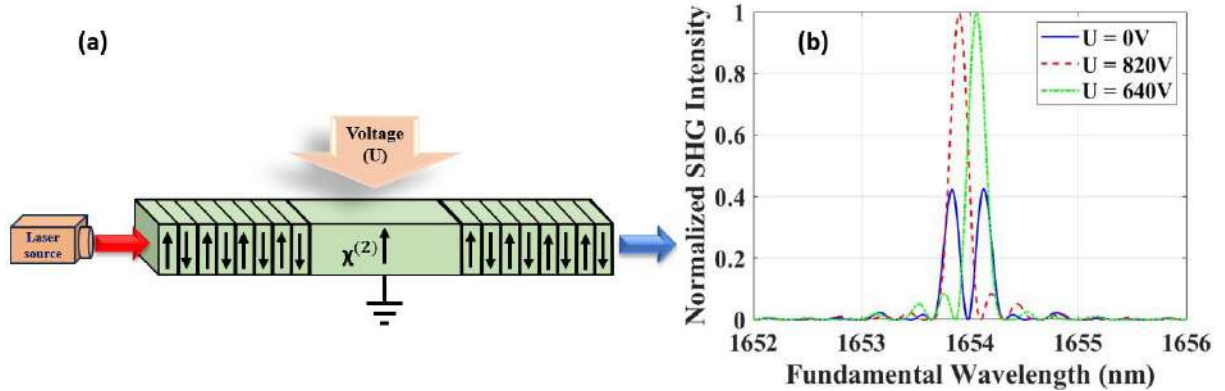


Fig. 1 (a) Schematic of a three-segment QPM LiNbO₃ device with electro-optic tuning, (b) Simulated normalized SHG intensity as a function of fundamental wavelength for applied voltages $U = 0$ V (blue), $+820$ V (red dashed), and -640 V (green dash-dot).

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Distribution Fitting Analysis in Tunable Diode Laser Absorption Spectroscopy

Nanda Nair A¹, Yedhu Krishna², Aravind Vaidyanathan³

¹Indian Institutes of Science Education and Research, Thiruvananthapuram- 695551

²Spectricle Scientific Pvt Ltd, Indian Institute of Space Science and Technology, Thiruvananthapuram- 695547

³Department of Aerospace Engineering, Indian Institute of Space Science and Technology, Thiruvananthapuram-695547

Tunable Diode Laser Absorption Spectroscopy (TDLAS) is a crucial laser diagnostic technique employed in combustion and aerospace applications. It enables non-intrusive temperature and species measurements in combustion systems. The main limitation of TDLAS is its path-integrated nature. We present a simulation-based study to evaluate the effect of different temperature distribution profiles on the temperature value estimated from the path-integrated absorption spectrum. Water vapor is a major combustion product and a popular target species in TDLAS applications. Therefore, water vapor absorption lines near 1392 nm, which can be scanned using a single diode laser [1], are considered for the simulation. Line parameters for spectral simulation are obtained from the HITRAN molecular spectroscopic database. Two idealized flame profiles are modeled to represent a flat-flame burner with an assumed peak temperature of 2000 K. Distribution fitting [2,3] is applied to retrieve the flame temperature from the path-integrated absorption spectrum, and estimates from both models are compared. Results show that the assumed temperature profile has a strong influence on TDLAS temperature accuracy, which impacts data interpretation.

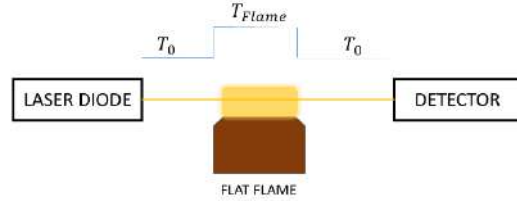


Fig. 1 Schematic diagram of the experimental set-up considered for simulation

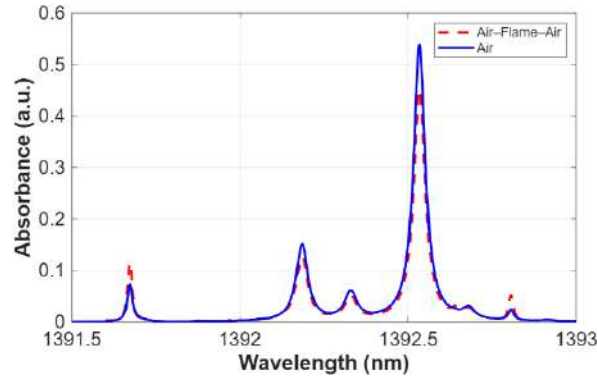


Fig. 2 Absorbance when only air is present and with flame in the beam path, as shown in Fig. 1

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Atomic-layered deposited mid-IR sensitive Superconducting Nanowire single photon detectors

Nidhi Choudhary^{1*}, Dmitry Morozov¹, Daniel Kuznesof¹, Vikas Vikas¹, Ciaran T. Lennon², Robert H. Hadfield¹

¹James Watt School of Engineering, University of Glasgow, Glasgow G12 8QQ, United Kingdom

²Oxford Instruments Plasma Technology, Govier Way, Bristol BS35 4GG, United Kingdom

Superconducting nanowire single-photon detectors (SNSPDs) are prized for their excellent sensitivity and performance across a wide wavelength range, from UV to mid-infrared [1]. SNSPDs are important advancements that enable quantum technology applications, such as quantum key distribution and single-photon LiDAR [2][3]. Advances in materials science, particularly with refractory metal nitride thin films such as niobium nitride (NbN) and niobium titanium nitride (NbTiN) [4], are crucial in enhancing SNSPD performance. Plasma-enhanced atomic layer deposition (ALD) is an advanced method that ensures exceptional film uniformity, making it ideal for a variety of applications. In this study, we present the fabrication and characterisation of NbTiN-based SNSPDs optimised for the near and mid-infrared wavelength range. The detectors were patterned on NbTiN film and operated in a closed-cycle cryostat at 0.9 K. The Figure below shows the current (I) vs voltage (V) characteristics of the fabricated detector on a 5 nm NbTiN ALD deposited film at 0.9 K base temperature. Photon detection rate was measured at different wavelength ranges, 1.5 μm , 2.0 μm , 2.9 μm and 3.5 μm under low dark count conditions, revealing high sensitivity across the measured wavelength bands. The combination of wide spectral coverage and high efficiency of our detectors based on ALD superconducting films indicates suitability for high-precision photon timing applications.

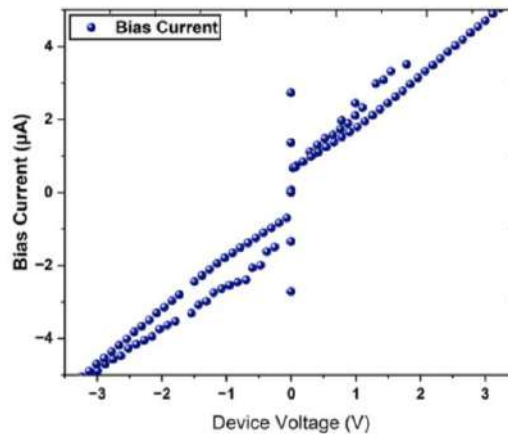


Figure 1: Current vs Voltage characteristics of SNSPD on 5 nm ALD NbTiN.

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Comprehensive investigation of the ultrafast excited state dynamics (ESA) and nonlinear optical (NLO) properties of SUDAN-IV push-pull chromophore molecule

S. Manvizhi^{1*}, M. R. Kannan¹, Raturaj Puranik², S. S. Prabhu², Naini Bajaj³, Amartya Sengupta³, T. Vijayakumar^{1*}

¹ Futuristic Materials Research Centre for Planetary Exploration, Department of Physics and Nanotechnology, College of Engineering and Technology, Faculty of Engineering and Technology, SRM Institute of Science and Technology, Kattankulathur - 603 203, Chengalpeta, Tamil Nadu, India

² Department of Condensed Matter Physics and Materials Science, Tata Institute of Fundamental Research, Mumbai, Maharashtra 400 005, India

³ Department of Physics, Indian Institute of Technology Delhi, New Delhi 110016, India

*Corresponding Authors Email id: ms7386@srmist.edu.in and vijayakt1@srmist.edu.in

Abstract

The intramolecular charge transfer (ICT) is an important phenomenon in nonlinear optical (NLO) materials. Tuning the ICT process in a molecule will help to modify the linear or NLO properties. Over decades, ICT processes have been explored in organic molecules exhibiting “push-pull” characteristics, where donor-acceptor moieties are connected through a π -bridge [1,2]. Our investigation is based on a combination of experimental (UV-Vis spectroscopy, FT-IR, FT-Raman) and computational (DFT) approaches. It is shown that: 1) the advanced optics helps in validating the ICT process in the molecule, 2) the computations, validated by different experimental data, are recommended as an extremely useful tool in the search for a greatly improved set of molecular NLO responses. The vibrational spectral investigations of SUDAN-IV have been comprehensively described with the FT-Raman and FT-IR spectra assisted by the density functional theoretical (DFT) computations to elucidate the contribution of vibrational modes to the linear electro-optic (LEO) effect. The influence of charge (CT) interaction between the phenyl ring and the dimethyl amino group of the nonlinear optical (NLO) chromophore on the endocyclic and exocyclic angles have been examined. To examine the effect of ICT on excited state absorption (ESA) and NLO properties using fs transient absorption spectroscopy (TAS) and z-scan experiments, respectively. TAS demonstrates the superposition of locally excited (LE) state based excited state absorption (ESA) and ICT-based ESA, effectively broadening the ESA at a longer time delay, influencing their NLO properties. The Z-scan study indicates an enhancement in two-photon absorption coefficient, and a variation in nonlinear refractive index at higher laser intensity, showing their potential for applications in nonlinear optical devices.

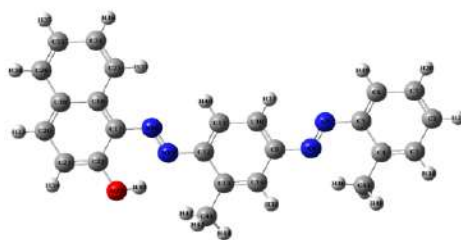


Fig.1. Optimized Molecular Structure of Sudan – 4

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Orbital Angular Momentum Encoded Photons from hBN Quantum Emitters Coupled to Hybrid Metasurfaces

Anagha K V¹, Anshuman Kumar^{1*}

1. Laboratory of Optics of Quantum Materials, Physics Department, Indian Institute of Technology

Bombay, Mumbai 400076, India

This study investigates, via both experiment and simulation, the on-chip generation of single photons carrying both spin and orbital angular momentum (SAM and OAM) using a dielectric-plasmonic hybrid metasurface. The platform consists of dielectric meta-atoms integrated on a plasmonic substrate, designed to couple efficiently with hexagonal boron nitride (hBN) quantum emitters. We present an optimization of the OAM metasurface to impart an azimuthally varying phase profile to the emitted radiation, enabling efficient emitter-SPP coupling and controlled outcoupling into free-space vortex beams with well-defined OAM topological charges. We demonstrate strong near-field confinement, efficient SPP excitation, and highly chiral far-field emission with low divergence, while preserving single-photon purity. The combination of SAM and OAM control in a compact, room-temperature-compatible architecture offers a promising route toward scalable, high-dimensional quantum light sources for advanced quantum communication and integrated photonic information processing.

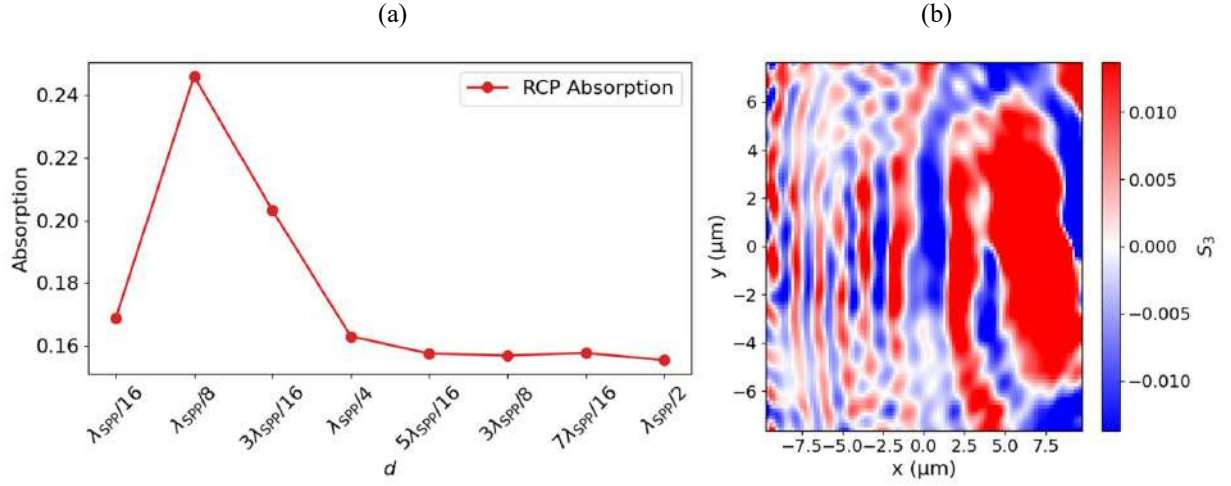


Fig. 1. (a) Absorption of RCP light as a function of nanorod separation d . (b) Simulated Stokes parameter S_3 distribution on the metasurface.

Photoluminescence Investigation of Er³⁺-Doped Ca₂SrWO₆ for Non-contact Optical Thermometry Applications

Chandan Rajpurohit¹, Naresh Degda¹

Department of Physics, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara-390002, India.

Er³⁺-doped Ca₂SrWO₆ phosphor was synthesized via high-temperature solid-state reaction. Stoichiometric amounts of high-purity CaCO₃, SrCO₃, WO₃, and Er₂O₃ (all AR grade) were weighed, mixed in an agate mortar for 30 min, placed in an alumina crucible, and calcined at 1200 °C for 12 h in air. The product was ground into fine powder for characterization.

X-ray diffraction (XRD) using a Bruker D8 Advance (Cu-K α , $\lambda = 1.5406 \text{ \AA}$) over $2\theta = 20^\circ\text{--}70^\circ$ confirmed the monoclinic phase of Ca₂SrWO₆, indicating successful Er³⁺ incorporation. Rietveld refinement verified phase purity and yielded lattice parameters matching calculated values [1].

Photoluminescence (PL) spectra, recorded on a spectrofluorometer, showed two intense green emissions at 526 nm and 560 nm upon 380 nm excitation, corresponding to the ²H_{11/2} → ⁴I_{15/2} and ⁴S_{3/2} → ⁴I_{15/2} transitions of Er³⁺. These thermally coupled levels enabled fluorescence intensity ratio (FIR)-based ratiometric thermometry. FIR measurements over the 300–500 K range displayed systematic, reversible variations, confirming suitability for non-contact temperature sensing [2].

The combination of phase-pure synthesis, structural validation, and temperature-dependent green emissions positions Ca₂SrWO₆:Er³⁺ as a promising, cost-effective, and efficient optical thermometry-material.

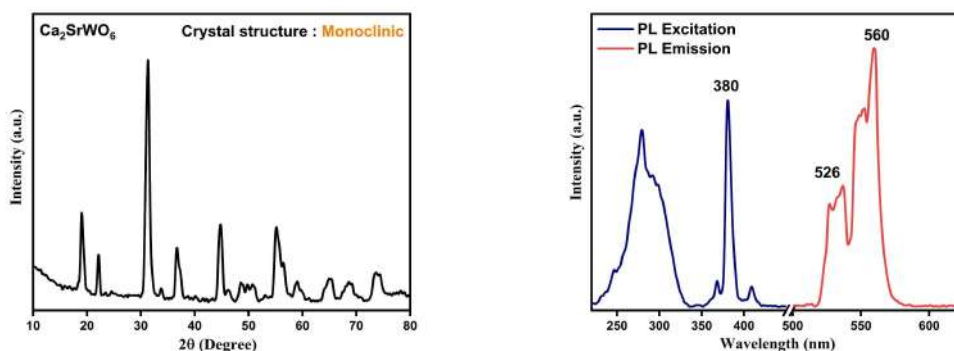


Figure 1. XRD pattern of Ca₂SrWO₆:Er³⁺ phosphor confirming monoclinic phase [1].

Figure 2. PL emission spectra ($\lambda_{\text{exc}} = 380 \text{ nm}$) showing green emissions at 526 nm and 560 nm from Er³⁺ transitions [2].

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Plasmon-Enhanced Whispering Gallery Mode Resonator for Label-Free Detection of Neural Spikes

Mahesh Kumar Pani, Amar Nayak, and Ramachandrarao Yalla*

School of Physics, University of Hyderabad, Hyderabad, Telangana 500046, India

rrysp@uohyd.ac.in*

The real-time, label-free detection of neural action potentials is quite challenging in neuroscience and brain-computer interfaces. We proposed a novel hybrid neurophotonic sensor designed for this purpose, by coupling a Whispering Gallery Mode (WGM) micro-resonator to an Optical Nanofiber (ONF) evanescently [1] as shown in Fig. 1 (a), enhancing its sensitivity by gold (Au) nanorods. Our detection is primarily based on the modulation of the resonator's optical properties via the electro-optic effects induced due to the transient electric field produced during the neural spike event in the nearby local region of our proposed hybrid system due to Kerr's effect [2,3]. We have developed a comprehensive hybrid simulation framework as shown in Fig. 1 (b) by integrating a computational neuroscience simulator (NEST) with a finite-difference time-domain (FDTD) photonics simulator (MEEP) [4,5]. We have generated biologically realistic action potential (~ 100 mV peak) using the Hodgkin-Huxley model [4]. The photonic structure of a $2.5\text{ }\mu\text{m}$ radius WGM resonator coupled to a 400 nm diameter ONF with a 10 nm gap was modelled, and its transmission spectrum was simulated under three conditions. The first one is a baseline system without plasmonic elements, the second one is a plasmon-enhanced system with a single $40\times 80\text{ nm}$ Au nanorod, and the third one is the plasmon-enhanced system during the peak of a neural spike.

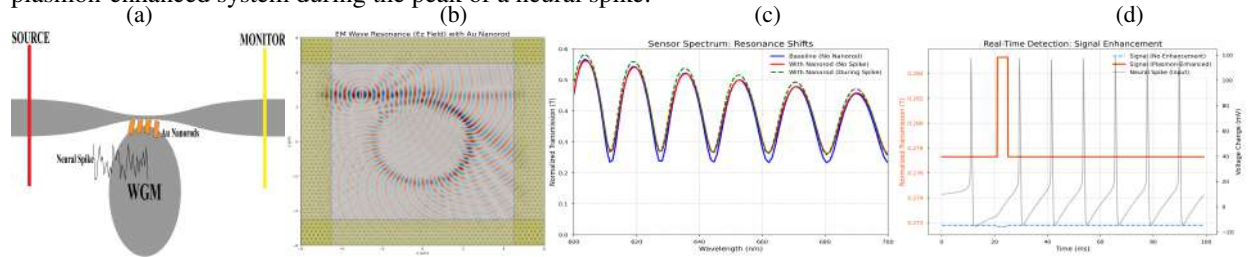


Fig. 1 (a) Schematic diagram of Hybrid system, (b) Plasmon enhanced EM field pattern in WGM, (c) Sensor spectrum; Resonance shifts with and without Au nano rod and neural spike, (d) Real time neural spike detection: signal enhancement.

Results: From the above simulation results we get strong clear visual confirmation of the sensor's mechanism and performance. The transmission spectra clearly demonstrate the effect of the addition of the Au nanorod induces a significant plasmonic coupling effect, leading to the red-shifting the primary resonance dip from 604 nm to 626 nm as shown in Fig. 1 (c). A further, smaller spectral shift was observed during the simulated spike, revealing the detection principle. A real-time analysis, plotting the optical output against the neural input, showed that the unenhanced sensor's signal remained flat and unresponsive but we saw plasmon-enhanced sensor's signal exhibited a distinct jump in transmission from a baseline of 0.277 to 0.285 , perfectly synchronized with the action potential pattern as shown in Fig. 1 (c), (d). This corresponds to a final detection signal of $+2.86\%$ change in transmission loss, a dramatic improvement over the negligible -0.016% from the unenhanced system as shown in Fig. 1 (d). This study successfully demonstrates the proof-of-concept for the proposed hybrid neurophotonic sensor and its functionality. The inclusion of a single Au nano rod amplified the detection signal by a factor of over 130 , converting a negligible response into a strong, real-time optical signal that directly traces the input neural waveform pattern. These findings validate the system's design and form the base for developing ultra-sensitive, label-free neural probes.

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Recovery of Spatial Quantum Correlation Distribution in Structured Bright Twin Beams

Jerin A Thachil*, Chirang R Patel, and Ashok Kumar †

Department of Physics, Indian Institute of Space Science and Technology
Thiruvananthapuram, Kerala, 695547, India

*jerinthachil@gmail.com and †ashokkumar@iist.ac.in

Spatial quantum correlations are a valuable resource for quantum technologies, owing to the inherently high-dimensional nature of their associated Hilbert space [1]. Understanding the dynamics of these spatial correlations is crucial for their effective manipulation and engineering in applications such as quantum information processing and quantum imaging [2, 3]. Here, we experimentally investigate the self-healing behaviour of transverse spatial quantum correlations in structured bright twin beams generated using a four-wave mixing process in a double- Λ configuration in hot ^{85}Rb vapor. The spatial quantum correlations are examined by performing intensity difference noise measurements on selected spatial subregions of the structured twin beams.

In the experiment, a strong pump beam is overlapped with a weak seed probe beam at an angle of 0.4° inside a ^{85}Rb cell to generate bright twin beams, probe and conjugate. We prepare the input seed probe beam in a superposition of Laguerre-Gaussian (LG) modes with topological charges l_1 and l_2 , to generate structured bright twin beams having petal-like transverse intensity distribution. To investigate the self-healing of spatial quantum correlations, we partially block the generated probe and conjugate in the near field using a knife edge and examine the spatial quantum correlation distribution in the far field. Figure 1 (a) and (c) present the spatial intensity profiles of the partially blocked twin beams in the near-field (top row) and their corresponding far-field (bottom row) distributions, when the seed probe is in a superposition of $l = 3$ and -3 , and $l = 3$ and -2 , respectively. In both cases, the probe and conjugate beams recover their spatial intensity profiles in the far field. This self-healing phenomenon is attributed to the transverse energy flow within the beams, governed by the Poynting vector.

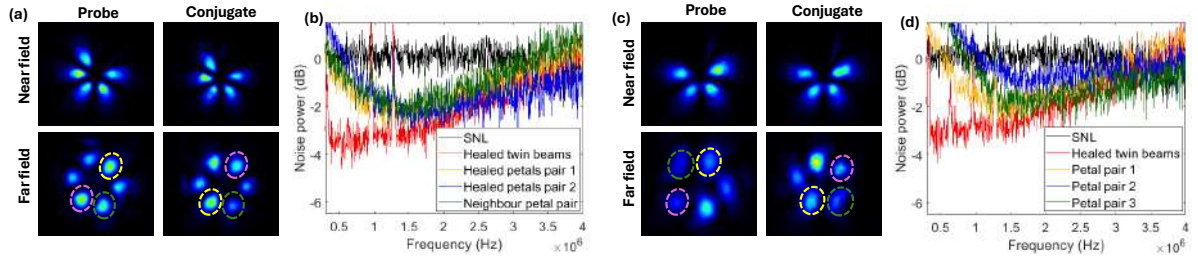


Figure 1: Spatial intensity profiles of the generated probe and conjugate in the near field (top row, (a,c)) and far field (bottom row, (a,c)) with the seed probe in a superposition of (a) $l = 3$ and -3 ; (c) $l = 3$ and -2 . (b) and (d) show the intensity difference noise as a function of analysis frequency for the configurations in (a) and (c), respectively.

Furthermore, the spatial quantum correlations between the healed twin beams are investigated through intensity difference noise measurements, and the results are shown in Figs. 1 (b) and (c). In Fig. 1(b), the seed probe is prepared in a superposition of LG modes with $l = 3$ and -3 . When one of the bright petals, located on the same side in both the probe and conjugate beams, is blocked in the near field, the resulting healed twin beams in the far field exhibit ~ 3.5 dB of squeezing (red trace). To determine whether individual petals retain spatial quantum correlations, we perform intensity difference measurements by selecting only diametrically opposite petal pairs in the probe and conjugate (highlighted by dashed circles of matching colors). Interestingly, each petal pair, including the previously blocked (healed) ones (yellow and blue traces), shows squeezing of ~ 2 dB, confirming the presence of quantum correlations between these spatial subregions in probe and conjugate. A degradation in squeezing is observed at lower analysis frequencies (< 1.5 MHz), which can be attributed to the two-beam coupling effect, that induces cross-talk among different spatial modes at the probe frequency. A similar behaviour in the squeezing traces can be seen in Fig.1 (d), where the input seed probe is in a superposition of $l = 3$ and -2 .

These results confirm that the photons contributing to the regenerated petals in both the probe and conjugate beams are spatially correlated. They are generated together within the bright regions in the near field and propagate toward the blocked regions, effectively reconstructing the spatial structure while preserving the underlying quantum correlations.

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Optical Design and analysis of a three mirror based compact multispectral imager for remote sensing applications

Gokul G. Nair¹, Moumita Dutta¹ and Somya S Sarkar¹

1. Space Applications Centre, Indian Space Research Organization, Ahmedabad, Gujarat 380015, India

This paper presents the design and analysis of a compact three mirror anastigmatic(TMA) based multispectral imager for remote sensing applications such as environmental monitoring, water resources management, disaster management etc. across IRS bands 1 to 4 ($0.45 - 0.86 \mu\text{m}$). The imager is having a focal length for 280 mm with F/# 4 and field of view of $\pm 7^\circ$. It is optimized for high performance observation in the visible to near-infrared range. The system is designed to be compact, aligning with the growing demand for smaller, more efficient payloads. The TMA configuration ensures minimal optical aberrations and high diffraction limited performance across a wide field of view, while maintaining the compact form factor. Simulations demonstrate excellent modulation transfer function (MTF) and low distortion, making this system ideal for space borne remote sensing applications requiring compact, high resolution imaging capabilities.

Keywords: Remote sensing, Three mirror anastigmatic, Aberration, Modulation transfer function, Distortion, Resolution

Introduction: Efficient and high-resolution remote sensing systems are critical for observing Earth's surface across diverse spectral bands. Conventional refractive designs often struggle to balance compactness with image quality and chromatic aberration control. To address these limitations, we propose a compact, off-axis three mirror anastigmatic (TMA) design for a multiband imager tailored for remote sensing applications. This design offers superior aberration correction (Spherical, coma and astigmatism), wide spectral coverage and minimized instrument volume- attributes especially crucial for space borne or airborne platforms.

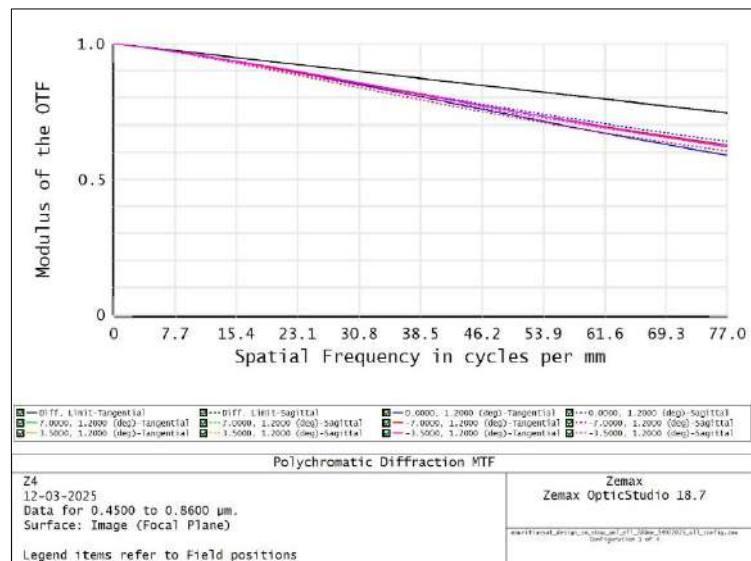
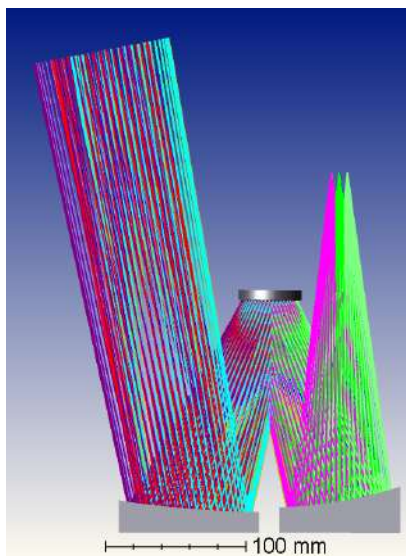


Figure 1: Optical Schematic of the TMA **Figure 2: Broadband (450 – 860 nm) MTF as a Function of Spatial Frequency**

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SCOPOSIS 2025

(Dynamics and Instability of Liquid Jet Fragments Driven by Femtosecond Laser)

Tamanna¹, S. Sree Harsha¹, Sourabh Singh¹, Prashant Kumar Singh¹

1. Tata Institute of Fundamental Research, Hyderabad 500046, India

The Rayleigh–Plateau instability is a fundamental phenomenon in fluid dynamics that describes the breakup of a cylindrical liquid jet into droplets due to surface tension forces. This instability arises from the liquid's tendency to minimize its surface area, resulting in droplet formation from a continuous jet. This study investigates the dynamics and instability of a cylindrical liquid jet impacted by femtosecond laser pulses, focusing on droplet formation and stability under varying pressure conditions and laser repetition rates.

In the absence of laser pulses, the jet undergoes natural Rayleigh–Plateau instability, forming spontaneous fluctuations and droplets along its length. However, when femtosecond laser pulses interact with the jet, the irradiated region experiences localized heating and rapid expansion, creating a pronounced curvature that enhances fragmentation. This laser-induced breakup is governed by surface tension and results in discrete droplet formation.

By fixing the pressure and varying the laser repetition rate, segments of different lengths were observed. Lower repetition rates produce longer jet segments with noticeable fluctuations, while higher repetition rates yield shorter segments with more uniform droplet patterns. This demonstrates a predictable breakup behaviour influenced by laser parameters.

Detailed data analysis was conducted to investigate the spatial correlation of droplets within segments of varying lengths. Longer fragments showed correlations approaching those of natural breakup, as the increased time between adjacent laser pulses allows droplets more time to evolve. Additionally, analysis of the fluid area within the fragments revealed common fluctuation patterns, indicating consistent breakup dynamics.

Understanding these interactions is crucial for applications in inkjet printing, material processing, and medical diagnostics. The ability to probe fluid instabilities and droplet formation on ultrafast timescales provides new insights into controlled droplet generation and jet dynamics under tailored conditions.

Through this comprehensive approach, the research offers detailed insights into the behavior of liquid jets under high-intensity femtosecond laser pulses, emphasizing the role of repetition rate and pressure in controlling droplet stability and uniformity. The findings contribute to fields that depend on precise droplet manipulation, including ink-jet printing, targeted material deposition, and medical diagnostics. This study not only advances understanding of fluid instabilities and controlled droplet generation but also provides critical data for optimizing processes that require reliable droplet ejection.

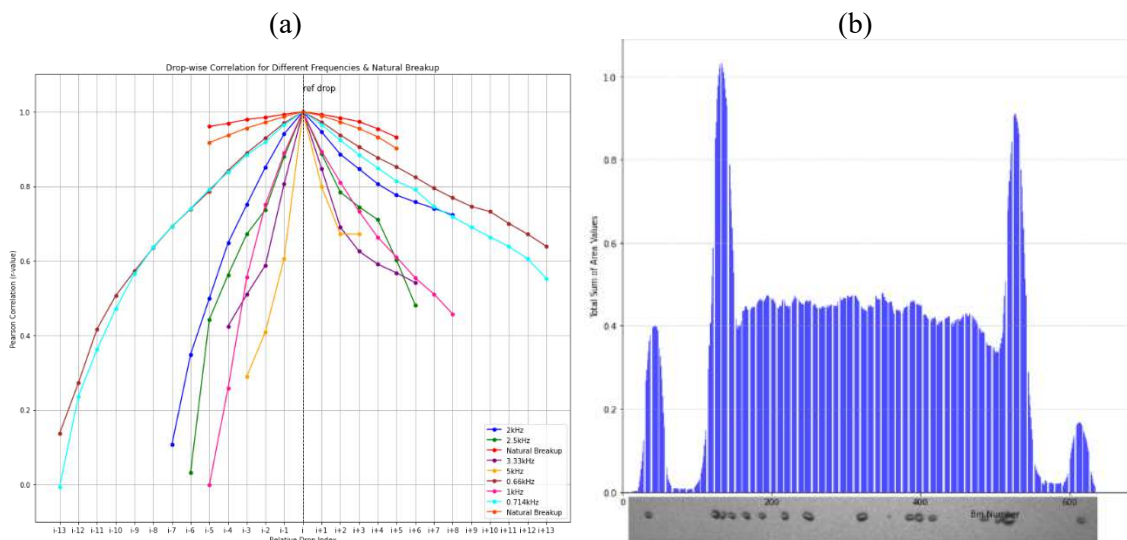


Fig. 1 (a) Spatial correlations for different laser rep rates vs natural breakup.

(b) Fluid area within the fragment length over the period of time for 1kHz rep rate.

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Large Core Hollow Bragg Fibers: A Modelling Method

Ajay Kumar^{1*} and Anurag Sharma^{1,2}

¹Department of Physics, Indian Institute of Technology Delhi, New Delhi, 110016, India

²Optics & Photonics Centre, Indian Institute of Technology Delhi, New Delhi, 110016, India

^{*}ajaykumar.physics.iitd@gmail.com

Hollow core Bragg fibers are used for their low propagation loss and strong light confinement for applications like chemical and biological sensing, terahertz guidance, and optical communications. The periodic high and low refractive index layers surrounding the hollow core form photonic bandgaps, allowing propagation of guided modes in a specific wavelength range. For applications in sensing, usually large core fibers (diameter ~ 0.5 - 1.0 mm) are used so that the measurand liquids could be injected into the core easily [1]. Modelling of such large core Bragg fibers becomes challenging due to highly non-uniform distribution of media with different refractive indices as the core of few hundred microns is surrounded by 20-25 bilayers of high and low refractive indices each of thickness of a fraction of a micron. This makes discretization of the radial domain for numerical solution very difficult as the field varies very slowly over the large core and very rapidly in the bilayers. We have developed a method to transform the radial domain so that the field variation is on a similar scale in the two regions. This also transforms the wave equation which is then solved to obtain the propagation characteristics of the propagating modes.

We have used the radial collocation method which has been specially adapted for azimuthally symmetric structures, like Bragg fibers, fiber gratings, fiber tapers, and ring-core fibers in order to solve the scalar wave equation efficiently in polar coordinates [2-3]. Unlike the FEM and the FDTD, which are computationally intensive in Cartesian coordinates, radial collocation leverages symmetry, offering faster, more efficient propagation [2-4]. We have implemented a suitable variable-transformation in the collocation method [5] to model the large core Bragg fibres. The transformation redistributes the collocation points (sample points) so as to increase their density in desired regions. As an example, we consider a Bragg fiber with a 0.8 mm diameter core, and 25 bilayers of high and low refractive indices (please see Fig.1(a)). Each high index layer has an index of 1.59 with thickness $0.13 \mu\text{m}$, and the low index layer with refractive index 1.49 and thickness is $0.37 \mu\text{m}$ (see Fig. 1(a)). The central wavelength used is $0.584 \mu\text{m}$. The refractive index of the core is 1.333 (water) [1]. The modeling is done using the variable-transformed collocation method with 380 collocation points. Without transformation, over would have to use more than 10,000 points so that there are sufficient points in the thin layer to model the field appropriately. The results are shown in Fig. 1(b). Our method represents a computational advantage by at least two orders of magnitude. More result will be presented in conference.

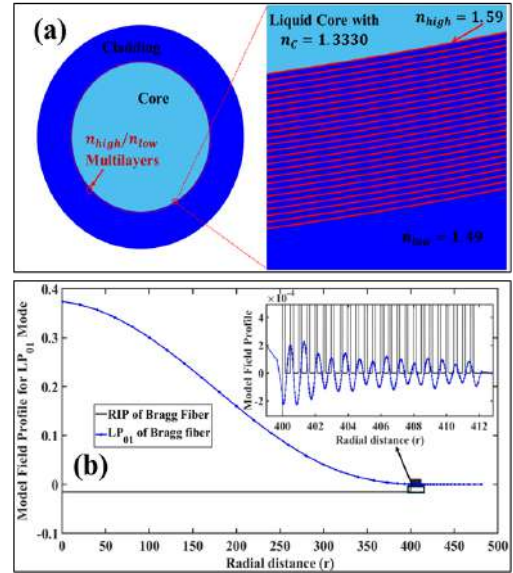


Fig. 1(a) Large hollow core Bragg fibre (b) LP_{01} mode of the fibres

Anurag Sharma is a NASI Distinguished Chair Professor and acknowledges support from the National Academy of Sciences, India (NASI).

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Investigation of NV Center Ground-State Spin for Precision Quantum Sensing

Rahul Dhankhar,¹ Durga Dasari,² Rajesh V Nair,^{1*}

¹Laboratory for Nano-scale Optics and Meta-materials (LaNOM), Department of Physics, Indian Institute of Technology Ropar, Rupnagar, Punjab, India

²3rd Institute of Physics, IQST, and Research Centre SCoPE, University of Stuttgart, Stuttgart, Germany

*Email: rvnair@iitrpr.ac.in

Color centers in diamond have emerged as a versatile solid-state quantum system with applications spanning quantum information processing, quantum computation, and precision sensing, owing to their remarkable spin-dependent optical emission properties and robustness under a wide range of environmental conditions [1]. Among these defects, the negatively charged nitrogen-vacancy (NV⁻) center-formed by a substitutional nitrogen atom adjacent to a vacancy in the diamond lattice-has attracted significant attention. The NV⁻ center hosts a ground-state electronic spin triplet (³A₂) that can be coherently manipulated using resonant microwave fields, optically initialized, and read out via spin-dependent fluorescence, even at room temperature. This unique combination of quantum coherence, optical addressability, and ambient-condition operability is enabled by the optically detected magnetic resonance (ODMR) technique, wherein microwave-induced spin transitions produce measurable changes in fluorescence intensity [2]. These properties position the NV⁻ center as a leading candidate for high-precision, nanoscale sensing of magnetic, electric, strain, and thermal fields. In particular, NV-based quantum magnetometry has emerged as a powerful tool for detecting weak magnetic fields with nanometer-scale spatial resolution, enabling applications that range from imaging current flow in nanoscale devices to probing spin textures in condensed-matter systems [3]. One promising area of application lies in the detection and characterization of magnetic nanoparticles, which play crucial roles in environmental monitoring, targeted drug delivery, magnetic resonance imaging contrast enhancement, and biosensing [4]. The high sensitivity and spatial resolution of NV-based magnetometers make them ideally suited for quantifying the magnetic fields produced by such nanoparticles, both in static and dynamic environments. In this work, we present the fundamental operating principles of NV-based magnetometry, followed by a quantitative framework for estimating the magnetic field as detected by NV centers in diamond. These findings underscore the potential of NV-based quantum sensing to advance nanoscale magnetic imaging, facilitate materials characterisation, and enable precision studies in biomagnetism and related disciplines.

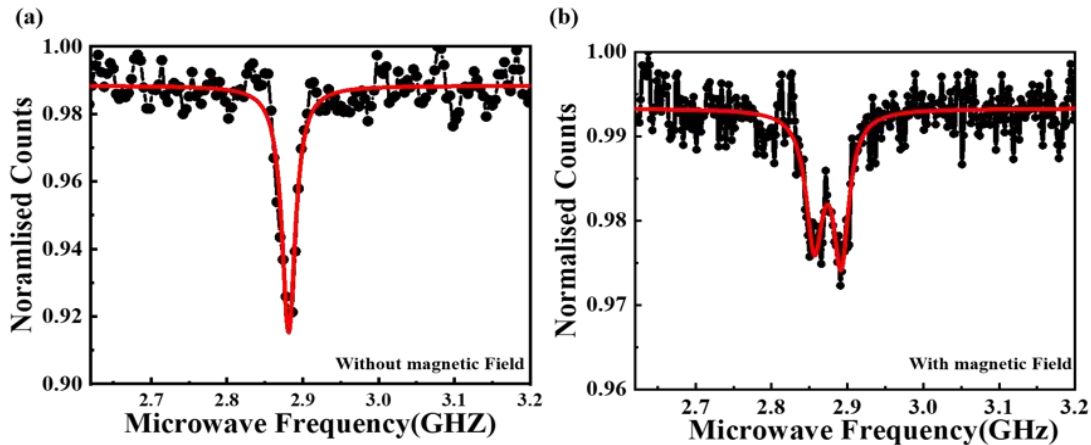


Figure 1: ODMR spectra of NV centers in diamond. The black markers represent experimental measurements, and the red solid curves correspond to theoretical fits. (a) Spectrum without an external magnetic field. (b) Spectrum under a static magnetic field generated

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Adaptive Quadriwave Lateral Shearing Interferometry Using Multiplexed Gratings for High-Sensitivity Wavefront Sensing

Jubin Jacob, Akshit Rajput and Biswajit Pathak*

Applied and Adaptive Optics Laboratory, Department of Physics, Indian Institute of Space Science and Technology,
Thiruvananthapuram, 695547 Kerala, India

*E-mail : biswajitpathak@iist.ac.in

Abstract: In the present work, we design and implement an adaptive quadri-wave lateral shearing interferometry (QWLSI) system that employs a multiplexed grating pattern, realized on a spatial light modulator to dynamically optimize system parameters, enabling high-resolution and highly sensitive wavefront sensing.

Summary: Phase measurements via wavefront distortion caused by the sample under observation can be measured using wavefront sensors like a Shack-Hartman Wavefront Sensor (SHWS). However, SHWS accuracy is quite low due to the poor spatial sampling that is limited by the lenslet size.

An efficient high resolution phase measurement method based on QWLSI is employed to accurately estimate wavefront distortions [1]. QWLSI utilizes a specialized grating known as a chessboard grating or modified Hartman mask, that splits the incident wavefront into four sheared replicas, producing four-wavefront interference. However, this grating is difficult to fabricate and requires exceptional precision to improve both sampling and transmittance. Once developed, these grating lacks parameters to regulate or optimize its wavefront sensing capabilities, such as sensitivity and dynamic range, using the grating itself. As a result, this study introduces an adaptive QWLSI system, by employing computer generated holography to dynamically optimize system parameters and enhance sensitivity. As shown in Fig. 1, this grating ensures an interference of four wavefronts diffracted by it in four directions.

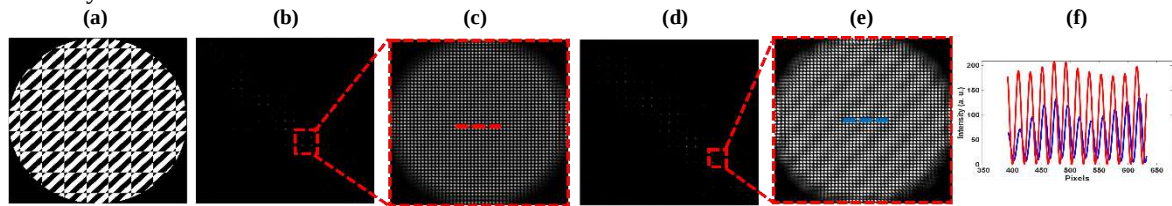


Fig. 1 (a) Multiplexed checked grating (b), (e) Higher orders in the Fourier plane that are further isolated and propagated again to execute QWLSI as shown in (c), (d), (f) and (g).

The modulation in the interferogram's intensity arises due to the amount of shear provided by a distorted wavefront while transmitting through the grating. Therefore, by controlling the grating frequencies and the transmittance using the SLM, the beam quality and shear among the interfering wavefronts can be controlled. This results in an interferogram that has the wavefront distortion information only. The measurement of the wavefront gradient via Fourier analysis of the interferogram [1] recovers the incident wavefront as shown in Fig. 2. By adjusting the grating's duty cycle, similar higher orders from the Fourier plane of the grating can be further used to build QWLSI, as illustrated in Fig. 1(e). It is possible to achieve a higher intensity modulation and control the interferogram's intensity, even for weaker distortions, via a sample, using the higher frequency information, thereby enhancing sensitivity without compromising the system's dynamic range. Additionally, one can modify the sensitivity by scaling the reconstructed wavefront under a specific boundary and applying it as a bias to the grating and reconstructing again, thus obtaining a more precise wavefront.

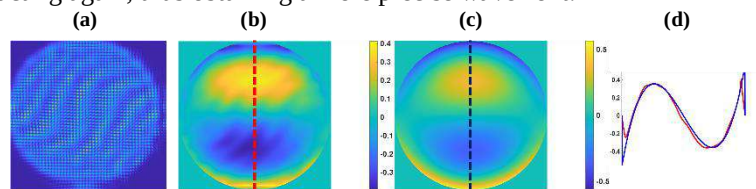


Fig. 2 (a) QWLSI under an aberrated wavefront (b) Reconstructed wavefront (c) Actual wavefront (d) 1D plot of the actual and the reconstructed wavefronts

Thus, the proposed adaptive QWLSI, leveraging the multiplexed grating, offers a wavefront sensing approach that facilitates high resolution, high sensitivity, programmable controllability, all while preserving dynamic range.

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Crosstalk correction for accurate correlation measurements in SPAD arrays.

Nikhil Shrivastava¹, Abhishek Yogi¹, Venkata Jayasurya Yallapragada¹

¹. Indian Institute of Technology Kanpur, Kanpur, Uttar Pradesh 208016, India.

In recent times correlation measurements have become the standard measurement, not only in the field of quantum optics, but also in nanoscale optics, biophysics and others. Traditionally, this was done, using two separate single photon avalanche diodes (SPADs), which can be difficult to integrate into a complex setup, where doing a correlation measurement is advantageous. With recently developed SPAD array detectors [1], now doing the same is as simple as adding a camera in the main path, without any need of splitting the signal that leads to loss of counts. On the downside, SPAD arrays exhibit artefacts like crosstalk [2] which refers to the situation where a detection in one pixel of the array causes a spurious detection in another pixel. Crosstalk adds significant complexity to the analysis, as it often depends on the exact pattern in which the pixels are illuminated. In this work, we aim to investigate the nature of crosstalk in SPAD arrays, characterize its non-uniform behaviour and provide a correction scheme which covers broad area of correlation analysis.

Here, we mainly deal with optical crosstalk which is due to photons penetrating the boundaries between two pixels. These photons are generated by the recombination that occurs during the avalanche within a pixel. Crosstalk manifests itself as the false peak near $\tau = 0$, in the second-order photon correlation plot (Fig. 1a).

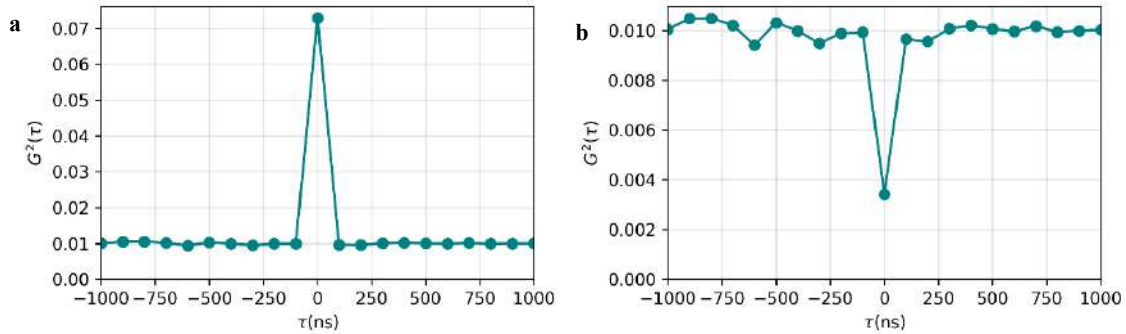


Fig. 1. Effect of crosstalk and its correction. Second order photon arrival time correlations $G^{(2)}(\tau)$ for: **a.** SPAD array data, with uncorrelated illumination. The bump is due to the presence of crosstalk, **b.** Corrected correlation plot for the same data. The dip is below the half value of side band, confirming presence of single photon emitter.

To correct for the crosstalk, it is needed to associate probability of crosstalk between two pair of pixels. To accurately determine these, we first illuminate the detector with uncorrelated light source in a similar way as done in the experiment in which we have to perform the correlation measurement. Whatever correlation we observe here beyond the noise level, is due to crosstalk as the illumination is uncorrelated. The area of the peak is directly proportional to the probability of the crosstalk event. By calculating the area of the crosstalk peak between pairs of pixels for different types of illumination we also characterize any asymmetry and non-uniformity in crosstalk across the detector. This enables us to determine second order correlation function (Fig. 1b) and fast spectral dynamics with enhanced accuracy.

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Three-Dimensional Polarization Structure: From Paraxial to Full-Vector Singularities

Mayank Soni* and Nirmal K. Viswanathan

School of Physics, University of Hyderabad, Gachibowli, Hyderabad 500046, India

*Email: 23ipmp03@uohyd.ac.in

This work details the development and application of a computational framework for simulating and analyzing the three-dimensional polarization structure of complex optical fields. Initial explorations with simplified $\mathbf{k}$ -cone-based wave models established the viability of the plane wave superposition approach for generating and visualizing $\mathbf{E}$, $\mathbf{B}$, and Poynting vector fields. We then progressed to a more rigorous paraxial model based on superposition of plane waves with a Gaussian $\mathbf{k}$ -space distribution, a standard representation for generic speckle fields. Using analytic field derivatives and a Newton-Raphson solver, we developed a robust pipeline for the high-precision location and classification of C-point polarization singularities.

This framework is rigorously validated through comprehensive statistical analysis. We confirm the local distribution of Star, Lemon, and Monstar types (50.0:44.7:5.3) [1]. Crucially, by varying both wavelength k and beam spread $\sigma_{k\perp}$, we map the C-point density (d_c) across the full spectrum of field behavior. These results demonstrate the theoretical transition from an isotropic ($d_c \propto k^2$) to a paraxial ($d_c \propto \sigma_{k\perp}^2$) regime [1,2], as shown in Fig. 1(a).

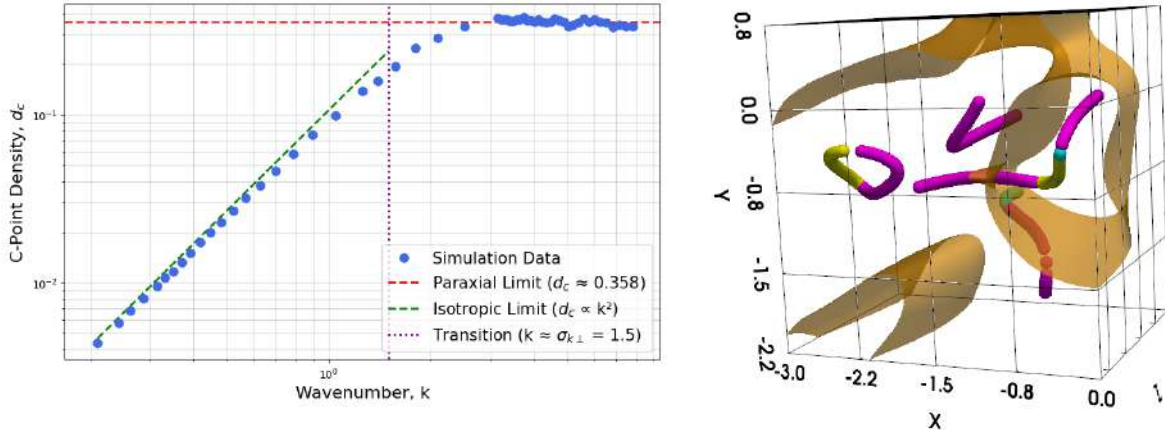


Fig. 1(a) Simulated d_c vs. k (log-log scale), showing a transition from isotropic ($d_c \propto k^2$) to paraxial ($d_c \propto \sigma_{k\perp}^2 = \text{constant}$) regimes. Theory and transition lines ($k \approx \sigma_{k\perp}$) shown for comparison.
(b) 3D rendering of C-lines color-coded by type (magenta: star, cyan: monstar, yellow: lemon) and L-surfaces. Loop illustrates topological event of C point creation and annihilation.

Extending this 2D Stokes-based model into three dimensions, we visualize the volumetric nature of C-lines and L-surfaces, capturing topological events such as C-point pair creation and annihilation (Fig. 1(b)). However, this extension reveals the fundamental limitations of the paraxial approximation. We therefore developed a full-vector simulation engine capable of describing arbitrary non-paraxial fields. This allows a more physically accurate definition of singularities based on 3D vector invariants: true circular singularities (C^T) where $\mathbf{E} \cdot \mathbf{E} = 0$, and true linear singularities (L^T) where the polarization ellipse area vanishes ($\Re(\mathbf{E}) \times \Im(\mathbf{E}) = \mathbf{0}$) [3]. Preliminary analysis directly compares these true vector singularity structures with their paraxial Stokes counterparts, revealing the regimes where the simpler model is valid and where it fails. More details will be presented in the conference presentation.

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MIM Metasurface with Enhanced Infrared Absorption at Glancing Incidence for Stray Light Mitigation

Jhuma Pan¹, Sachin Kumar Srivastava^{1,2}

1. Department of Physics, Indian Institute of Technology Roorkee, Uttarakhand, Roorkee 247667, India

2. Center for Photonics and Quantum Communication Technology, IIT Roorkee, Uttarakhand, Roorkee 247667, India

Abstract: A flexible metal-insulator-metal (MIM) metasurface absorber with 97% absorption in the near-infrared (NIR) at 83° incidence for TM-polarized light has been developed to enhance the signal-to-noise ratio by suppressing unwanted oblique IR radiation.

Introduction: The performance of space optical systems degrades due to the presence of stray light at large incidence angles, reducing efficiency [1]. Traditional solutions like baffles are bulky and unsuitable for weight-constrained environments [2]. Metasurfaces offer planar, lightweight alternatives for selective absorption of oblique IR light. Here, we demonstrate a 1D MIM metasurface absorber optimized for grazing-angle NIR absorption. The absorber structure consists of periodic Ag-TiO₂-Ag layers on a flexible polydimethylsiloxane (PDMS) substrate with 1450 nm periodicity. The PDMS substrate was patterned using a compact disc (CD) template directly transferred to the polymer. The deposition of Ag and TiO₂ films was performed by using physical vapor deposition technique. To understand the requirement of a MIM structure, a plasmonic absorber (PA) with a 100 nm Ag layer was fabricated on similar 1D patterned PDMS substrate and its performance was compared with that of the MIM. Figs. 1a and 1c show the FE-SEM cross-sectional view of the PA and MIM metasurface structures, respectively. Simulations in COMSOL Multiphysics software were performed for the PA and MIM absorber considering their geometrical parameters obtained in FE-SEM to support the experimental results. The Floquet periodic boundary conditions and periodic ports at substrate and superstrate (air) side were employed.

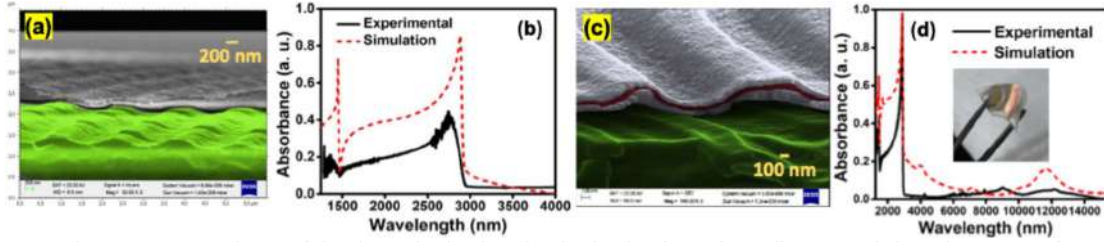


Fig. 1: (a) FE-SEM image of the plasmonic absorber. (b) Simulated and experimentally measured absorption spectra of plasmonic absorber at $\theta_i=83^\circ$ for TM polarized light. (c) FE-SEM image of the MIM absorber. (d) Simulated and experimentally measured absorption spectra of MIM absorber at $\theta_i=83^\circ$ for TM polarized light. Inset shows the image of absorber sample held in a tweezer.

Results & Discussions:

Optical characterization of the fabricated absorbers was performed using Fourier transform infrared (FTIR) spectrometer (1250-15500 nm) equipped with a variable angle specular reflectance accessory with an angle adjustment system (30°- 83°) and an IR polarizer [3]. Absorption spectra were obtained by measuring the specular reflectance from the top side, and having zero transmittance ($T = 0$) due to the thick bottom metal layer. Fig. 1b shows the absorption spectra of PA with maximum absorbance of 46% at the resonance wavelength (λ_{res}) of 2881 nm. The absorption is attributed to the excitation of surface plasmons at the Ag-air interface. Fig. 1d shows the simulated and experimentally measured absorption spectra at $\theta_i=83^\circ$ for TM polarized light. The absorption has been enhanced to 97% in case of MIM absorber. A good agreement has been found between simulation and experimental results. The inset of Fig. 1d shows the image of uniform and highly flexible absorber sample.

Conclusions: The flexible MIM metasurface achieves 97% grazing-angle NIR absorption, which is almost double that of PA. The ultrathin, cost-effective absorber suppresses stray light in space optics, promising improved performance in satellites.

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A novel experimental approach for robust underwater optical wireless communication using vortex dipole beam

Athira T Das¹, Khansa C A², Pramod Gopinath^{1*}, R Rajesh^{2*}

1. International School of Photonics, Cochin University of Science and Technology, Kochi, Kerala, 682022, India

2. Naval Physical and Oceanographic Laboratory, Kochi, Kerala, 682021, India
rajeshr.npol@gov.in, pramod@cusat.ac.in

Underwater optical wireless communication (UOWC) has the immense potential for short-range marine communication links [1]. It has been stated that the vortex beams are found to be stable in turbulence, where it may "split, deviate, and wander" and never vanish from the detector [2]. Vortex dipole that has two counter rotating vortices, is not studied yet in UOWC channels. In this study, a reliable and robust UOWC setup is designed using a vortex dipole beam that can be generated using Sagnac interferometer [3].

At the transmitter side, a TO5-9mm packaged green LD is mounted on a thermoelectric cooler (TEC) module and a copper-based heat sink developed in the laboratory. Both the DC bias current and the square signal from the function generator is combined using a bias tee and fed into the LD. The OOK modulated signal is fed into LD. At the output of LD, the beam is elliptical in shape, which is converted into Gaussian beam using a pinhole. The collimated Gaussian beam is directed into the Sagnac interferometer. Asymmetry in propagation of beams in Sagnac interferometer results in the superposition two out of phase beams. Adjusting the components in the Sagnac interferometer, introduces a lateral shear and radial phase difference between beams. The radial phase difference coupled with the lateral shear generates the vortex dipole [3]. The modulated vortex dipole and Gaussian beam propagates through 10-meter-long water column which is filled with salt at the concentration of 34 g/L uniformly. the medium turbulent DC motors is used. Here the beam propagation is studied in stagnant, weak and moderate turbulence conditions, by keeping the input power of both beams the same. The divergent low-intensity light signal is focused into the SiPM detector, which is operating at the bias voltage of 27V.

The received Signal-to-noise ratio (SNR) of vortex dipole of the beam is studied and compared with traditional Gaussian beam to evaluate their performance in UOWC at different turbulence rates. The results shows that the vortex dipole have high SNR in comparison with Gaussian beam in all turbulent conditions with data rate of 50Mbps at 10m distance. These results show the vortex dipole can offer higher data rates, long-range and turbulence-resilient UOWC system in comparison with the traditional Gaussian beam. Extended functionality is the design refinement for practical deployment, and system validation in an actual ocean environment will be the main goals of this work in the future.

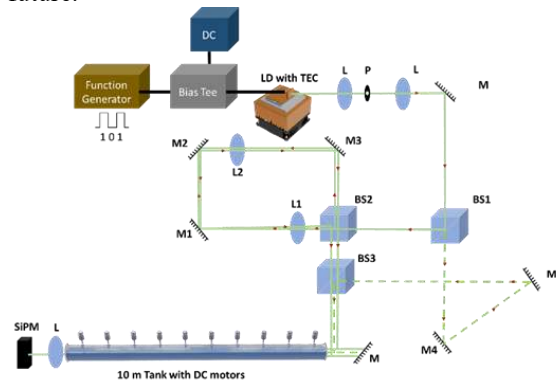


Fig. 1. Schematic of the experiment setup where L – plano-convex lens, M- mirror, BS – beam splitter.

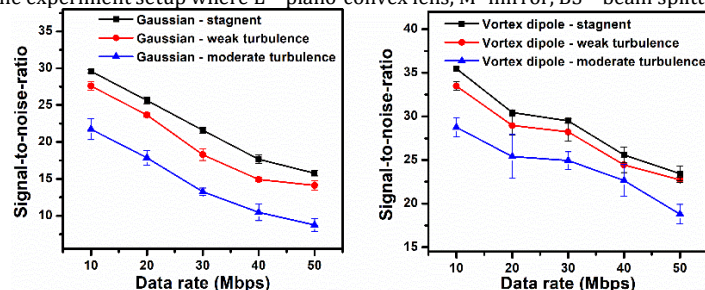


Fig. 2 Received signal-to-noise ratio of the Gaussian beam and vortex dipole beam after 10 m propagation.

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Study of Temperature Induced effects on Infrared Spectra of Astromixtures using Machine Learning

Aayushi Raval, Debjani Bagchi

The Maharaja Sayajirao University of Baroda, Sayajigunj, Vadodara, Gujarat, 390020, India

There is a plethora of data available for the astromolecules detected in the outer space due to the several conditions prevailing in the interstellar medium (ISM). The several conditions of ISM include density and temperature, radiation field, presence of dust grains and turbulence. Since the acquisition of mid infrared (IR) spectra has speeded up the detection of complex astromolecules under variable conditions existing in stellar and planetary atmospheres, we have explored the temperature induced changes in the IR spectra of pure molecules and mixtures, with the help of peak feature analysis of IR modes. Isolation of prominent modes and quantification of changes in IR modes have been carried out using relative intensity estimates. The differences in IR peaks of pure molecules compared to the mixed astromolecules have been quantified. Temperature not only induces peak centre shifts, but qualitative changes too. Machine learning analysis has been done with the help of clustering and principal component analysis. Testing of few machine learning algorithms has been carried out for higher accuracy in astromolecule detection from IR spectra.

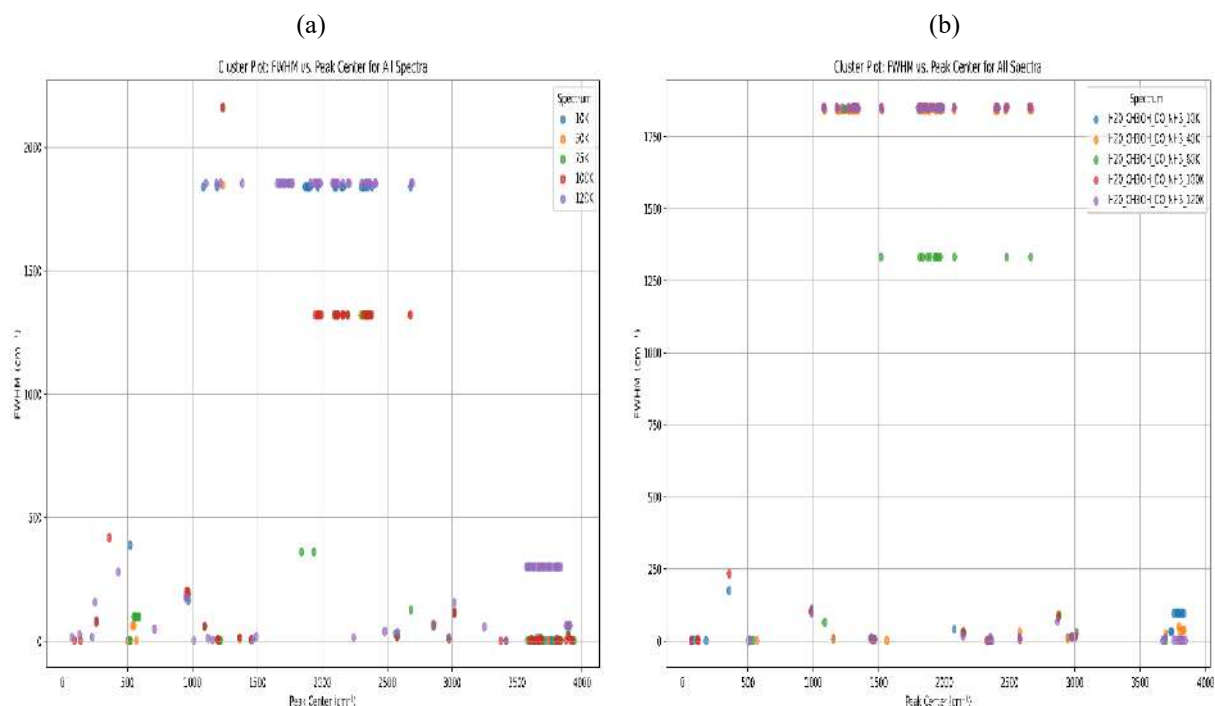


Fig.1 (a) FWHM vs. peak center of all modes in IR spectra of pure methanol (CH_3OH) at different temperatures. (b) FWHM vs. peak center of all modes in IR spectra of $\text{CH}_3\text{OH}+\text{H}_2\text{O}+\text{CO}+\text{NH}_3$ mixture at various temperatures.

Figure 1 shows the consolidated changes occurring in the IR modes of pure CH_3OH and $\text{H}_2\text{O}+\text{CO}+\text{CH}_3\text{OH}+\text{NH}_3$ mixture with respect to temperature in the form of cluster plots, which makes it easy to visualize the changes through dimensional reduction techniques. These cluster plots are plotted with FWHM vs. the peak center, for the pure and mixed astromolecules at the four different temperatures examined.

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Shaping Light, Guiding Matter: Optical Trapping of Mesoscopic Objects

Md Majid Hussain¹, Yazhini A R¹, Dr. Deepak Kumar Gupta²

¹. Indian Institute of Engineering Science and Technology, Shibpur, West Bengal 71103 India and National Institute of Technology, Trichy, Tamil Nadu 620015 India

². Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, Chengalpattu, 603102 India

Abstract: We demonstrate optical trapping of polystyrene microsphere using a single-laser beam gradient trap. Trap stiffness was analyzed via video-based particle tracking, revealing a linear relationship between laser power and confinement strength.

Principles: Optical trapping relies on the radiation pressure exerted by light, implemented using optical tweezers, main principle is momentum transfer between photons to the trap particles two forces mainly occurs.

Scattering Forces: Pushes the particles in the direction of the light beam due to photon momentum transfer.

$$F_{\text{scat}} = \frac{I_0}{c} \frac{128\pi^5 R^6}{3\lambda_0^4} \left(\frac{m^2 - 1}{m^2 + 2} \right)^2 n_m$$

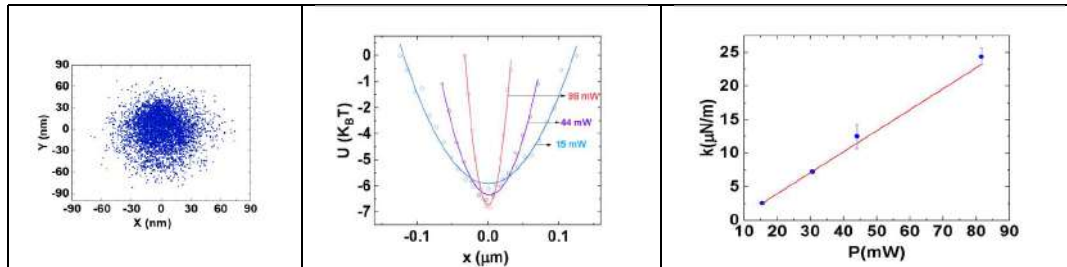
Gradient Force: Arising from the intensity gradient of the laser beam, pulls the particles towards the region of higher light intensity, centre of the beam. $F_{\text{grad}} = -\frac{n_m^3 R^3}{2} \left(\frac{m^2 - 1}{m^2 + 1} \right)^2 \nabla E^2$

1. Sample preparation: Polystyrene microsphere is diluting with water, now create the sample chamber, a clean glass microsphere slide is used as the base, and thin spacer is placed on it to create a cavity. A small drop (5-10 μL) of dilute solution is added to the centre of the slide, a clean cover slide is gently placed over the drop.

2. Experimental setup: A infra-red laser (1064nm) is used, beam is directed through a high numerical aperture ($\text{NA} > 1.2$) lens, which focuses the beam tightly into the sample chamber. The beams ensures optimal focusing and a strong gradient force at the focal point. As the laser is focused glass surface into the solution, Brownian motion causes individual particles to drift into the focal region, where they become trapped if $F_{\text{Grad}} > F_{\text{Scat}}$. Temperature also effects the traps. A camera attached to the microscope allows real-time visualization and recording of the trap particles, processed using image processing software.

3. processing the image and extracting the coordinates: A video of the trapped polystyrene bead is recorded using a microscope camera, using image analysis software (Image j) to extract the two dimensional (x,y) coordinates of the particles. Only use one coordinate (either x or y). The extracted positional data is binned to create a histogram that represents how particles occupies each spatial position. Maxwell-Boltzmann distribution, the probability $P(x)$

of finding the particles at a position x is related to the optical potential $U(x)$, $P(x) \propto e^{-\frac{U(x)}{k_B T}}$, where k_B Boltzmann constant and T is the absolute temperature. By taking the natural logarithm of the normalized histogram, the potential energy $U(x)$ can be obtained, $U(x) = -k_B T \ln P(x)$.



This potential curve reflects the shape and depth of optical trap. The procedure is repeated for different laser powers, allowing the study of how trap stiffness and potential depth vary with laser intensity. This analysis helps to quantify the strength of the optical trap and provides insight into the particles confinement under different experimental conditions.

Factor Affecting Stiffness Constant: 1. Numerical Aperture(NA) 2. Refractive Index(RI) 3. Size of the Particle 4. Laser Power

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Development of an Interferometric Reflectance Imaging System for High Resolution Phase-Contrast Microscopy

Gaurav Jha, Rohit Kumar and Venkata Jayasurya Yallapragada

Department of Physics, Indian Institute of Technology Kanpur, Kanpur, Uttar Pradesh 208016, India

Interferometric microscopy has recently emerged as a powerful tool to study deep subwavelength particles [1]. In particular, it has been demonstrated that it can be used to determine the molecular masses of single protein molecules [2]. The basic principle common to these techniques is that the small particle, located on a glass substrate such as a cover slip, is illuminated with a collimated spatially coherent light beam. The camera images a superposition of the light scattered by the particle and the light reflected from the substrate surface.

In this work, we present our first results with such a microscope designed and built in-house, to achieve high contrast and high-resolution images of small nanoparticles. A schematic of the experimental setup is shown in the Figure 1a below. The setup uses a 475 nm wavelength laser whose beam is spatially filtered and collimated through the microscope objective (Obj). Since the scattered light intensity is typically much smaller than the reflected intensity, one needs to detect a low contrast interference pattern against a large offset, which demands a camera with a very large dynamic range. We have used several means to overcome these limitations, including maximizing the available dynamic range in the camera and suitable frame averaging.

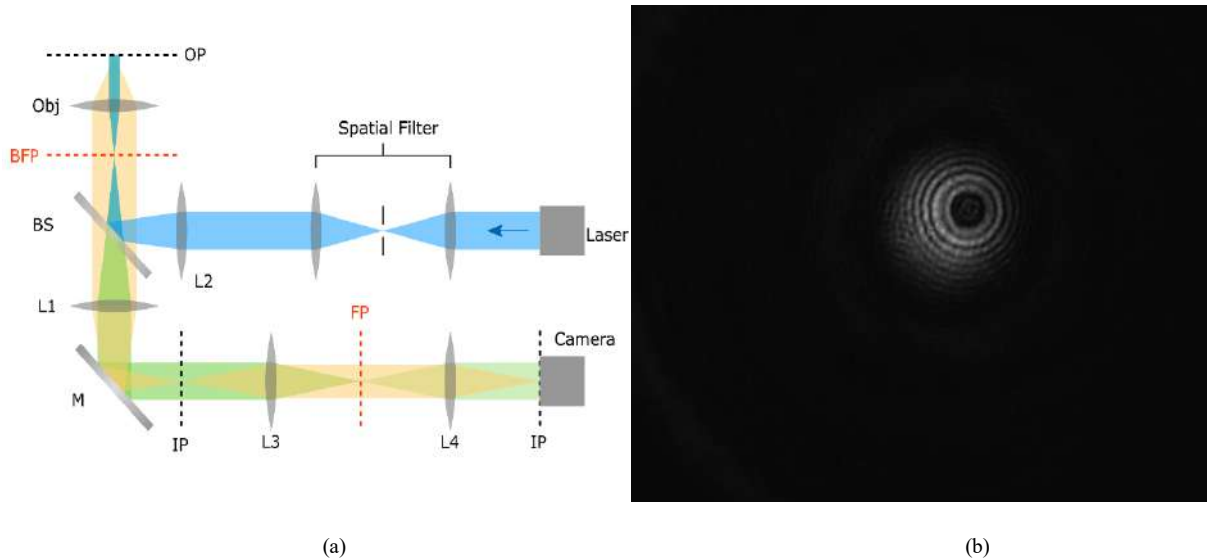


Fig. 1 (a) Schematic of the microscopy setup: The laser output is spatially filtered and focused into the back focal plane of the microscope objective, so that it reaches the sample collimated. The light reflected by the substrate and scattering from the sample are superposed at the camera plane, and their interference pattern is measured. A 4 f relay makes the Fourier plane accessible to improve the imaging quality further. **(b)** Image of a gold nanorod taken using the described microscopy setup.

Figure 1b shows an image of a small gold nanorod recorded using this setup. From these recorded images, we are able to infer the size of the particles and their orientation. Our efforts are currently directed towards measuring even smaller particles in the ~ 5 nm size regime. Our results demonstrate that quantitative information can be extracted from the interferometric reflectance and scattering images of deep sub-wavelength particles.

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Stabilizing an interferometric imaging system for quantum light

Pradeep Kumar Saini *, Venkata Jayasurya Yallapragada

Department of Physics, Indian Institute of Technology Kanpur, Uttar Pradesh 208016, India

*pradeepks21@iitk.ac.in

Optical holography has emerged as a powerful optical technique for retrieving the phase information of light in the context of microscopy [1]. Conventional holography is based on the interference of two mutually coherent beams, one of which interacts with an object, while the other serves as a phase-stable reference. However, the requirement of direct interference and detection of the object beam imposes limitations when detectors are inefficient at the detection wavelength. In addition, it is often desirable to improve the phase sensitivity and spatial resolution of such imaging systems. The use of entangled light sources can provide improvements in both these aspects [2,3]. In this work, we demonstrate the design and stabilization of an interferometric imaging system capable of operating with quantum light in multiple configurations.

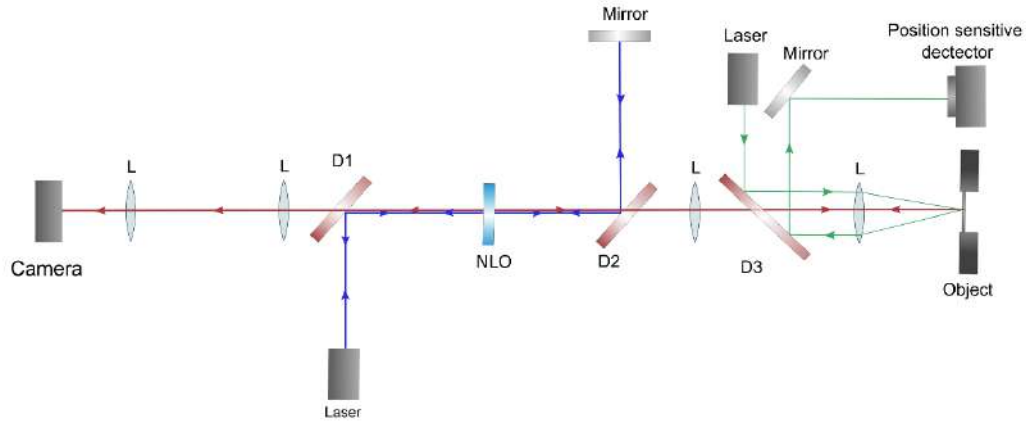


Fig. Geometry of the quantum imaging system. The path indicated in blue represents the pump beam, the path in red indicates the down converted photons, and the path in green represents the position sensing laser beam. Dichroic mirrors help isolate the down converted light from the pump (D1 and D2) and feedback laser beams (D3). The image is relayed to the nonlinear crystal (NLO) where SPDC takes place.

The layout when used with a single illumination beam functions as a two-beam classical interferometric imaging system. When a reflecting object is placed at the object place the system forms its image at the camera plane via a sequence of $4f$ systems. Any spatially varying phase acquired by the beam during reflection will manifest itself as a change in intensity in the interferogram. Collinear degenerate spontaneous parametric down conversion (SPDC) in the nonlinear crystal (NLO), of the pump beam routed by the dichroic mirrors (D1 and D2) will lead to an image formed at the camera plane via the down converted photons alone. Due to the inefficiency of SPDC, acquisitions in such an interferometric image system will take a much longer time (minutes to hours) It is important that the interferometer remain stable throughout the measurement. To ensure this, we introduce a (spatially and temporally) coherent beam of light using a third dichroic mirror (D3). The beam can either be centered and co-propagated with the SPDC beam or aligned in an off-center configuration (as shown in the Figure). Variations in this beam can be used in a feedback loop that stabilizes the position of the sample against drift using a piezoelectric actuator. Our presentation will include a detailed account of the results and performance of this stabilized imaging system, and its utility in facilitating long-duration interferometric imaging measurements.

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Spectrally resolved relative intensity noise of the Supercontinuum: Continuous-Wave pumping SMF28e architectures compared against pulsed pumping PCF architecture.

V. Meher¹, Shantanu Dambare¹, V. Balaswamy¹

1. Department of Electrical Communication Engineering, Indian Institute of Science, 560012, Bengaluru, India

Fiber supercontinuum (SC) sources are used in optical frequency metrology, spectroscopy, and ultra-high resolution optical coherence tomography (UHR-OCT), where high relative intensity noise (RIN) degrades performance. Conventional femtosecond or picosecond pulsed SC sources require complex, costly setups and specialty fibers for low noise [1]. Continuous wave (CW) laser pumped SC offers a simpler, cheaper alternative, providing smoother spectra and high average power spectral density (PSD), albeit with an incoherent spectrum—a trade-off acceptable for OCT where RIN is critical. This work numerically compares CW-pumped SMF28e SC with picosecond-pumped PCF SC and experimentally compares SC from different CW pump architectures: fiber Bragg grating (FBG) lasers, FBG-MOPA (master oscillator power amplifier seeded with FBG) lasers, RING-MOPA lasers, and commercial ps-pumped PCF SC (data sourced from [2]).

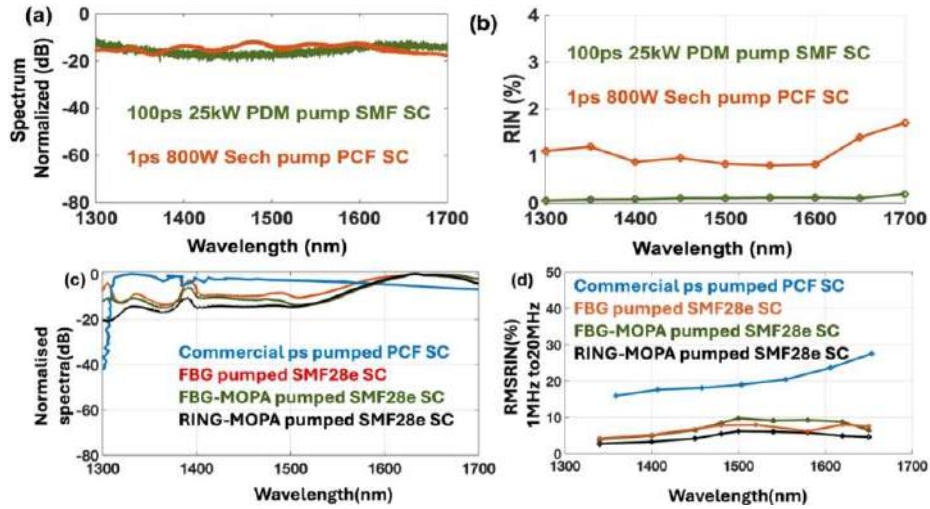


Fig1a, b: Numerically simulated, (a) normalized spectrum of sech pulse pumped PCF SC and CW (PDM model) pumped SMF SC, and their (b) Spectrally resolved RIN comparison. Fig1c,d shows the comparison between different (FBG, FBG-MOPA, RING-MOPA) CW architectures and the ps pumped PCF SC spectra and their respective RIN.

Fig 1a shows normalized spectra for picosecond-sech-pumped PCF SC and CW-pumped (PDM model) SMF SC, both within 10dB power range over the wavelength. Fig 1b shows CW-pumped SMF28e SC RIN is 0.05%-0.19%, >7x lower than picosecond-PCF SC 0.8%-1.75%. Fig 2b compares normalized spectra of CW-SMF28e SC (PSD 23mW/nm) and picosecond-PCF SC (PSD 1mW/nm [2]), both within 15dB power. Fig 2d compares RIN over 400nm: CW-pumped FBG/FBG-MOPA SMF28e SC RIN is 3.91%-8.8%, ~3x lower than picosecond-PCF SC's 16%-27.5% [2]. RING-MOPA-pumped SC achieves the lowest RIN (2.72%-4.93% rms), a 1.4-1.8X improvement over other CW configurations (3.91%-8.8% rms), attributed to its lower pump RIN (0.18% vs. 0.45%). RIN was measured over 1MHz-20MHz (avoiding pump noise, matching OCT detector bandwidth). Results identify RING-MOPA as a low-noise, cost-effective CW pump for ultrahigh-resolution OCT SC requiring low RIN.

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Full-Spectrum White Light Source

Dheeraj Kumar*, R. K. Varshney and Dalip Singh Mehta*

Department of Physics, Indian Institute of Technology Delhi, New Delhi, India-110016

*phz212507@physics.iitd.ac.in, mehtads@physics.iitd.ac.in

This study presents a significant advancement in white light sources by achieving stable, full-spectrum emission with high colour fidelity. We utilized a strategic blend of far-red and commercially available phosphors to overcome the limitations of traditional single-phosphor systems. The optimized blend yielded an exceptionally high CRI >95, with high deep red and deep blue colour values, and a CCT range of 2000-7000K daylight. The source delivers high illuminance, making it suitable for high-power, colour-critical applications. The successful integration into illumination devices demonstrates the practical application for medical surgery, photography, broadcasting, etc.

Miniaturized, high-quality light sources are essential for modern illumination systems, especially in applications requiring precise colour fidelity and diagnostic accuracy. Conventional lighting technologies often suffer from a discontinuous spectral output, which leads to poor color rendering and limited diagnostic capabilities [1-3]. This spectral mismatch can hinder the accurate identification of subtle tissue variations, lesion margins, and vascular structures in fields like medical diagnostics.

To overcome these limitations, we have developed a novel white light source designed to deliver a continuous, full-spectrum output. This paper details the synthesis of a key far-red phosphor and the engineering of a composite phosphor film to achieve superior colour fidelity and miniaturization for advanced lighting applications. Driven by progress in fabrication and decreasing component costs, our devices are well-positioned to become a primary illumination source for diverse applications. This technology facilitates more precise and less invasive medical procedures by providing a continuous, broadband, and sun-like full spectrum illumination. Figure 1 displays the color fidelity of an image captured using a OnePlus Nord CE2 mobile camera, as evidenced by its spectral analysis.



Fig. 1 The illuminating object image of the (a) hibiscus flower colours with its stigma and style, and (b) Neem leaf's midrib and veins

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Enhanced Phase Sensitivity in DSU(1,1) Interferometer via Photon Recycling

Taj Kumar, Aviral Kumar Pandey, Anand Kumar, Devendra Kumar Mishra

Department of Physics, Institute of Science, Banaras Hindu University, Varanasi 221005, India

In the SU(1,1) interferometer, proposed by Yurke [1], beam splitters are replaced by nonlinear elements like optical parametric amplifiers (OPA) to achieve the sensitivity up to the Heisenberg limit [2]. Non-Gaussian operations, like photon addition or subtraction, can further improve its phase sensitivity and robustness against photon loss but at a high implementation cost. To address this, Wei Ye *et. al* [3] introduced the displacement-assisted SU(1,1) (DSU(1,1)) interferometer, using a displacement operator with displacement strength $|\gamma|$.

In this work, we propose a novel approach to enhance the phase sensitivity of the DSU(1,1) interferometer through photon recycling [4]. We begin with a DSU(1,1) interferometer having a vacuum state at port "a" and a squeezed vacuum state (with squeezing parameter r) at port "b". We consider a phase shift Φ , experienced in the arm "b". This setup is modified by re-injecting the output mode "a" into the input mode after a phase shift θ , and photon loss is characterized by $\sqrt{1-T}$, where T is the transmission coefficient of a fictitious beam splitter. We examined the phase sensitivity of the PR-DSU(1,1) interferometer $\Delta\phi^{\text{PR}}$ under both single-intensity detection (SID) and homodyne detection (HD) schemes. We also calculated the quantum Cramér-Rao bound (QCRB), denoted as $\Delta\phi_{\text{QCRB}}^{\text{PR}}$. In order to analyze the improvement in performance induced by photon recycling, we have compared the performance of the PR-DSU(1,1) interferometer with the conventional DSU(1,1) interferometer by introducing two enhancement factors $\Sigma = \Delta\phi^{\text{Conv.}}/\Delta\phi^{\text{PR}}$ and $\Xi = \Delta\phi_{\text{QCRB}}^{\text{Conv.}}/\Delta\phi_{\text{QCRB}}^{\text{PR}}$ represent the enhancement factors for phase sensitivity and QCRB of PR-DSU(1,1) interferometer relative to DSU(1,1) interferometer, respectively.

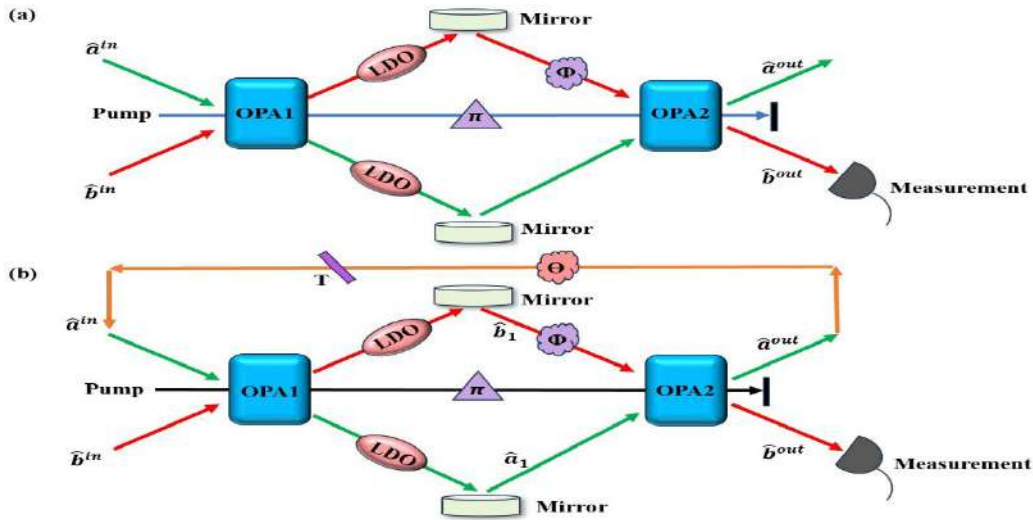


Fig.1 Scheme for phase estimation with photon recycling technique: (a) Schematic diagram of a DSU(1,1) interferometer with the output beam "a" disregarded. (b) The modified scheme with the output mode "a", re-injected into the input mode "a" (PR-DSU(1,1) interferometer).

Our findings show that we can attain the values of Σ and Ξ , greater than unity, which clearly indicates that the PR-DSU(1,1) interferometer can possess phase sensitivity and QCRB beyond those in the case of the conventional DSU(1,1) interferometer. This highlights the significance of photon recycling in enhancing the sensitivity of the interferometer. Comparing the phase sensitivity of the PR-DSU(1,1) interferometer under both SID and HD schemes, we observe that the HD scheme outperforms the SID scheme. The HD scheme also exhibits a broader region of θ and ϕ for enhanced phase sensitivity beyond SNL, further demonstrates its superiority over the SID scheme. Therefore, our findings show that this modified scheme has phase sensitivity and QCRB beyond the SNL as well as beyond those in the case of a conventional DSU(1,1) interferometer, offering a novel approach to increase phase sensitivity via photon recycling.

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Deep neural network for wavefront sensing with synthetic Shack-Hartmann lenslet images

Akash Kumar Tarai*, Suman Sangiri, Vyas Akondi#

Department of Physical Sciences, Indian Institute of Science Education and Research (IISER) Berhampur, Berhampur, Odisha 760003, India

Email: *akashktarai@gmail.com, #vakondi@iiserbpr.ac.in

Recent advancements in deep learning are transforming ophthalmic imaging and intraocular lens (IOL) design, enabling improved wavefront sensing and predictive modeling of optical performance [1-2]. In this work, we present a neural network-based framework for wavefront sensing for ophthalmic applications, employing a deep neural network trained on a synthetic dataset of Shack-Hartmann wavefront sensor (SHWS) spot patterns to estimate ocular aberrations. The model is specifically developed and optimized to handle cases with missing lenslet images caused by noise, cataracts, or pupil obstructions [3-4].

A dataset of 10,000 SHWS images, each consisting of an 8×8 array of lenslets, was simulated using Zernike coefficients up to the 4th order (15 terms), randomly simulated from statistical analysis of myopic eye data [5]. To preserve the circular aperture, intensity values from the lenslets outside the aperture were removed. Removing them reduced the dataset size by approximately 32%, which helped in decreasing computational time and improving the accuracy. After the feature selection, each image was then flattened into a one-dimensional vector to serve as input to an artificial neural network (ANN). The resulting dataset was divided into 70% training, 15% validation and 15% testing subsets. The ANN architecture was optimized through hyperparameter tuning, including the number of hidden layers, neurons per layer, activation function and regularization strategies such as dropout and early stopping, with mean squared error (MSE) and validation loss as performance matrices.

The proposed model achieves root mean square error (RMSE) of 12 nm for SHWS images with no missing lenslets and 13 nm for cases with a single random missing lenslet (randomly picked), outperforming the conventional centroid-based reconstruction method (RMSE ~ 19 nm) for both cases. The predicted Zernike coefficients match well with the simulated ground truth for both scenarios, as shown in Fig. 1. Furthermore, the network delivers per-wavefront reconstruction time of 0.3–0.4 milliseconds, highlighting its potential for real-time ophthalmic applications. Unlike traditional methods, the ML-based approach can learn and compensate for incomplete or degraded spot patterns, enabling accurate reconstruction under suboptimal imaging conditions.

Overall, our results establish a scalable and efficient deep learning approach for accurate wavefront sensing, with strong translational relevance to adaptive optics and clinical diagnostics in ophthalmology. Notably, this approach can be extended to multifocal intraocular lens (M-IOL) wavefront sensing, which is particularly valuable for post-surgical assessment in pseudophakia. Beyond ophthalmology, the proposed method offers a versatile foundation for wavefront reconstruction in diverse domains, including microscopy, astronomy, and free-space optical communication, where high-speed and resilient wavefront analysis is critical. We are currently working on cases with more and more missing lenslets.

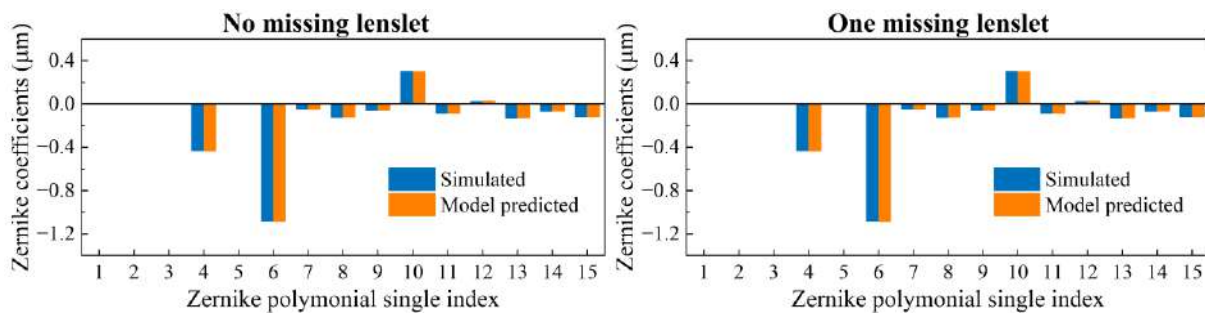


Fig. 1 Comparison of simulated and neural network predicted Zernike coefficients for a single SHWS images with no missing lenslet and single randomly missing lenslet.

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Density Functional Theoretical analysis on the first order hyperpolarisability and charge transfer interaction of Carbazole-based derivatives

Mohamed Ashfaaq^{1,2*}, Paven Kuruvilla^{1,2}, Alisha K^{1,2}, M. R. Kannan¹, S. Manvizhi¹, and T. Vijayakumar^{1*}

¹ Futuristic Materials Research Centre for Planetary Exploration, Department of Physics and Nanotechnology, College of Engineering and Technology, Faculty of Engineering and Technology, SRM Institute of Science and Technology, Kattankulathur - 603 203, Chengalpet, Tamil Nadu, India

² Department of Electronics and Communication Engineering, College of Engineering and Technology, Faculty of Engineering and Technology, SRM Institute of Science and Technology, Kattankulathur - 603 203, Chengalpet, Tamil Nadu, India

*Corresponding Author Email id: ma0365@srmist.edu.in and vijayakt1@srmist.edu.in

Abstract

The growing demand for advanced optoelectronic technologies has accelerated interest in efficient nonlinear optical (NLO) materials. Organic π -conjugated systems have become key candidates in this field due to their large hyperpolarizabilities and rapid response times. Among them, carbazole-based derivatives stand out for their electron-rich aromatic framework, rigid planar backbone, and the ease of tuning their optical properties through donor–acceptor substitution strategies [1,2]. In the present study, the carbazole and its derivatives have been explored using quantum chemical computations. A TD-DFT method was employed to study the intramolecular charge transfer (ICT) interaction strategy to identify the electronic transition exhibited in the UV–visible spectrum, and the vibrational analysis of FT-IR and FT-Raman was computed theoretically. Natural population analysis and molecular electrostatic potential (MEP) surface analysis of the molecule were performed to predict the molecule's reactive site. Natural bond orbital analysis (NBO) and natural charge analysis were used to study the charge transfer interaction. The NLO activity of the studied compound was highlighted by computing the first and second order hyperpolarizability. According to the results, the carbazole could be used in optoelectronic applications.

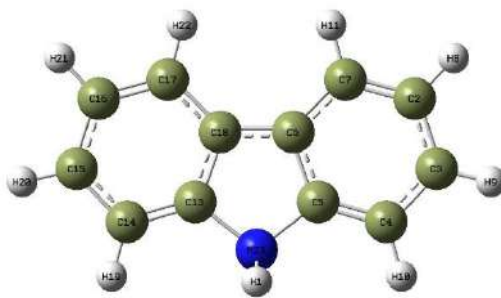


Fig.1. Optimized Molecular Structure of carbazole

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First-Time Experimental Observation of Dark Soliton States on Cnoidal Wave Backgrounds in Fiber Lasers

Subrata Manna¹, Nithyanandan Kanagaraj^{1*},

¹ Ultrafast Fiber Optics and Smart Photonic Technologies, Dept. of Physics, IIT Hyderabad, Telangana, India-502285

We present, for the first time, the experimental observation of dark solitons coexisting with cnoidal wave backgrounds in a passively mode-locked fiber laser. Cnoidal waves, which are exact periodic solutions of the nonlinear Schrödinger equation described by Jacobi elliptic functions, represent a bridge between sinusoidal oscillations and localized soliton trains. While bright solitons on cnoidal wave backgrounds have been studied, experimental evidence of dark solitons on such periodic backgrounds has been lacking until now.

In this work, we construct an NPR-based erbium-doped fiber laser cavity with carefully adjusted nonlinear polarization evolution to realize conditions where dark solitons emerge as localized intensity dips with phase discontinuities, supported by a periodic cnoidal wave. Time-domain measurements reveal stable dark notches embedded within oscillatory patterns, while spectral analysis confirms the nonlinear balance of dispersion and Kerr nonlinearity that stabilizes these states. This observation uncovers a unique regime of nonlinear wave dynamics in which dark solitons coexist with cnoidal periodic fields inside a single cavity.

The setup includes a 3 m erbium-doped fiber gain medium, pumped by a 976 nm diode providing up to 1 W through a wavelength-division multiplexer. Two polarization controllers and a polarization-dependent isolator enable NPR-based mode locking and unidirectional operation. Output is taken from the 10% port of a 10:90 coupler. The cavity length, extended to 25 m with additional single-mode fiber, provides a net anomalous dispersion of -0.17 ps², enabling soliton operation.

In the anomalous dispersion regime, the fiber laser initially emitted continuous-wave output at 4 mW, confirming operation in a low-nonlinearity regime. Increasing the pump power to 124 mW produced stable cnoidal waveforms with switchable temporal periods (3.11 ns, 4.44 ns, 24.88 ns), narrow multi-peaked spectra (0.4 nm bandwidth), and clean RF spectra with 36–43 dB SNR [Fig. 1(d)], indicating excellent stability and negligible jitter. At 243 mW, the pulses narrowed (184 ps) and weak Kelly sidebands appeared, marking a transition toward soliton-like dynamics, but the structures remained bound in the cnoidal wave [Fig. 1(c)]. At 300 mW, a clear shift to bright soliton states occurred, with freely propagating solitons, strong spectral broadening, and mutual collisions, consistent with NLSE soliton behavior.

In the normal dispersion regime, stable cnoidal waves were observed at 4.3 mW, with temporal periods of 2.5 ns and 4 ns and broad spectral sidebands due to intracavity modulation. As the pump power increased to 216 mW, the cnoidal background evolved into a hybrid state, where dark pulses coexisted [Fig. 1(a,b)] with the periodic waveform. At 304 mW, well-defined black solitons (few-ps width) formed, demonstrating temporal stability and confirming the emergence of dark solitons on a cnoidal wave background.

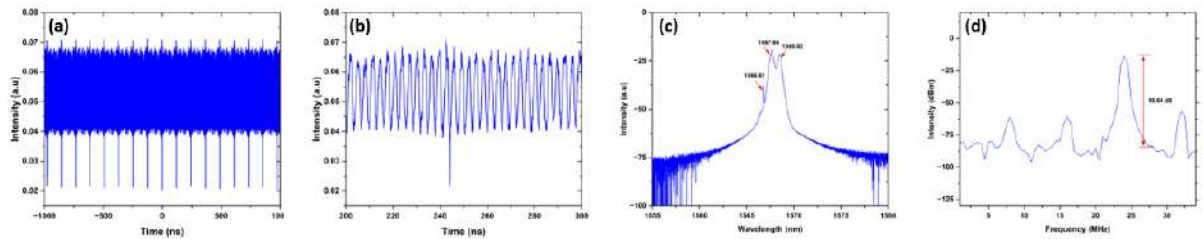


Figure 1: Dark soliton on cnoidal wave background. (a) Pulse train. (b) single pulse. (c) Optical spectrum with weak kelly side band and (d) RF spectrum.

This experimental breakthrough enriches the broader landscape of nonlinear optics by demonstrating that cnoidal waves can act as fertile backgrounds for both bright and dark soliton dynamics. Beyond its fundamental significance, the discovery opens new opportunities for designing novel dark-pulse fiber lasers, investigating soliton crystal formation, and exploring structured nonlinear wave for advanced photonic applications.

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Size estimation of Silver Nanoparticles (Ag NPs) using Static light Scattering.

Aayush Mishra*, Sudhisht Srivastava*, Mausumi Pohit*.

*Department of Applied Physics, School of Vocational studies and Applied Sciences, Gautam Buddha University, Greater Noida, 201312, Uttar Pradesh, India.

Characterization of size and material properties of particles in liquid suspension is in very high demand e.g. in analysis of colloidal samples, for example vaccine bottles, etc. Light scattering techniques outperforms structural techniques [such as Transmission electron microscopy (TEM), Atomic force microscopy (AFM)] (Guilbaud & Saiani, 2011) [1], having a few advantages.

The study's objective is to use the Static Light Scattering (SLS) method to determine the size of silver nanoparticles (Ag NPs) made using chemical reduction process to a size of 12 ± 2 nanometer (Solomon et al., 2007) [2]. We investigated size using 630nm (5mW) generic laser diode and 406 nm (90mW) Ultraviolet laser diode each. The study examines how aggregation affects the optical characteristics of Ag NPs. The paper discusses and uses UV-visible spectroscopy of the sample to verify increase in size of Ag NPs due to aggregation. Fig. 1 displays temporal analysis of fresh sample of Ag NPs from immediately after preparation to 70 minutes, using $\sin^2(\theta/2)$ on X-axis and natural log of intensity of scattered light on Y-axis. Fig.2 shows the Guinier fit of freshly prepared sample dataset using UV laser diode. The size of Ag NPs is **64.48** nm according to the Guinier equation (Beaucage & Schaefer, 1994) [3].

$$\ln(I_s) = \ln(I_0) - \frac{q^2 R_g^2}{3}$$

The verification of the size of Ag NPs with various structural techniques TEM is also done. A thorough protocol outlining our light scattering study methodology is included.

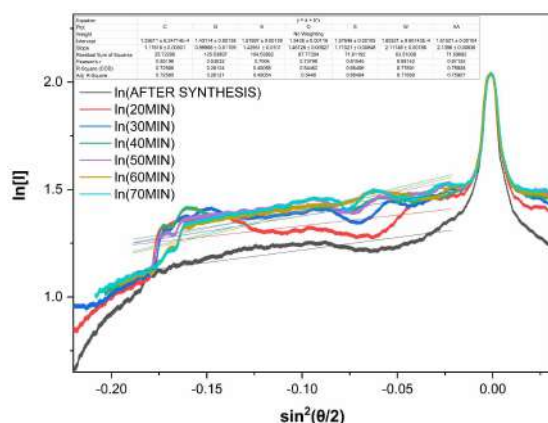


Fig. 1: Time Analysis of Ag NPs data from SLS.

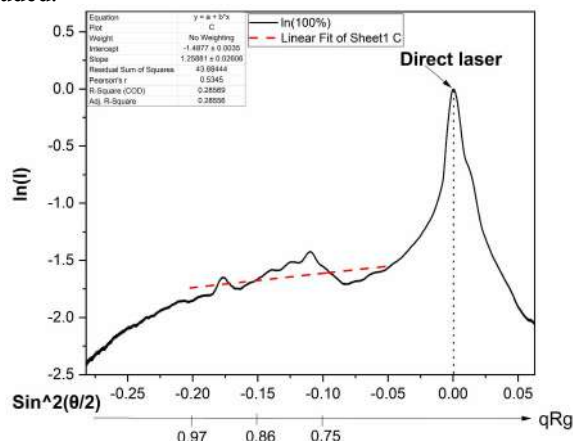


Fig. 2: Guinier plot of Ag NPs using 406 nm UV laser diode.

Keywords: Silver nanoparticles (Ag NPs), Static light Scattering (SLS), UV-visible spectroscopy, TEM

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Angle-resolved early-time plasma emission dynamics in Cu plasma

Satyaranjan Satyajit*, Poulami Das, Subhankar Nanda, Pratyush Dash, Amitava Adak

Department of Physics, Indian Institute of Technology (ISM) Dhanbad, Jharkhand 826004, India

Nanosecond laser-induced plasma has been in prime focus of researchers owing to its numerous applications, such as Laser-Induced Breakdown Spectroscopy (LIBS), Extreme Ultraviolet (EUV) Lithography, Pulsed Laser Deposition (PLD), etc. Early-time plasma emission studies have been performed on a Cu plasma generated using 1064-nm, 7-ns pulses from a Nd:Yttrium Aluminum Garnet (Nd-YAG) laser. Plasma continuum emission is captured by moving a fast Si-photodiode along various polar (θ) and azimuthal angular (ϕ) positions in space. By keeping the solid angle of the photodiode constant, the plasma emission peaks are considered here. Anisotropic behavior of plasma continuum radiation is observed. Plasma emission intensity is found to be maximum near normal to the sample surface and decreases as we move away from the normal in both polar (θ) and azimuthal (ϕ) angular directions. In addition to that, the temporal evolution of plasma emission is observed at different angular distributions. We observed the anisotropic nature of plasma continuum radiation in Cu for the first time.

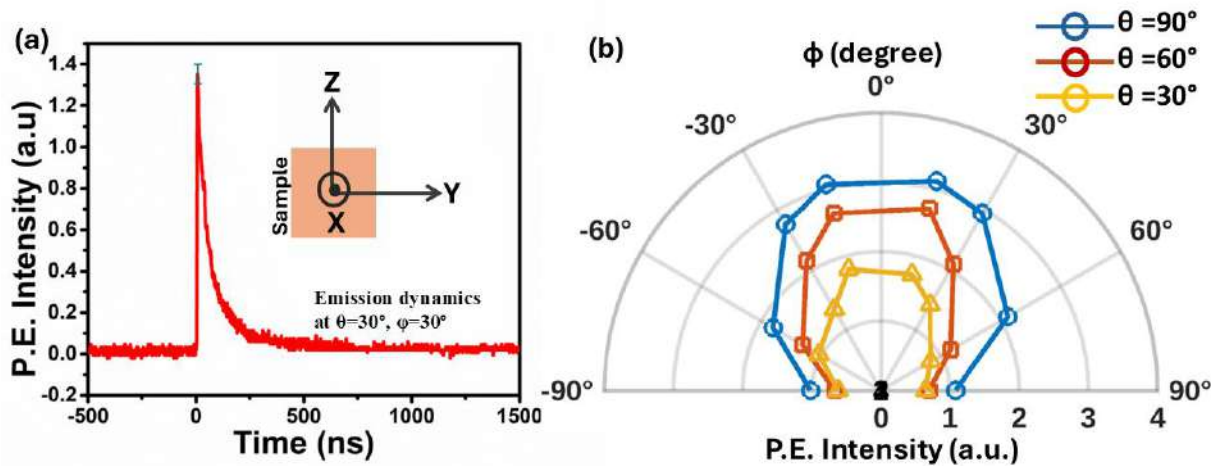


Fig. 1(a): Temporal evolution of plasma emission dynamics; the laser incidence is along the negative x-axis and peaks at 0 ns. **(b)** Plasma emission intensity in various azimuthal angular positions (ϕ) in three different polar angles (θ).

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Angular Super-resolution Imaging with light carrying OAM

Nilakshi Senapati¹, Abhinandan Bhattacharjee^{1,2}, Anand K Jha¹

1. Department of Physics, Indian Institute of Technology Kanpur, Kanpur, Uttar Pradesh 208016, India

2. Currently at Department of Physics, Paderborn University, Paderborn 33098, Germany

We demonstrate that illumination of OAM beam serves as a better candidate for imaging predominantly angular featured objects. With theoretical and experimental support, we show that resolution increases with the OAM mode l , following a specific periodicity.

High-resolution imaging is essential for acquiring precise information about an object. Both the illumination and detection schemes play equally crucial roles in enhancing the resolution. Thus, over the time, super-resolution is achieved by using structured illumination and by developing different detection schemes. Here we introduce the concept of naturally optimal beam choices tailored to specific object structures. When an object has predominant spatial features, then plane wave is a natural choice, whereas plane wave with higher k -vector helps to improve the resolution. If an object has predominant angular structures then OAM beam with suitable l -mode resolves it better whereas plane wave ceases to do so.

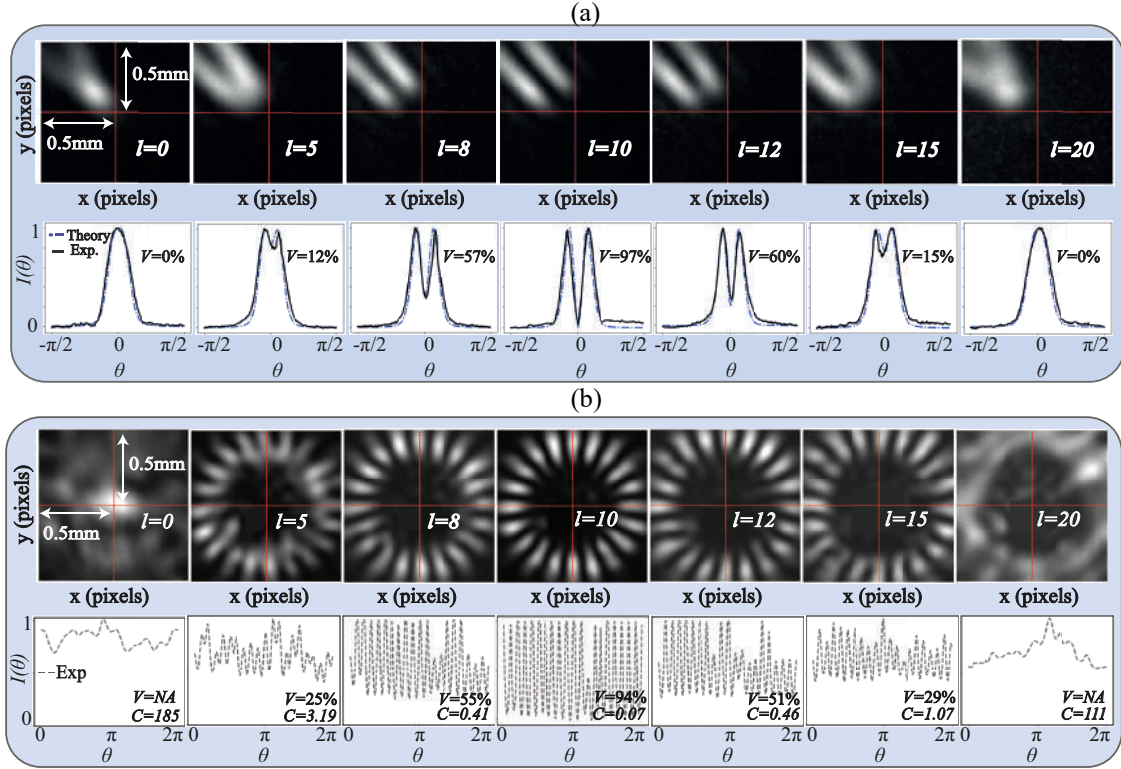


Fig. 1 Experimental results of angular super-resolution imaging with (a) angular double slits (b) siemens star.

In this case, angular double slit type of object is illuminated with phase structured OAM beam which passes through a $2f - 2f$ imaging system and finally get detected by a detector. As shown in Fig. 1(a), we observe as the OAM mode increases, the resolution starts increasing and we obtain almost perfect visibility at $l = 10$ for a particular separation of 0.1π between two slits. Again, the resolution starts decreasing and falls to almost zero at $l = 20$, which provides a periodicity in visibility. Observed periodicity depends on the object's specification. Fig. 1(b) captures the same situation for more complicated siemens star object. Overall, this study lays the foundational framework for angular imaging in the angle-OAM domain, unveiling its properties as natural manifestations of the underlying physics. OAM-based imaging holds promise for studying biologically relevant structures with azimuthal symmetry, such as centrosomes or the coronavirus cross-section.

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Synthesis and Characterization of Rare Earth-Free Phosphor for Solid-State Lighting Applications

Deepak Kumar, Praveen C Pandey*

Department of Physics, Indian Institute of Technology (BHU), Varanasi, U.P. 221005, India

* Corresponding author, Email: - pcpandey.app@iitbhu.ac.in, Tel: - (+91)5427165473

Abstract: LiZnVO₄ phosphors synthesized via solid-state, sol-gel, and auto-combustion methods were studied. Auto-combustion at 800 °C for 4 hours yielded the highest luminescence at 532 nm, highlighting its potential as a rare-earth-free phosphor for pc-WLED applications.

Keywords: pc-WLED; Rare-earth-free, photoluminescence;

Introduction: Phosphor-converted white light-emitting diodes (pc-WLEDs) are garnering increasing attention in solid-state lighting for the next generation of illumination due to their merits, including longer life, greater efficiency, compactness, reliability, low power consumption, and environmental friendliness. The quality of WLEDs used in lighting and display is affected by phosphors [1,2]. Rare-earth-free phosphors are luminescent materials that do not contain rare-earth elements (e.g., Eu³⁺, Ce³⁺, Tb³⁺) but still exhibit efficient light emission. They serve as sustainable alternatives for lighting, displays, and optoelectronic applications [3–5]. In this study, we synthesized a rare-earth-free LiZnVO₄ phosphor exhibiting yellowish-green emission through three distinct synthesis routes and systematically characterized its luminescent properties for pc-WLEDs applications. Phase purity, crystal structure, photoluminescence excitation and emission spectra, CIE color coordinates, internal quantum efficiency (IQE), and thermal stability were investigated.

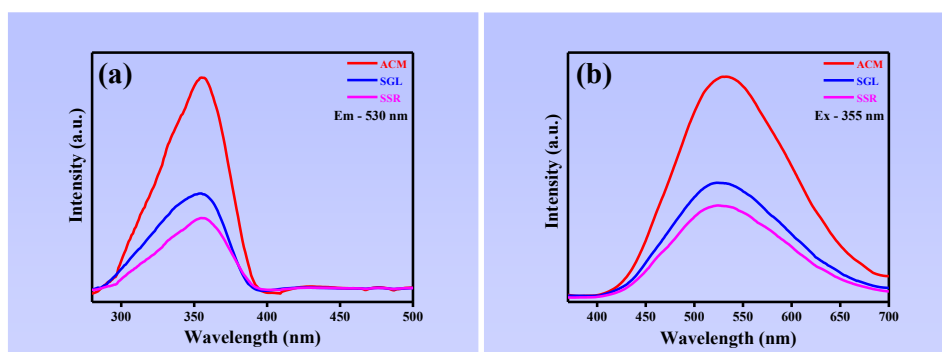


Fig. 1. (a) Photoluminescence excitation and (b) Photoluminescence emission spectra of LiZnVO₄ phosphor.

Results: Fig. 1.(a) shows the excitation spectra of the prepared phosphors were recorded in the 280-500 nm wavelength region, with the emission wavelength remaining constant at 530 nm. Fig. 1.(b) shows the emission spectra of the prepared phosphors. The PL emission was monitored in the 370 - 700 nm spectral region at excitation wavelength of 355 nm.

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Performance analysis of Gaussian and Bessel-Gaussian vortex beams with fractional topological charge in turbulent atmosphere

Neha Choudhary, Allarakha Shikder, and Naveen K. Nishchal*

Department of Physics, Indian Institute of Technology Patna, Bihta 801106, Bihar, India

*nkn@iitp.ac.in

Free-space optical communication has gained considerable interest but face challenges due atmospheric turbulence, caused by temperature, humidity, and pressure changes that alter the air's refractive index, resulting in distortion into light waves. The Kolmogorov model offers the most comprehensive depiction of atmospheric turbulence, assuming that the inner scale of eddies approaches zero while the outer scale extends to infinity [3]. When a laser beam propagates through atmosphere, its initial properties degrade due to phenomena such as scintillation, beam wandering, broadening, and deflection. Therefore, it is crucial to conduct studies focused on beam that are more resilience to turbulence condition. Structured light beams, especially optical vortex beams carrying orbital angular momentum, have shown strong resilience to turbulence-induced distortions. Bessel-Gaussian (BG) vortex beams compared to Gaussian vortex beams are promising due to their non-diffracting propagation and self-healing abilities, which allow them to maintain beam integrity even in turbulent conditions [4-5]. While several studies have explored vortex beams with integer topological charge (TC), the behavior of BG and Gaussian vortex beams with fractional TC beams, particularly BG vortex beams, under atmospheric turbulence remains less explored.

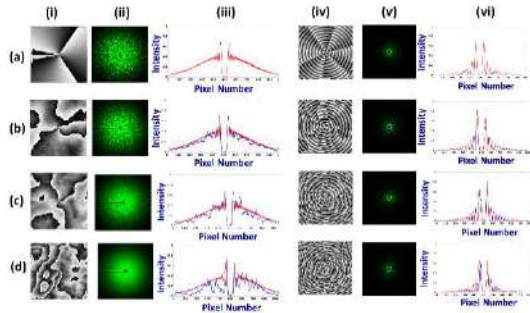


Fig. 1 Columns (i-ii) intensity and phase distributions of Gaussian vortex beam of TC = 3.2 (iii) intensity distribution of Gaussian vortex beam (iv-v) intensity and phase distributions of BG vortex beam of TC = 3.2 (vi) intensity distribution of BG vortex beam (red line - without turbulence and blue line with turbulence), rows (a) no turbulence (b) low level of turbulence (c) moderate level of turbulence (d) high level of turbulence.

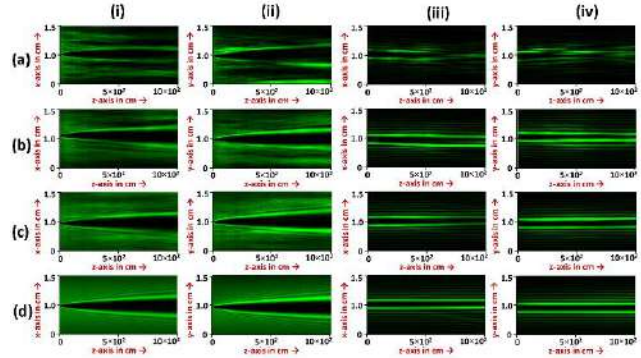


Fig. 2. Columns (i) intensity values in x-z plane of a Gaussian vortex beam with TC = 3.2, (ii) intensity values in y-z plane of a Gaussian vortex beam with TC = 3.2, (iii) intensity values in x-z plane of BG vortex beam with TC = 3.2, (iv) intensity values in y-z plane of BG vortex beam with TC = 3.2, rows (a) high level of turbulence, (b) moderate level of turbulence, (c) low level of turbulence, (d) no turbulence.

Figure 1 shows the phase and intensity distributions of BG and Gaussian vortex beams under no, low, moderate, and high level of turbulence for a distance of 140 cm. The results indicate the BG vortex beam demonstrates superior structural integrity and reduced intensity distortion. The results presented in Fig. 2 shows intensity profile x-z and y-z plane for Gaussian and BG vortex beam. The spatial structure of the intensity distribution of the BG beam remains unchanged up to a propagation distance of 10 meters.

Acknowledgment

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Low-Voltage, High-Extinction Ratio Microring Modulator based on Si-ITO Heterojunction

Nikita Mohanta¹, Ashutosh Kumar¹, Mukesh Kumar^{1,2}

1. Department of Electrical Engineering, Indian Institute of Technology Indore, Indore, Madhya Pradesh, 452553, India

2. Centre of Advanced Electronics, Indian Institute of Technology Indore, Indore, Madhya Pradesh, 452553, India

Microring resonators are key components in integrated photonics for optical interconnects, wavelength-division multiplexing (WDM), and signal processing. Indium tin oxide (ITO) offers strong electro-optic tunability due to its high plasma dispersion and epsilon-near-zero (ENZ) effect [1-2]. By integrating ITO with silicon in a semiconductor heterojunction, high extinction and low-voltage operation can be achieved without the need for high-k dielectrics [3-4].

The device is fabricated on a silicon-on-insulator (SOI) wafer with a 220 nm p-type Si layer over a 2 μm buried oxide. A p-type Si rib waveguide (180 nm thick (t_{Si}), 1 μm wide (w)) with 30 nm thick (t_{ITO}) n-type ITO atop is conformally deposited via RF sputtering. The microring has a 3.2 μm inner radius and is coupled to a bus waveguide with a 100 nm gap, defined using optical lithography and wet etching processes. Applying forward bias causes carrier accumulation at the Si-ITO interface. Near the ENZ condition, the real permittivity of ITO approaches zero, leading to strong electric field confinement and higher absorption. The change in refractive index also shifts the resonance wavelength, enabling efficient modulation.

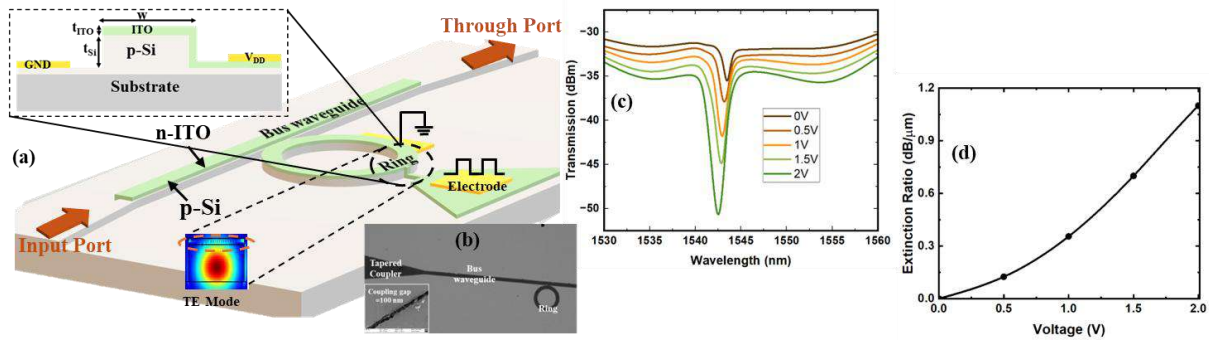


Fig. 1 (a) Schematic of the silicon-ITO heterojunction-based microring modulator with a cross-sectional view showing the p-Si/n-ITO interface, electrodes for electrical bias, and simulated TE-mode profile. (b) Optical microscope image of the fabricated device, with inset showing high-resolution SEM image of the coupling gap of ~ 100 nm between the bus and ring. (c) Measured transmission (dBm) spectrum with respect to wavelength (nm) at different bias voltages from 0 V to 2 V, showing resonance shift and extinction ratio enhancement. (d) Extracted extinction ratio ($\text{dB}/\mu\text{m}$) as a function of applied bias voltage.

Fig. 1(a) shows the schematic of the proposed device design with the TE optical mode distribution, highlighting charge carrier accumulation at Si-ITO interface under applied voltage, while Fig. 1(b) presents the optical microscope and SEM image with bus and ring waveguide with tapered couplers for alignment. The transmission spectra [Fig. 1(c)] show a resonance shift caused by carrier accumulation in the ITO layer under forward bias. The extinction ratio increases with voltage [Fig. 1(d)], reaching 1.1 $\text{dB}/\mu\text{m}$ at 2 V. This high extinction performance was achieved by designing the device in an overcoupled regime at 0 V, so that the applying voltage drives the microring toward critical coupling as the ITO approaches its epsilon-near-zero (ENZ) condition, enhancing light-matter interaction and absorption. The measured Q-factor of 3100 with FWHM of 0.75 nm and FSR of 27.9 nm, offering a balance between extinction ratio and modulation speed, mitigating the speed limitations of ultra-high Q resonators. The calculated electrical bandwidth using formula : $f_{3\text{ dB}} = \frac{1}{2\pi R_s C_{\text{total}}}$ (where, R_s is 120 Ω , the series resistance and C_{total} is 0.05 pF, the junction capacitance) is 26.5GHz, supporting the data rates above 40 Gbps, while maintaining minimal degradation from junction parasitics.

The Si-ITO heterojunction microring achieves high extinction ratio at low voltage with compact footprint. Its design exploits ENZ-enhanced light-matter interaction and coupling control for efficient modulation. The CMOS-compatible platform is suitable for optical interconnects, tunable filters, microwave photonics, and neuromorphic computing.

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A Broadband and Thermally Robust Metamaterial Absorber for Solar Energy Harvesting

Neha Singh, Praveen C Pandey*

Department of Physics, Indian Institute of Technology (Banaras Hindu University), 221005, India

*Corresponding author, Email : nehasingh.rs.phy23@iitbhu.ac.in, pcpandey.app@iitbhu.ac.in, Tel : - (+91)5427165473

Abstract : We propose a thermally robust, polarization-insensitive metamaterial absorber achieving 97.10% absorption across 200–2500 nm, with high angular stability and a short-circuit current density of 37.761 mA/cm², optimized for efficient solar thermal and photovoltaic energy harvesting applications.

Keywords: Metamaterial Absorber; Solar Energy Harvesting; Photovoltaics; Titanium Nitride;

Introduction: This work demonstrates a thermally stable, polarization-insensitive metamaterial absorber that achieves near-unity absorption across the entire solar spectrum (200–2500 nm), addressing spectral mismatch and radiative losses for enhanced solar energy harvesting efficiency. The structure comprises a hollow square Titanium Nitride (TiN) resonator, a Silicon Nitride (Si₃N₄) dielectric spacer, and a Tungsten (W) ground plane. This design facilitates strong light-matter interaction through localized surface plasmon resonances and multiple interference effects, achieving an average absorption of 97.10% [1,2]. Numerical simulation is done using COMSOL Multiphysics. TiN is used since it is a refractory material that shows plasmonic resonance from the vis-IR region [3]. Si₃N₄ acts as a dielectric spacer and has high intrinsic absorption [4]. W acts as a back reflector. TiN and W both are thermally and mechanically robust. Together, TiN-Si₃N₄-W stack helps in impedance matching with air, reducing reflection and increasing average absorption. With compact unit cell dimensions of 450nm × 450nm × 360nm, the absorber is well-suited for integration into thin-film and miniaturized photovoltaic systems.

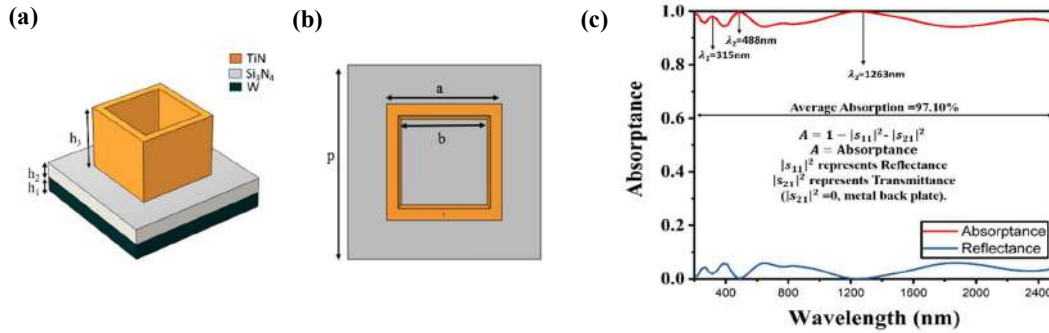


Fig. 1. Schematic diagram of the MPA, (a) Perspective view, (b) Top view, (c) Absorption spectra of the proposed structure.

Result: The TiN-Si₃N₄-W solar absorber achieves high absorption (97.10%) and J_{sc} (37.761 mA/cm²) across the full solar spectrum, while using simple, cost-effective, and durable materials. Its design overcomes complexity and scalability issues, making it a strong candidate for practical photovoltaic and solar thermal applications. This work offers a promising pathway toward efficient and robust solar energy harvesting technologies.

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4. Silicon nitride-based ultra-wideband ultra-long infrared metamaterial absorber with large angle and high absorption

Measurement of Surface Profile of Phase Objects using Spin-Orbit Beams

Anuj Maurya¹ and P. Senthilkumaran²

1. Physics Department, Indian Institute of Technology Delhi, Hauz Khas, New Delhi (110016)
2. Optics and Photonics Centre, Indian Institute of Technology Delhi, Hauz Khas, New Delhi (110016)
e-mail: anujmaurya925@gmail.com

Abstract: The Spiral interferometry is a very effective method to realize or measure the phase profile of a phase object. The spiral phase plays a vital role in the method. We have presented a method which uses Spin-Orbit beams and can perform multiple interferometry in a single setup using polarization transformation.

Optical interferometry has been used to measure the phase profiles of phase objects. Optical interferometry is distinguished by its non-contact approach and sub-wavelength precision, providing a key advantage in achieving highly accurate surface profile measurements [1,2]. An interferogram exhibits closed contour lines that encircle regions of interference maxima and minima. Polarization-based and spiral phase based optical interferometry can also be utilized to measure a sample's phase profile [3-5]. This modified approach produces spiral fringes rather than closed contours, differentiating between elevation and depression. Severin Fürhapter demonstrated the use of modulated fork grating at the frequency plane in a $4f$ configuration to distinguish between the positive and negative nature of phase gradient using the sense of spirals formed in the interferogram [4,5].

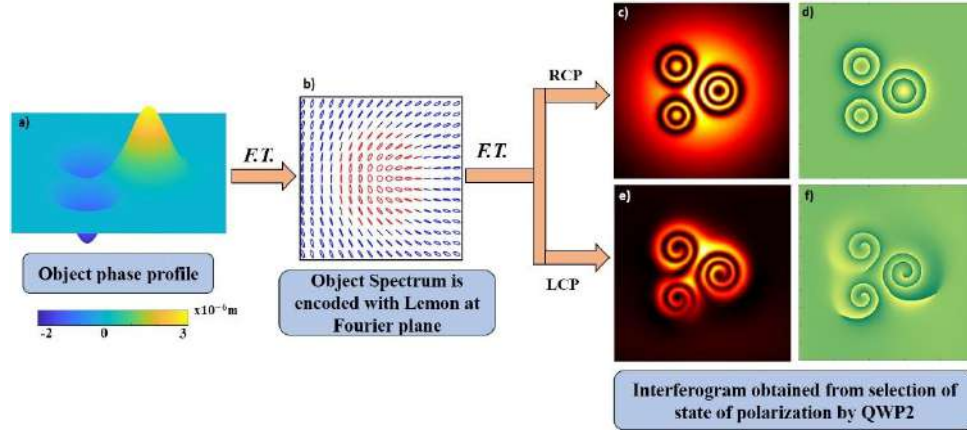


Figure 1: Simulation results for spiral interferometry using C-point. a) Object phase profile, b) Lemon c-point for encoding the phase profile for interferometry. Intensity after state of polarization selection of total intensity using quarter waveplate for c) right circular polarization component and e) left circular polarization component.

In this study, we present a Mach-Zehnder interferometer for profiling phase objects, utilizing a C-point polarization singularity for polarization encoding within a $4f$ configuration as shown in figure-1. The singularities incorporated within inhomogeneous polarization optical fields are called, C-points. Lemon and star c-points are the generic spatially varying polarization distributions containing C-points surrounded by elliptically polarized states across the beam cross section. By combining polarization singularity with a $4f$ optical Fourier processor in Mach-Zehnder setup, we obtain various types of interferograms through polarization transformation as shown in figure-1. The c-point is introduced in beam at Fourier plane to encode the object Fourier frequencies with the polarization singularity. Using different polarization transformation, different types of interferograms can be obtained and further processed for phase reconstruction.

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Optics of Finite Self-Assembled Disordered Sphere Arrays

Srikant Moharana^{*}, Nikhil Shrivastava[‡], Venkata Jayasurya Yallapragada[†]

^{*}skm20@iitk.ac.in, [‡]snikhil21@iitk.ac.in, [†]jayasurya@iitk.ac.in.

Indian Institute of Technology Kanpur, Kanpur, U.P, 208016, India

Many biological structures exhibit structural colours due to the light-matter interaction produced by nanostructures[1] present in them. This coloration is due to the short-range and long-range positional correlations among the constituent particles[2]. The investigation of how the density and arrangement of spheres within a material can impact optical phenomena is central to the study of these disordered sphere-packed structures. The longitudinal width of the sphere assembly significantly impacts its reflection efficiency and spectrum. In this work, we have modelled the disordered sphere packing by using Monte-Carlo simulations followed by Finite-Difference Time-Domain (FDTD) analysis to get the optical behaviour of the disordered assembly. For experiments, we self-assembled a colloidal suspension in a spacer of desired thickness to get the disordered assembly of polystyrene spheres.

The randomly packed structure was generated using molecular dynamics simulations by varying parameters such as the initial velocity and growth rate of particles[3]. Finite difference time domain (FDTD) numerical method was used to get the optical response of these structures having different longitudinal features. Using this simulation data, we compared the reflectance of two assemblies having different thicknesses. Fig.1 shows reflection peak for a 2.71 μm thick assembly of particles whereas complete transmission for a 4.27 μm thick assembly. For the relatively thick structure, there are a lot of scattering events which disperse all the light in all directions preventing us from seeing any peaks in the reflection corresponding to structural effects, but in case of a packing having finite width, the scattering events are fewer, and we can observe a distinct peak in the reflection spectrum.

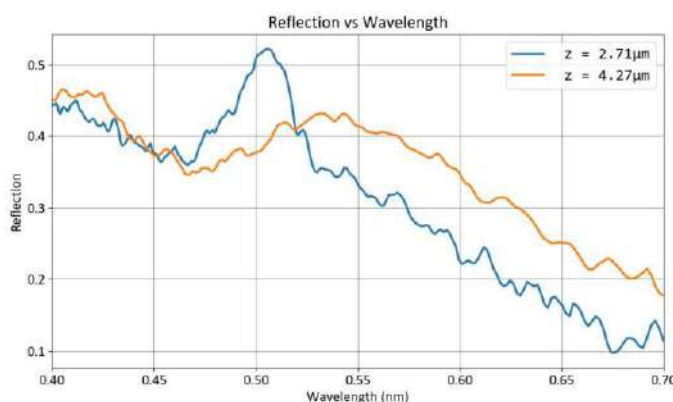


Fig. 1: shows the comparison of reflection spectra of two assemblies of particles having a thickness of 2.71 μm and 4.27 μm .

To observe the qualitative predictions of the calculations, we have performed colloidal self-assembly of polystyrene nanospheres of radius ~ 200 nm. We placed a dense suspension of the spheres between two glass coverslips supported by a series of pillars fabricated in resist by photolithography. Preliminary results indicate that confining disordered assemblies leads to an increased reflectance at specific wavelength bands.

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Non-linear pulse compression using multi-pass gas cell to overcome pulse energy and repetition rate limitations.

Rakesh Yembadi¹, RamGopal¹, Prashanth Kumar Singh¹ and M. Krishnamurthy^{1,*}

1. Tata Institute of Fundamental Research, Hyderabad, 500046.

Abstract:

Ultrashort pulse (< 100 fs) driven high rep. rate ($> \text{kHz}$) laser plasma particle acceleration [1,2] hold promise for compact, table top, university scale particle accelerator which could advance real-time applications and fundamental physics as well. Such table top accelerator requires short pulse laser operation at high repetition rates. Current Ti: Sapphire based high power lasers face limitations in pulse energy and repetition rate, restricting the accelerator scalability to advance applications. Multi-pass gas cell (MPC) [3] is an excellent tool for the high repetition rate spectral broadening, pulse shortening and stability. So that, the psec, Joule class, high rep. rate lasers could be compressed to < 100 fs, even < 10 fs. For a higher-power laser with energies > 10 's of mJ, a larger MPC would be required. This power to compression length scaling is linear. To understand and engineer: the pulse compression efficiency, power scalability and pulse energy range of the MPC: the gas dependent spectral broadening and the pulse duration measurements were carried out. Optimization and tunability of the pulse parameters like beam quality, amplitude, and spectral phase to ensure stable and efficient operation of the accelerator at high rep. rate is an important aspect of the investigation. This work demonstrates the pulse compression of 180 fs, 10 kHz (25 fs, kHz) laser pulses to < 40 fs, 10 kHz (< 8 fs, kHz) using a single stage 1-metre long multi-pass gas cell.

Pre-plasma tailored [4] electron acceleration studies are being carried out with the compressed kHz, sub-8 fs (< 40 fs) pulses where electrons are accelerated to 100's of keV energies. The initial electron acceleration results and the pulses compression technique would be presented.

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Optical Fiber Based SPR Sensor for Direct Detection and Quantification of Urease in Soil

Ojasvi Singh¹, Sachin Kumar Srivastava^{1,2}

1. Centre for Photonics and Quantum Communication Technology, Indian Institute of Technology Roorkee, 247667, India

2. Department of Physics, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India

Abstract: A highly sensitive optical fiber SPR sensor for direct urease detection is reported, with sensitivity and figure of merit as 0.47 nm/pM and $4.01 \times 10^9 \text{ pM}^{-1}$ respectively. Quantification in real soil samples was done and verified using SERS.

Introduction: Urease, an enzyme crucial for soil health, converts urea into ammonia and carbon dioxide with water, indicating soil quality [1]. While its activity is well-studied, direct concentration measurement remains unexplored. The knowledge of its concentration can be very helpful in determining soil quality and further exploration of the connection between the quantity of enzyme and its activity in soil. Optical fiber SPR sensors offer high sensitivity because of large field enhancement near the sensor surface among other advantages like miniaturization and real time monitoring capabilities. Here, an FO-SPR sensor has been developed using N-(n-butyl) thiophosphoric triamide (NBPT) as biorecognition element for ensuring specificity towards urease enzyme[2]. The developed sensor probe offers direct quantification of urease enzyme rather than estimation about its enzyme activity.

Results and Discussions: The cladding of 1 cm length from the middle of a 13 cm long chunk of plastic clad silica (PCS) optical fiber of 600 μm core diameter and 0.39 numerical aperture (From Molex, USA) was removed using a razor blade. The sensor probe was prepared by depositing a thin layer of gold (50nm) over the uncladded portion of the core. The surface was further functionalized by urease inhibitor NBPT so as to ensure specific and effective binding with urease. It defends the probe from change in refractive index near the sensing surface due to presence of other interferents. Fig.1(a) shows the schematic of the experimental set up used for optical characterization of the probe consisting of mainly light source, sensor probe and detector. Fig.1(b) shows the SPR spectra of different concentration of urease enzymes till 40pM with PBS buffer as solvent. The SPR spectra show a red shift with an increase in the concentration of urease. To accurately quantify the response, the resonance wavelength i.e. λ_{res} (nm) was extracted from the SPR spectra. The shift in resonance wavelength with concentration of urease as measured from the PBS buffer i.e. $\Delta\lambda_{\text{res}} = \lambda_{\text{res}} - \lambda_{\text{PBS}}$ has been plotted with concentration in the inset of Fig. 1(c). It also shows a red shift as the concentration of urease is increased. However, it starts to saturate after 10pM. Fig.1(c) depicts the trend of $\Delta\lambda_{\text{res}}$ variation to be linear for the 1 -10 pM concentration range. The sensitivity was estimated from the slope of the curve in Fig. 1(c) to be 0.478nm/pM. The detection accuracy was estimated from the reciprocal of FWHM of the spectra from Fig. 1(b) to be 8.54pm. The figure of merit (FOM=S/FWHM) for the sensor represents the overall sensing performance and was calculated to be $4.01 \times 10^9 \text{ pM}^{-1}$. This calibration curve was further used to quantify urease in real life soil sample and the result was verified using SERS.

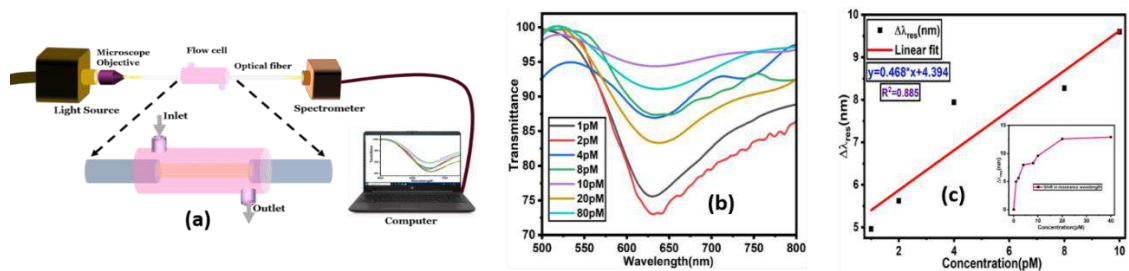


Fig.1.(a) Schematic of the experimental setup. (b) SPR spectra for different concentration of urease for Au-coated optical fiber sensor.(b) The trend of $\Delta\lambda_{\text{res}}$ with different concentration of urea

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Robust Sensor-less Adaptive Optics System with Reduced Crosstalk

Devesh Sharma and Biswajit Pathak*

Applied and Adaptive Optics Laboratory, Department of Physics, Indian Institute of Space Science and Technology,
Thiruvananthapuram, 695547 Kerala, India

*E-mail : biswajitpathak@iist.ac.in

Abstract: We present a robust sensor-less adaptive optics (sAO) system using multiplexed grating patterns, where partially corrected phase (PCP) from conventional holographic modal wavefront sensing (HMWS) is utilized to estimate the actual applied phase more accurately, by reducing the crosstalk. Proof-of-concept simulation and experimental results are provided to demonstrate the practicality and efficiency of the proposed sAO system.

Modal wavefront sensing (MWS) measures aberration by comparing the on-axis intensities of two wavefront copies, each modified with orthogonal bias modes. A programmable version of MWS is implemented using a binary grating pattern, realised with a spatial light modulator (SLM) that produces a pair of ± 1 diffraction orders, at the Fourier plane. The $+1$ order corresponds to the positive bias and the -1 order corresponds to the negative bias. Multiplexed hologram can produce multiple biased spot pairs simultaneously, enabling faster aberration measurement. HMWS is valued for its time efficiency and wide applicability but suffers significantly from crosstalk between modes. Although, HMWS is effective for lower order modes or in the presence of only a few modes, its accuracy decreases significantly as mode count increases or if there is presence of higher order modes, thereby degrading the performance of the sensor.

To address this limitation, we propose a robust method that improves the estimation accuracy and also eliminates the unwanted modes. Our method starts by estimating the incident wavefront profile initially using a conventional (HMWS) method. A PCP is obtained by applying the scaled estimated phase to the incident beam. After that, PCP is remeasured using HMWS, and the PCP and scaled estimated phase are combined to estimate the final phase. This sequential approach reduces crosstalk between modes and enhances sensitivity, enabling more accurate wavefront reconstruction, especially when dealing with multiple aberration modes simultaneously. Simulation and experimental result validate the method's feasibility and effectiveness.

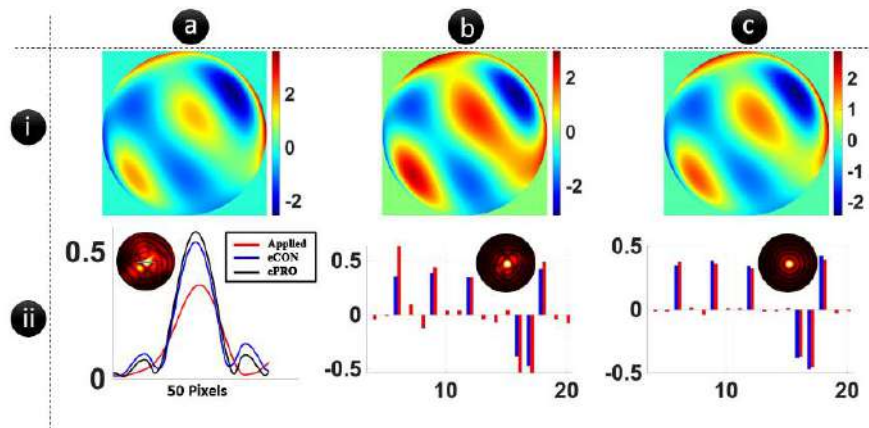


Fig. 1 Simulation result demonstrating the estimation using conventional estimation method and the proposed estimation method, containing six Zernike modes.

The simulation results are presented in Fig. 1 where, the applied profile in (i)(a) contains six modes, while the phase profile estimated using the conventional HMWS method is shown in (i)(b). The final correction obtained using the proposed method is shown in (i)(c). The bar plots and PSFs corresponding to (i)(b) and (i)(c) are shown in (ii)(b) and (ii)(c), respectively. The line plots across the center of each of the PSFs (shown in (ii)(a)), shows the improvement in estimation accuracy of the proposed method in comparison to the conventional method. Moreover, the reduction in cross-talk and accurate estimation of the applied modes are also evident from the bar plots.

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Optical Spectroscopy for Remote Sensing of Vitrified Molten Waste Material

Vedika Chavan¹, V K Unnikrishnan^{*1}

1. Manipal Institute of Applied Physics, Manipal Academy of Higher Education, Manipal, Karnataka-576104, India

*Email: unnikrishnan.vk@manipal.edu

Advancements in analytical approaches have been greatly limited to the lab-based techniques or those requiring a controlled environment. This approach has a potential limitation in certain circumstances where it is difficult to reach out to the analyte due to hostile environmental conditions, hazardous sample nature, or the sample cannot be retrieved from its original position, like in a nuclear waste immobilization plant. The analysis of vitrified molten waste is essential for monitoring purposes. Laser-based spectroscopy systems are suitable for such applications due to the convenient excitation of the sample from stand-off distances, collecting optical signals from the sample for characterization. The laser-induced breakdown spectroscopy (LIBS), Raman spectroscopy, and laser-induced fluorescence (LIF) consist of similar instrumentation for remote analysis [1], which includes of source, beam focusing optics, signal collection optics, analyzer, and detector. The hyphenated system capable of LIBS, Raman spectroscopy, and LIF yields ionic, atomic, and molecular information of the analyte [2]. Thus, the detection and characterization of the standoff sample became more accurate, reliable, and efficient.

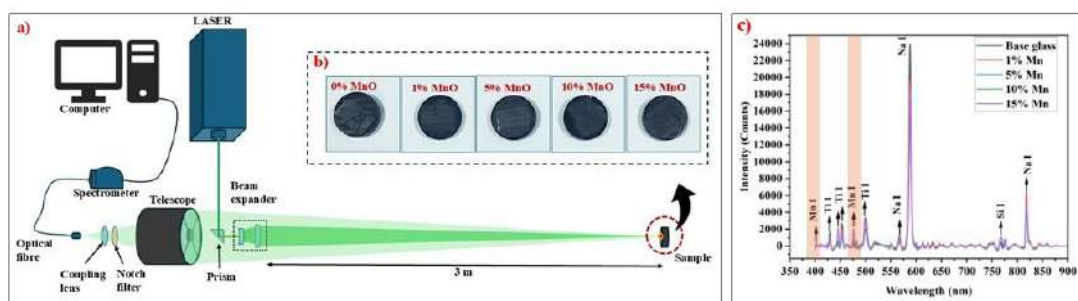


Fig. 1 (a) Schematic of the coaxial experimental setup for standoff LIBS analysis, (b) Simulated glass samples having different MnO concentration, and (c) Obtained LIBS spectra of different Mn-doped samples from 3m.

The LIBS, Raman signals are highly propagating in the direction of incidence of the laser beam [3, 4]. Hence, a coaxial back collection scheme is utilized for the LIBS analysis of a simulated glass sample of vitrified molten waste material, which consists of different Mn wt.% in the samples. A second harmonic Q-switch Nd: YAG pulse laser with 532 nm wavelength, 6 ns pulse duration, and 10 Hz repetition rate was utilized as an irradiation source for obtaining LIBS emission spectra. To achieve a tightly focused beam on the remotely placed sample surface for plasma formation, a combination of a plano-concave and a plano-convex, was used. The beam was focused at 3 m by adjusting the separation distance between the lenses. The high-energy laser pulse ablates an insignificant amount of material and creates a micro plasma consisting of electrons, ions, and atoms in an excited state. In the first few nanoseconds, continuum spectra are obtained due to inverse bremsstrahlung, arising from collisions between electrons and photons. Further, plasma starts to decay, and during this, the electrons, atoms, and ions in the excited energy states fall into ground states, leading to photon emission with distinct spectral peaks. These spectral peaks are characteristic of the emitting atoms and ions. The generated signal was collected with the Cassegrain telescope. The collected signal is passed through the 532 nm specific notch to remove the Rayleigh scattering, and a biconvex lens couples the signal to the fibre optic cable to feed it to the compact spectrometer “Goya lab SAS Model V1, Andor” shown in Fig.1. The spectra were recorded with SpectroLab software. The LIBS spectra of Mn-doped glass samples were recorded from a 3m standoff distance. The intensity and wavelength curve for each sample is shown in Fig. 1 (c). The obtained peak values were verified and assigned corresponding to NIST data set values.

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AUTOCORRELATION: TRACING THE OVERLAP OF AN ULTRAFAST, INVISIBLE LASER WITH ITSELF TO MEASURE PULSE WIDTH

M V Boomika¹, Dr. Pritam Shetty², Dr. Sivarama Krishnan²

1. Indian Institute of Science Education and Research, Berhampur, Odisha 760003, India

2. Indian Institute of Technology, Madras, Tamil Nadu 600036, India

In ultrafast optics, laser pulses are too short(10-100fs) to be measured directly. Therefore, autocorrelation is used to measure the pulse width of the laser. Autocorrelation is a process where we record how strongly a pulse interacts with a delayed version of itself. When the two pulses interact, a cross term of the electric field($E(t) \times E(t - \tau)$) gives us a second-harmonic generation (SHG) signal.

$$E(t)=E_0(t) + E_0(t-\tau) \quad (1)$$

$$P^{(2)}(t) \propto [E(t)]^2=[E_0(t)+E_0(t-\tau)]^2 \text{ (P is polarization)} \quad (2)$$

$$P^{(2)}(t) \propto E_0^2(t)+E_0^2(t-\tau) + 2E_0(t)E_0(t-\tau) \quad (3)$$

The SHG process acts as a gate that only opens during the pulse overlap. The phase difference causes destructive interference and eventually cancels pulses. However, it is difficult to measure the pulse width. In this project, we measure the pulse width of a femtosecond laser of two different pulse durations (275fs and 500fs) using interferometric autocorrelation. We detected the voltage reading for every delay change. We observed the appearance and movement of fringes in a particular span of the entire stage movement. Correspondingly, we observed a smooth bell curve/envelope in our voltage vs time reading during the span for both autocorrelation traces. We took the reading three times for both the 275fs pulse and the 500fs pulse and plotted the data acquired. We observed a smooth interferometric autocorrelation trace. We enveloped the plot to acquire the intensity autocorrelation trace. We used the envelope plot to fit a Gaussian curve. From there, we got the full-width at half maximum (FWHM) value of the trace and deconvolved it to get the pulse width. Our results for the 275fs pulse were 348fs, 349fs, and 349fs, and we got 467fs, 469fs, and 469fs for the 500fs laser. Furthermore, our lower envelope was not perfectly symmetric, which indicates some chirp. This might be due to dispersion, instrumental error, etc.

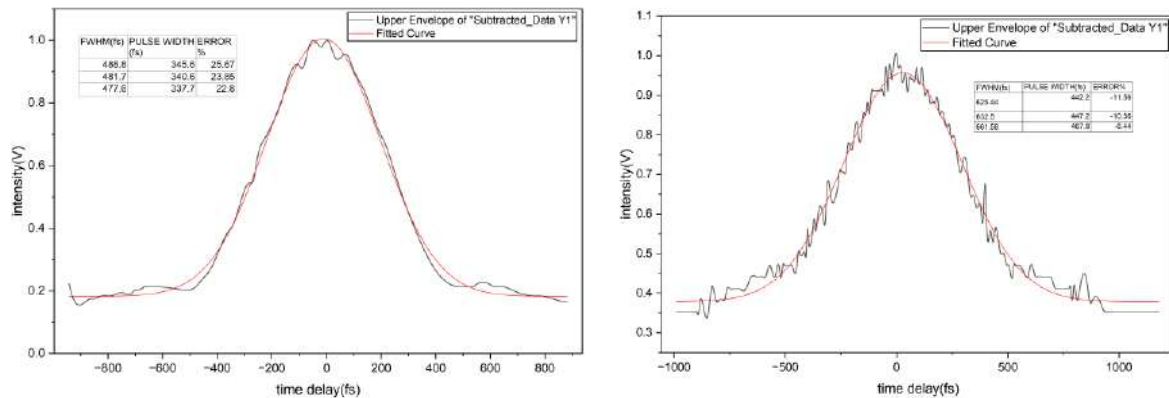


Fig. fitting the Gaussian curve in the envelope of the attained curve (a) 275fs (b) 500fs.

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Securely Hiding Information within the Quantum Noise of Twin Beams

Chirang R Patel ^{*}, Jerin A Thachil and Ashok Kumar [†]

Department of Physics, Indian Institute of Space Science and Technology
Thiruvananthapuram, Kerala, 695547, India

^{*}chirangpatel648@gmail.com and [†]ashokkumar@iist.ac.in

Quantum communication protocols use the fundamental principles of quantum mechanics to enable secure transmission of information with the ability to detect eavesdropping [1]. These protocols operate in two regimes, discrete-variable and continuous-variable. The discrete-variable approaches rely on single photons or entangled photon pairs, whereas the continuous-variable approaches use quantum states such as coherent and squeezed states, and offer higher data rates. In continuous-variable regime, the bright two-mode squeezed states or twin beams have gained significant attention due to strong quantum entanglement and their ability to reduce noise beyond the classical limit. In the current work, we explore the possibility of hiding information securely within the quantum noise of the twin beams.

In order to generate twin beams, we use a four-wave mixing process (FWM) in hot ⁸⁵Rb atoms. In this process, two photons from the pump beam are converted into a pair of photons in two different modes, the probe and the conjugate or the twin beams, as shown in inset of Fig. 1(a) [2]. In presence of a weak seed probe beam, the FWM process amplifies the probe and generates a conjugate beam. After the interaction, the pump beam is filtered out, and the resulting probe and conjugate beams are directed to photodetectors, D1 & D2. The probe and conjugate intensity noise along with their intensity-difference noise is analyzed using a spectrum analyzer.

In this work, we present an information encoding scheme based on twin beams where information is encoded in different modulation frequencies, f1-f10, (Fig. 1(b)) in one of the twin beams. The amplitude of each frequency modulation is kept in such way that it is less than the individual noise of the twin beams. Thus, the modulated signal is hidden within the quantum noise of the individual mode, which is more than the shot noise limit. As a result, single-mode measurements cannot extract the signal, while the joint measurements can recover the encoded frequency, ensuring security against eavesdropping.

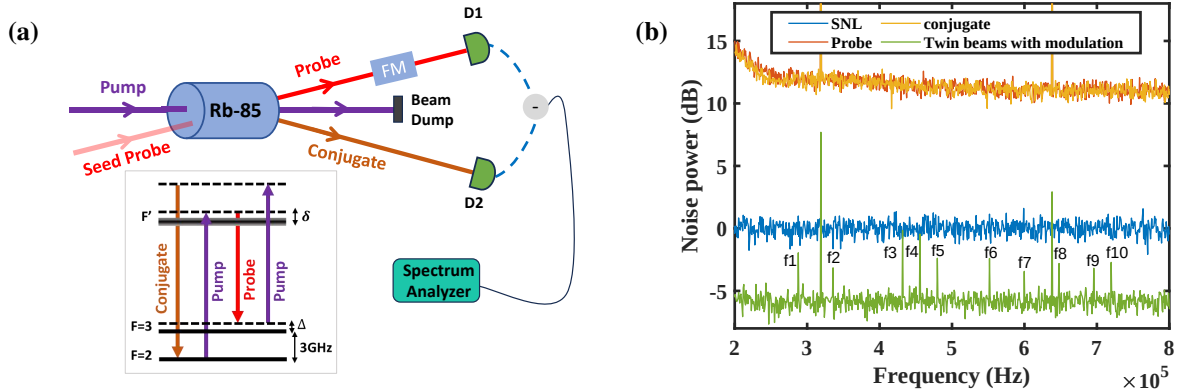


Fig. 1: (a) Schematic diagram of experimental setup and (b) Normalized noise power to the SNL as a function of noise analysis frequency. Here f1 to f10 are the modulated signal frequencies intended for information encoding in range of 250 - 750 kHz.

In Fig. 1(b), we present the experimental results of noise power versus noise analysis frequency. The plot shows a noise reduction of ~ 6 dB (green trace) below the shot noise limit (SNL, blue trace) with two-mode squeezed state, confirming the presence of strong quantum correlations. In contrast, the individual noise levels of the probe (red trace) and conjugate (yellow trace) beams are significantly above the SNL. To demonstrate the frequency modulation based encoding, the probe beam is modulated at distinct frequencies (f1 - f10). The resulting intensity difference noise spectrum reveals peaks at the modulation frequencies, as shown in green trace. Additionally, two extra peaks exceeding SNL are observed in both the intensity-difference noise and individual beam noise, these arise from technical noise in the laser and are unrelated to the encoded signal. The present results confirm the feasibility of encoding multi-bit information in the frequency domain while maintaining security via quantum correlation properties.

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Distributed Sensing in a network of Optical Gyroscopes using bright Two-Mode Squeezed States

Priyanka M. Kannath^{1†}, Girish S. Agarwal², and Ashok Kumar^{1*}

¹Department of Physics, Indian Institute of Space Science and Technology, Thiruvananthapuram, Kerala, 695547, India

²Institute for Quantum Science and Engineering, Department of Physics and Astronomy,

Department of Biological and Agricultural Engineering, Texas A&M University, College Station, Texas 77843, USA

E-mail: [†]priyankam.23@res.iist.ac.in, ^{*}ashokkumar@iist.ac.in

Quantum sensing is a rapidly growing field in the domain of metrology that exploits the advantages of quantum resources. Squeezing and entanglement are the most leveraged quantum resources in improving the performance of various sensing applications over their corresponding classical schemes [1]. Recently, more developments have emerged towards the sensing of multiple spatially distributed parameters known as distributed quantum sensing [2]. Using continuous variable entangled probe states, one can estimate unknown global parameters in a distributed network with quantum-enhanced sensitivity [3].

Here, we present a scheme for measuring the average angular velocity of a distributed network of M optical gyroscopes, as shown in Fig. 1. For that, we use bright two-mode squeezed states generated by a parametric amplifier (PA), and it is projected to an M -mode entangled state using symmetric beamsplitter networks (SBN). We measure the joint phase quadrature of all the gyroscope outputs via homodyne detection to estimate the average phase shift that occurred in the gyroscope network. Since the phase shift due to rotation in a gyroscope is directly proportional to the angular velocity, the lesser the uncertainty in measuring the average phase shift, the greater is the phase sensitivity and angular velocity sensitivity.

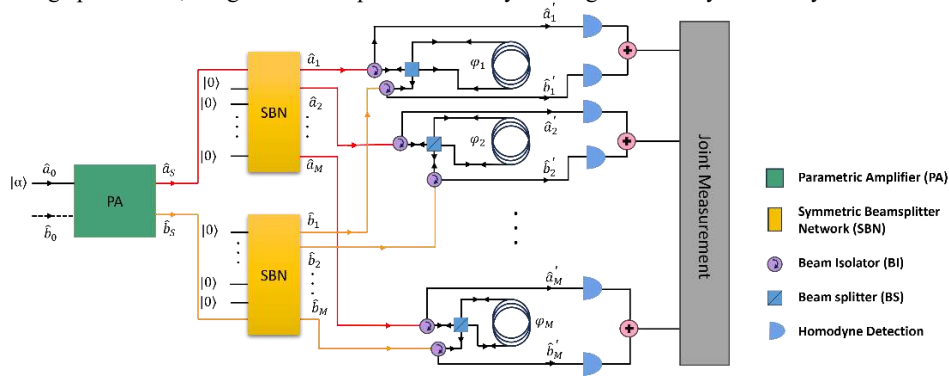


Fig. 1 Configuration for distributed quantum sensing in optical gyroscope network using M -mode entangled states.

Our results show that the average phase sensitivity can be improved beyond the shot-noise limit, which is the classical limit. To check the performance of the system arising from the mode entanglement of the states, we compare the phase sensitivity with that of a similar setup that uses separate two-mode squeezed states generated from M independent PAs. In Fig. 2 (a), we show the phase sensitivity corresponding to the mode-entangled probe state and the separable states as a function of the number of gyroscope units at different transmissivities (η). We found that, at any given value of transmissivity, the mode-entangled case exhibits enhanced phase sensitivity compared to the separable case.

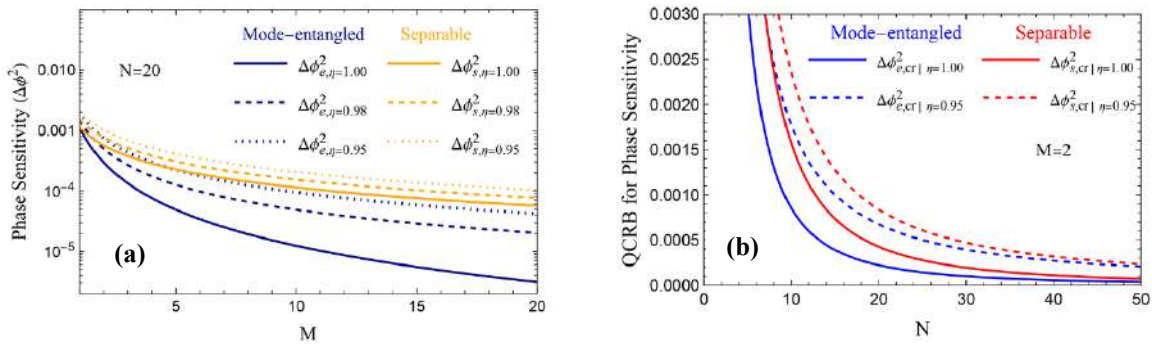


Fig. 2 (a) Phase sensitivity as a function of the number of gyroscopes. (b) QCRB for phase sensitivity as a function of the number of photons.

We also calculate the ultimate bound of sensitivity, that is, the quantum Cramér-Rao Bound (QCRB) for the phase sensitivity of the system using mode-entangled states and separable states and plot it in Fig. 2(b) for two different transmissivities. It shows that for any given transmissivity, the performance of the mode-entangled case outperforms the separable one, and the QCRB can be saturated at higher photon numbers.

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Spin-dependent Dispersion in Plasmonic Crystals

Sujit Rajak^{1*}, Nishkarsh Kumar^{2*}, Suman Mandal¹, Jeeban K Nayak³, Ayan Banerjee¹, Subhasish Dutta Gupta, Oliver J.F Martin³, Nirmalya Ghosh¹

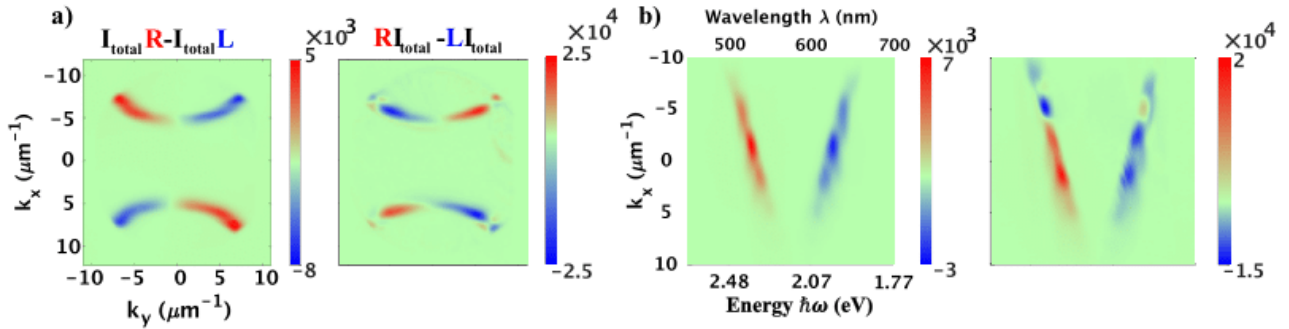
¹. Indian Institute of Science Education and Research Kolkata, Department of Physical Science, Mohanpur,, India

². Indian Institute of Technology Kanpur, Department of Physics, Kanpur, India

³Institute of Electrical and Microengineering, EcolePolytechniqueFederale de Lausanne, Lausanne, Switzerland

E.mail-^{*}sr23rs061@iiserkol.ac.in

In this study, we report Rashba like spin (circular polarization) dependent dispersion effects in plasmonic crystal metamaterials. We have previously reported momentum(k)-domain forward and inverse Spin Hall effects of light in plasmonic crystals using a custom designed k -domain Mueller matrix measurement system [1]. Here, we have improvised our k -domain Mueller matrix experimental embodiment to observe, analyze and quantify spin-dependent dispersion (w vs k) effects in the plasmonic crystal system. In our system, the spin orbit interaction (SOI) effects and the resulting spin-dependent dispersion effects originates from the spatially varying polarization due to tight focusing and its subsequent interaction with the anisotropic plasmonic crystal. This two



stage

Fig. 1 (a) Manifestation of the forward and inverse Spin Hall effect of light in the circular anisotropy descriptor M14 and M41 elements of the momentum (k_x, k_y) domain Mueller matrix images of the Au grating plasmonic crystal. **(b)** Rashba-like spin-dependent dispersion, indicative of spin-orbit interaction (spin-momentum locking of light) is clearly manifested as spin (circular polarization)-selective dispersion branches in the M14 and M41 Mueller matrix elements.

interaction of polarized light leads to an azimuthal gradient of the geometric phase in the momentum space. Unlike the conventional Photonic Rashba effect where the spin-dependent dispersion arises from spatial inversion symmetry breaking in specially designed metamaterials, in our case the spin-split dispersion emerges due to symmetry breaking in the momentum (k) domain. This new type of SOI effect is interpreted in terms of combined effect of geometric linear birefringence and linear diattenuation (geometric LB-LD effect) arising due to a sequential polarization interaction in plasmonic crystals. The details of the results on the k -domain spectral Mueller matrices and the observed spin-dependent dispersion effects of the plasmonic crystal and their polarimetric analysis, interpretation will be presented.

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Cancer Detection – Spherical Silver Nanoparticles for the identification of diseased tissues via Surface Enhanced Raman spectroscopy

Nidhi Mehta^{*a}, Pramila Thapa^{a,b}, Shivakumar N^b, Akshay Trimukhe^b, Varun Surya^b, Deepika Mishra^b, L.M. Kandpal, Dalip Singh Mehta^a

^aBio-photonics and Green Photonics Laboratory, Indian Institute of Technology Delhi, Hauz-Khas, New Delhi, 110016, India

^bDepartment of Oral Pathology and Microbiology, Centre for Dental Education & Research (CDER), AIIMS, Hauz Khas, New Delhi, 110016, India

Owing to the lack of ability to detect the cancer at its early stages, there is a marginal improvement in the survival rate of the patients [1]. This is largely due to the inherent limitations of histopathology, the current gold standard which is invasive, costly, time-consuming, requires advanced equipment and specialized pathologists, have potential risk of cancer spread during biopsy, and is available only at tertiary healthcare centers [2]. Due to this, the development of a technique to detect the disease at its infancy is the prime need of the time and to improve the lives of the patient by saving them from painful treatments at later stage [3,4].

The surface enhanced Raman spectroscopy (SERS) is an emerging technique to sense the changes in the biomarkers at the early stages of disease progression [5]. In this work, spherical Ag nanoparticles have been synthesized via microwave synthesis. The aqueous solutions of 10 mM AgNO₃ and 20 mM tri-sodium citrate were allowed to react in the microwave synthesizer at power 110W, temperature 110°C for 10 minutes. The fixed tissues were incubated with the synthesized nanoparticles for SERS measurements. The as-prepared samples were characterized using a Raman spectrometer with a 785 nm excitation laser. Spectra were recorded at a laser power of 100 mW with an acquisition time of 10 s per scan, and each final spectrum represented the average of three consecutive measurements.

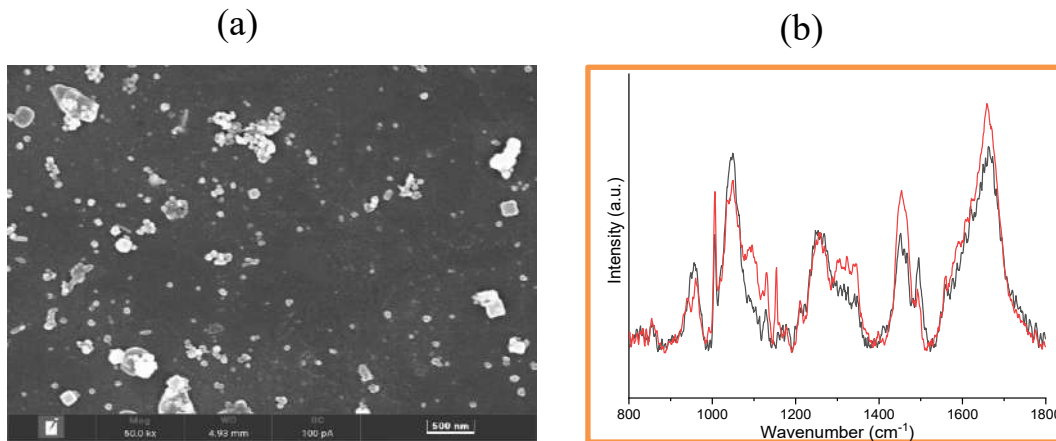


Fig. 1 (a) FESEM image of spherical silver nanoparticles, (b) SERS spectra of malignant (red) and non-malignant (black) tissues.

The SERS spectra of malignant tissues and non-malignant tissues have significant differences in peak intensities, as shown in Figure 1(b). The peaks at 1245, 1280, 1337, 1452, and 1664 cm⁻¹ are the major peaks that reveal the difference between the two categories of tissues. The proteins, keratins and DNA peaks have higher relative intensities in malignant tissues [6]. The peak at 1452cm⁻¹ corresponds to CH₂ bending in diseased tissues [7,8]. The protein peaks at 1452 cm⁻¹ and 1664 cm⁻¹ are higher in the malignant tissue as compared to the non-malignant tissue and these results are consistent with those reported in the literature.

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Bell Type Inequalities for Four Qubit Dicke State

Tomis Prajapati¹, Harsh Mehta², V. Narayanan^{1,2}

1. Department of Physics, Indian Institute of Technology Jodhpur, Jodhpur, Rajasthan 342030, India

2. Quantum Information and Computation (IDRP), Indian Institute of Technology Jodhpur, Jodhpur, Rajasthan 342030, India

Quantum Entanglement is an exotic phenomenon which is central to many techniques of Quantum Technologies. Bell or Bell-type inequality violation is one of the fundamental techniques which characterizes entanglement of a quantum system [1]. However, as the dimensions of system increases number of terms required for inequality also increases and for multi-partite inequalities such as Mermin-Ardehali-Belinskii-Klyshko (MABK). This increased complexity reduces the practicality of experimental implementation. However multi-partite CHSH-type inequalities have been proposed having few terms [2]. In This work we discuss generation of four qubit Dicke state and two qubit bell state and violation of Bell-type inequality for these states [3]. We construct our custom operators in terms of Pauli matrices ($\sigma_x, \sigma_y, \sigma_z$) and show inequality violation using IBM QPUs for two qubit bell state and for four qubit dicke state.

We explore two distinct methods for preparation of four qubit dicke state. 1). Gate-based approach and, 2). Statevector based approach. Based on the method discussed in [2], we constructed bell-type inequality for Four-qubit dicke state as :

$$|\hat{A}\hat{B}\hat{C}\hat{D} + \hat{A}\hat{B}'\hat{C}'\hat{D}' + \hat{A}'\hat{B}\hat{C}'\hat{D} - \hat{A}'\hat{B}'\hat{C}\hat{D}'| \leq 2 \quad (1)$$

Where the local observables are in the form of general operator in three dimensional spherical space as : $\hat{X}_n = \sin(\theta) \cos(\varphi) \hat{\sigma}_x + \sin(\theta) \sin(\varphi) \hat{\sigma}_y + \cos(\theta) \hat{\sigma}_z$ where $(\sigma_x, \sigma_y, \sigma_z)$ are Pauli matrices and $\theta \in (0, \pi), \varphi \in (0, 2\pi)$. Optimum values of θ and φ is calculated by maximizing value of bell polynomial over each term in eq. (1).

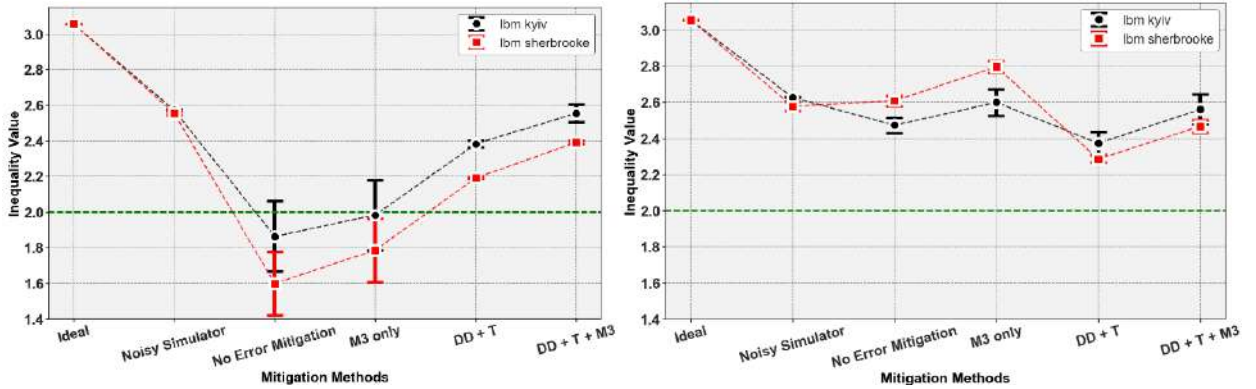


Fig. 1 A comparison of the Bell type inequality violation values of Ideal Simulator, Noisy, and real hardware with and without mitigation methods on two IBM QPUs for Dicke state prepared by Gate based method (left) and statevector-based method (right).

We implemented these custom operators on IBM's two different Superconducting Quantum Processing Units (QPUs), namely *ibm_kyiv* and *ibm_sherbrooke* using *Qiskit* – an open-source quantum SDK [4]. Fig. 1 Shows comparison of theoretical value of inequality along with obtained values with noisy simulation, without any error mitigation method and with different mitigation methods for both state preparation methods and both IBM's QPUs. In our investigation, the state vector-based method gives better results than the gate-based method. This could be because it initializes the system directly into the desired Dicke state, minimizing the overall circuit depth and noise exposure.

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Experimental Determination and Analysis of Coherence Time, Outage Duration and BER in Practical Bubble Turbulence-Induced Underwater Optical Channel

Sonal Shashikanth¹, Dr. Raghavendra B.S.², Dr. U Shripathi Acharya³

1. National Institute of Technology Karnataka, Surathkal, Karnataka-575025, India

2. National Institute of Technology Karnataka, Surathkal, Karnataka-575025, India

3. National Institute of Technology Karnataka, Surathkal, Karnataka-575025, India

Underwater Visible Light Communication (UVLC) is challenging owing to the intrinsic absorption and scattering-based attenuation of the underwater medium. In addition to the intrinsic medium attenuation, bubble-induced Underwater Optical Turbulence (UOT) creates significant fluctuation in the intensity of light, causing an increase in the Bit Error Rate (BER). This makes it essential to determine the statistical, time, and frequency domain characteristics of the channel. There were abundant simulation-based works on UVLC channels. However, relatively few works have involved the practical establishment of the underwater channel and corresponding characteristic analysis. Keeping this motivation in mind, our study involves the practical establishment and analysis of a 530 nm wavelength LED, Intensity Modulation-based Direct Detection (IM-DD) optical link enabled with On-Off Keying (OOK). An evaluation of the outage probability and Bit error Rate (BER) is conducted to understand the extent of attenuation caused by each of the bubble sizes in a bubble turbulence-affected channel. The coherence time is considered crucial for determining the packet length. Hence, this study investigates the variation of coherence time with bubble size and the beam width.

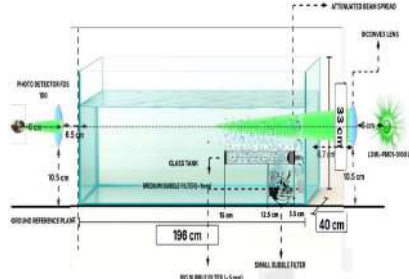


Fig. 1: Schematic Diagram of the Constructed Experimental Optical Channel

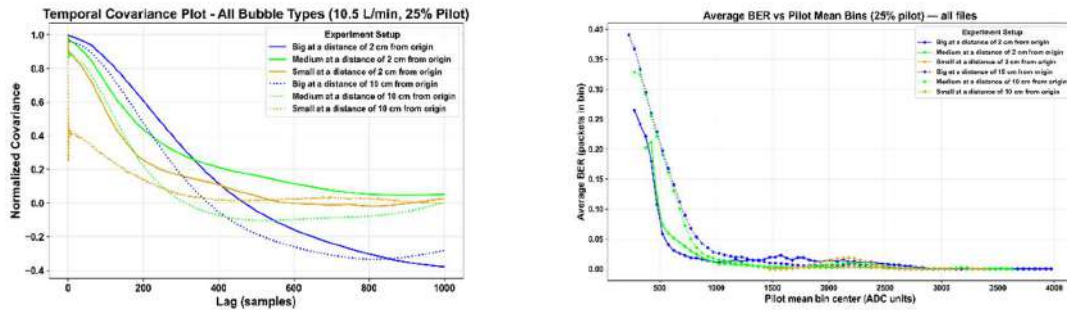


Fig. 2 and 3 (left to right): Temporal Covariance and BER plots portraying bubble size and beam width fluctuation.

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Impact of mechanical jitter on Laguerre Gaussian beam combination system

Mukesh Kumar¹ and Nithyanandan Kanagaraj¹

¹Ultrafast Fiber Optics and Smart Photonic Technologies, Dept. of Physics, IIT Hyderabad, Telangana, India-502285

High-energy lasers are crucial for directed energy applications requiring high-intensity beams [1]. Beam combining addresses power-scaling challenges, enabling efficient high-power outputs. Higher-order Gaussian beams, such as Laguerre-Gaussian beams (LG), are more efficient due to their unique spatial structure and reduced susceptibility to losses from atmospheric turbulence [2]. However, long-range propagation introduces mechanical jitter, causing random beam deviations that affect spot size and intensity. Prior studies have analyzed jitter effects on Gaussian and Hermite-Gaussian beam systems [3-4]. This study investigates the mechanical jitter impact on Laguerre-Gaussian beam modes in incoherent beam combination systems. An LG beam is a higher-order Gaussian beam characterized by its circular symmetry and mode patterns described by Laguerre polynomials (L_m^l) as given by its intensity profile [2]

$$I_{l,m} = I_0 \left[\frac{W_0}{W(z)} \right]^2 \left(\frac{\rho}{W(z)} \right)^{2l} L_m^{2l} \left(\frac{2\rho^2}{W^2(z)} \right) \exp \left(-\frac{2\rho^2}{W^2(z)} \right) \quad (1)$$

Where I_0 is the initial intensity, W_0 the initial spot size, and $W(z)$ the spot size at distance z , given by $W(z) = W_0^2(2l + m + 1) \left[1 + \left(\frac{\lambda L}{2\pi W_0} \right)^2 \right]$ [5]. The indices l and m represent beam modes, λ is the wavelength, and L is the propagation distance. Mechanical jitter, caused by random angular deviations, results in beam direction fluctuations and can be expressed as the product of the deviation angle and propagation distance. The combined intensity of an LG beam under jitter is calculated by

$$\langle I_{l,m}(x, y, L) \rangle_{\text{jitter}} = \sum_{i=1}^{19} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} I_{l,m}(x - r_x, y - r_y, L) f(r_x) f(r_y) dr_x dr_y \quad (2)$$

Where $f(r_s) = \frac{1}{\sqrt{2\pi}\sigma_r} \exp \left(-\frac{r_s^2}{2\sigma_r^2} \right)$ is a zero-mean Gaussian distribution along x and y direction, $r_x = \theta_x L$, $r_y = \theta_y L$, and $\sigma_r = \sigma_\theta L$ represents the standard deviation of the beam displacement. The spot size under jitter is calculated as $W^2(z)_{\text{jitter}} = W_0^2(2l + m + 1) + 4\sigma_r^2$. To investigate jitter effects, 19 LG beams arranged in the hexagonal array with $W_0 = 5$ cm are propagated over $z = 3$ km, and a 241×241 grid with a step size of 0.5 cm is used to calculate target intensity. The spot size variations of different Laguerre Gaussian modes are shown in Fig. 1(a). It is observed that the spot size increases with mechanical jitter, with higher modes showing a slower rate of increase compared to lower modes. This suggests that higher modes are less affected by mechanical jitter, experiencing less broadening than their lower mode counterparts. This is due to their more complex intensity distribution with multiple radial lobes. In lower-order modes, the intensity is concentrated in a central lobe, so jitter causes significant spot size broadening. In higher-order modes, the intensity is spread across the beam, so jitter has less impact, leading to less broadening of the spot size. The combined normalized intensity variation, as shown in Fig. 1(b), reveals that the intensity of the combined beam decreases with increasing mechanical jitter across all LG beam modes, with higher modes experiencing reduced impact. In conclusion, higher-order LG beams are less affected by mechanical jitter, making them highly suitable for beam combination systems, especially in high-precision applications and other critical scenarios.

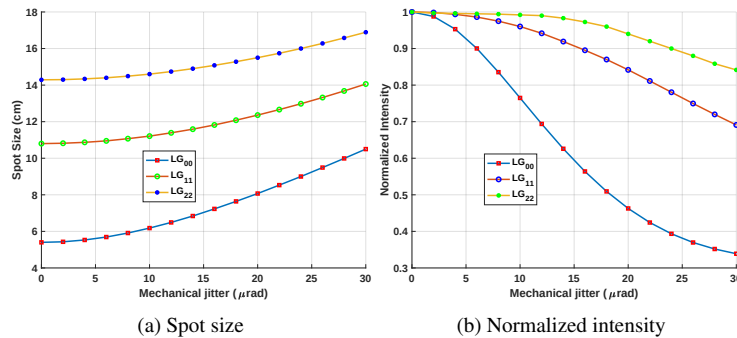


Figure 1: Spot size and normalized intensity of various LG modes with mechanical jitter

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Fiber Cavity Interferometry Based Hydrophone for High Temperature Bubble Acoustics

Arvind Kumar Maurya¹, and Rajan Jha¹

1.Nanophotonics and Plasmonics Laboratory, Department of Physics, Indian Institute of Technology Bhubaneswar -752050

Introduction

Understanding the sounds produced during boiling is essential in fields like power generation, chemical processing, and safety monitoring, where being able to monitor bubble activity in real time can help prevent catastrophic failures [1]. Conventional acoustic sensors, such as piezoelectric hydrophones, often fail in high-temperature environments because they can't handle the heat, are prone to corrosion, and are affected by electromagnetic interference [2]. Fiber optic hydrophones operating on cavity interferometry, provide a promising alternative with advantages like, compact, sturdy, and unaffectedness on electromagnetic noise. In this study, a fiber cavity interferometer hydrophone with a metal diaphragm was tested in boiling water, showing that it remains sensitive and reliable even in conditions that disable traditional sensors. This technology could greatly improve real-time monitoring and safety in demanding, high-temperature environments.

Working Principle

The fiber cavity interferometer hydrophone operates on the principle of optical interference within a micro-cavity formed between a fiber tip and a thin metal diaphragm. It operates by detecting the modulated cavity length due to acoustic pressure fluctuations, such as those generated by boiling bubbles (as shown in Fig.1 (a)). Light from a broadband source is introduced into the fiber, and partial reflections occur at both the fiber end (via Fresnel reflection) [3] and the diaphragm. The resulting optical path difference leads to interference fringes in the reflected spectrum, which shift in wavelength proportionally to changes in cavity length caused by acoustic events. By tracking specific wavelengths in real time using an interrogation monitor, the system converts minute acoustic signals into measurable optical shifts (a 500 Hz acoustic oscillation is shown in the inset of Fig. 1(a)). The free spectral range (FSR) of the interference pattern is inversely related to the cavity length, allowing for precise quantification of pressure-induced displacements. This configuration is highly sensitive, compact, and immune to electromagnetic interference, making it ideal for deployment in high temperature environments.

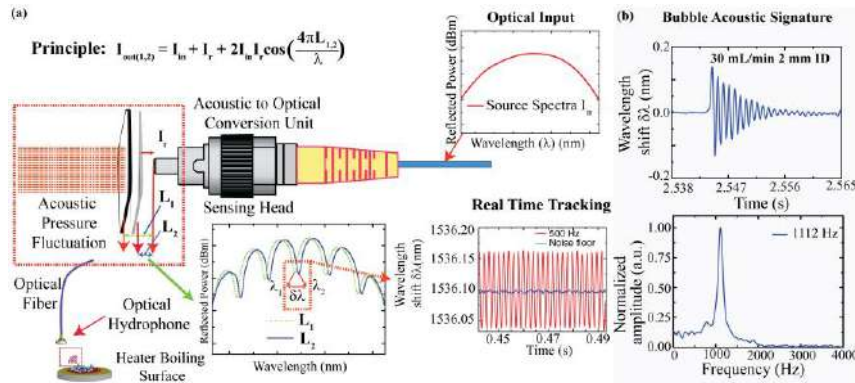


Fig. 1 (a) Detailed working principle of proposed optical hydrophone. (b) shows the bubble acoustic signature of an air bubble produced under water using a nozzle of inner diameter 2 mm and flow rate at 30 mL/min.

The hydrophone's performance is demonstrated in the Fig. 1 (b), which shows its ability to detect single bubble acoustics in real time. The system captures the wavelength shift caused by bubble oscillations, with the frequency spectrum revealing a clear acoustic signature at 1112 Hz, matching theoretical predictions [4]. Real-time tracking of wavelength shifts confirms the hydrophone's high sensitivity and effective noise discrimination. The results validate the device's capability to resolve individual bubble events and their frequencies in challenging boiling environments, outperforming conventional sensors and enabling robust diagnostics and monitoring in extreme conditions.

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Optical Nonlinearity-Assisted Trapping of Hollow-core Microparticles under Femtosecond Pulsed Excitation

Abdul Alim¹, Sumit Yadav^{1,3}, Anita Devi^{1,4}, and Arijit K. De^{2*}

1. Department of Physical Sciences and 2. Department of Chemical Sciences, Indian Institute of Science Education and Research Mohali, Knowledge City, Sector-81, SAS Nagar, Punjab 140306, India

3. Present address: CNRS, CESQ-ISIS University of Strasbourg (UMR 7006), F-6700 Strasbourg, France.

4. Present address: Assembly Integration & Test Scientist, Pasqal, Quebec (J1K 2X8), Canada.

*akde@iisermohali.ac.in

The trapping force and potential of core and core-shell microparticles are investigated under pulsed excitation. We demonstrate that in hollow-core microparticles, the optical force can reverse from repulsive to attractive by chirping the pulse or increasing the laser power.

Optical tweezers use a tightly focused laser beam to trap and manipulate particles of varying sizes [1]. Under pulsed laser excitation, the trapping force/potential is influenced by nonlinear optical and thermal effects due to the high peak power [2-3]. Earlier theoretical studies demonstrated that the trapping force/potential could be reversed for a hollow core nanoparticle when it is excited with a pulsed laser beam; the overall polarizability switches from negative to positive with increasing power, rendering the force from repulsive to attractive [4].

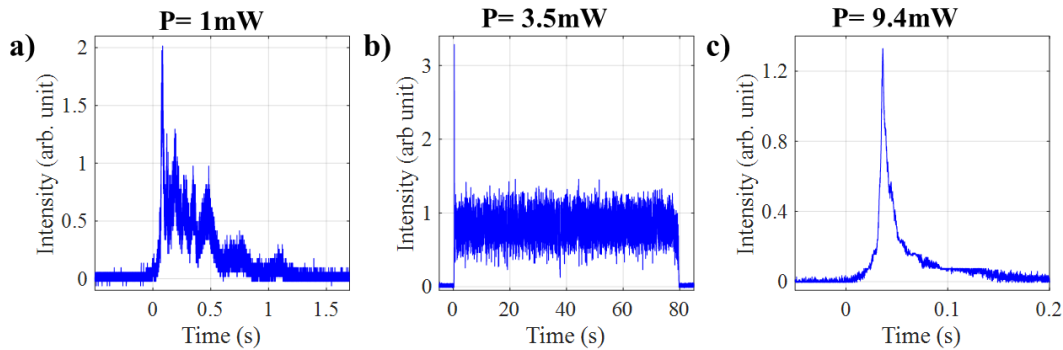


Fig. 1 (a) The trapping of a Hollow core microparticle at low average power, which shows a radial ejection due to less radial gradient, (b) stable trapping at 3.5 mW average power, and (c) axial ejection of the particle due to large scattering force.

In this study, we experimentally demonstrate that, at a fixed pulse width (~ 50 fs), the trapping of a hollow core microparticle at low average power ($\lesssim 1$ mW) is not possible, as shown in Figure 1a. In contrast, stable trapping is observed at moderate trapping power (~ 3.5 mW), as shown in Figure 1b. But at very high average power ($\gtrsim 9$ mW), the trapping is again destabilized, as shown in Figure 1c. Similarly, for a fixed trapping power, a variation in the strength of trapping is observed with changing pulsed width. Further, we theoretically model the trapping force/potential using the ray optics approximation [5-7] extended to a hollow core microparticle [8].

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Spectral broadening of IR femtosecond pulses by tailoring the dispersion of silica nanowire

Seth Mathew V, Neha, Ravi Pant

Laboratory for Phoxonics and Nonlinear Optics in Nanostructures (Phonon), School of Physics,
Indian Institute of Science Education and Research (IISER), Thiruvananthapuram, Kerala-695551

Frequency combs are characterized by equispaced frequency lines in the spectral domain and in general have a multitude of applications ranging from optical clocks, frequency metrology and spectroscopy [1]. But frequency combs in Mid-IR (MIR) frequency range (2 - 20 μm) have a domain of interest for science and technologies because of the characteristic vibration transition of many molecules. This leads to mid-IR spectroscopy which enables both qualitative and quantitative identification of molecular species. Besides developing understanding of the molecular species, MIR comb is a great tool for nonintrusive analysis of composite systems of gases and even biological samples. The traditional methods for generating MIR frequency combs includes Optical Parametric Oscillators (OPO) [2], Difference frequency generation [3], Micro-resonator based micro-combs [4] and mode-locked lasers [5]. Most of these setups are complex and bulky due to their free-space optics arrangement, which makes them inconvenient as a portable MIR comb source. Recent studies on Silicon nitride waveguides demonstrated compact MIR combs through dispersive wave phase matching of 1550 nm IR comb [6].

In this study, we experimentally analysed the role of dispersion engineering for MIR comb generation in silica nanowires using Er-doped femtosecond fiber laser (1560 nm) as the pump source. In order to study the role of dispersion engineering, we fabricated tapers having diameters of 1.6 and 1.8 μm with similar transmission loss (~ 0.7 dB). Figure 1(a) shows the schematic diagram of the experimental setup for MIR comb generation where mode locked pulses from an 82 MHz repetition rate Erbium fiber laser, having input power 56 mW and pulse width of 126 fs, are passed through dispersion engineered tapers of waist diameters 1.6 μm and 1.8 μm and the transmitted spectrum was observed in an Optical Spectrum Analyzer (OSA). Optical spectrum for the tapers is shown in Figs. 1(b) and 1(c). Dispersion plots for both the tapers are shown in Fig. 1(d), showing zero dispersion wavelengths for the 1.6 μm and 1.8 μm tapers at 1996 nm and 2240 nm respectively. The broadening of IR spectra is attributed to conversion of soliton in the lower order to higher order soliton in the taper region due to the variation of dispersion and nonlinear parameters.

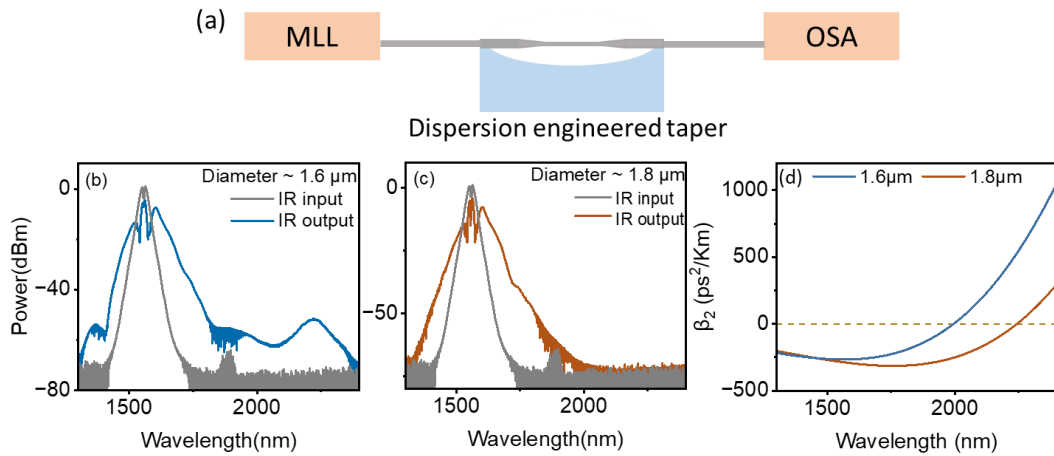


Fig 1. (a) Experimental setup. (b), (c) input and output spectrum corresponding to 1.6 μm and 1.8 μm tapers, respectively. (d) β_2 parameter for 1.6 and 1.8 μm tapers

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Fabrication of prism-free RGB holographic waveguide couplers using only two lasers

Sheenam Saxena¹, Rajveer Kaur¹, Raj Kumar^{1,*}

¹CSIR – Central Scientific Instruments Organisation, Sector 30C, Chandigarh 160030

*raj.optics@csio.res.in

Abstract - This paper presents prism-free fabrication of red, green and blue (RGB) volume hologram gratings (VHG) using only two lasers for near eye displays (NEDs) with enhanced field of view (FOV).

Keywords – Near eye display (NED), Volume Holographic Grating (VHG), Field of view (FOV)

Augmented reality (AR) near eye display (NED) design consists of display modules and image combiners which seamlessly integrate digital content with the real-world environment. A combiner typically comprises couplers as well as a waveguide that transmits information via total internal reflection (TIR). As a key component, combiner should have a high transmittance and produce a clear image with large FOV. They can be realised through various techniques including half mirror, freeform optics, diffractive optical elements (DOEs), and holographic optical elements (HOEs). Among them, HOEs fabricated by laser exposure are known for their wavelength selectivity and wavefront reproduction. Despite being a promising technology, accommodation of prisms in the system complicates the HOE recording process. Bragg degenerate technique has enabled prism free simplified recording geometry with customised recording angles allowing for a different playback beam wavelength than recording beam [1]. RGB VHGs recorded using this technique can be used as in-coupler and out-coupler to design full color waveguide. One approach is to multiplex RGB gratings within a single layer [2]. However, it limits entire FOV in full colour waveguide to 8°. Alternative approach is to fabricate three separate RGB VHGs to improve FOV as it imparts better flexibility in selecting the propagation angle [3]. Some preliminary experiments have been performed to record RGB holographic waveguide couplers. Contrary to conventional techniques that need three (red, green and blue) lasers, only two lasers are used as shown in Fig 1. The 660 nm wavelength is used to record gratings corresponding to the red and green wavelengths whereas 532 nm wavelength is employed to record grating for blue wavelength. The reconstruction wavelength for red, green and blue corresponds to 633 nm, 532nm and 465 nm respectively.

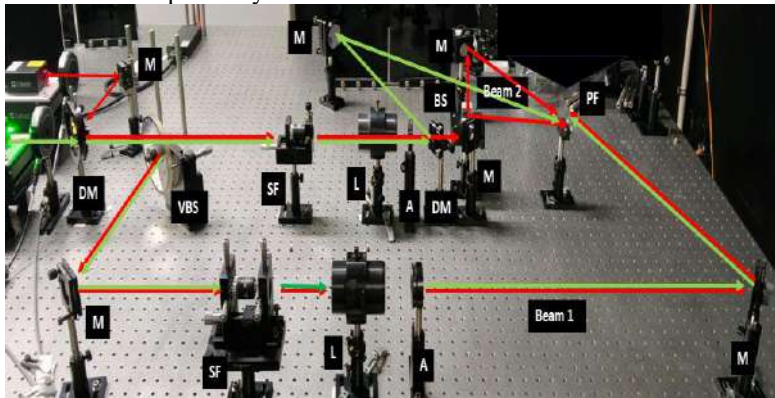


Fig. 1 Experimental Setup

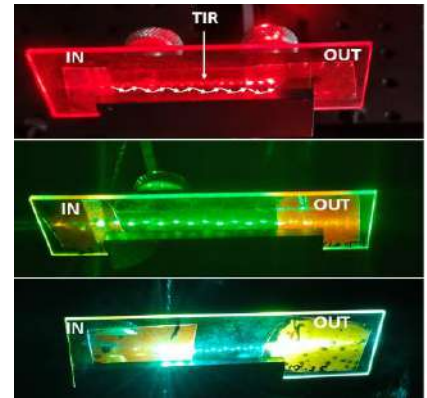


Fig. 2 Red, green and blue VHGs as In-coupler (IN) and out-coupler (OUT)

The present work demonstrates gratings recorded for red, green and blue wavelengths on BAYFOL HX photopolymer film with 70%, 90% and 90% diffraction efficiency, respectively. The monochrome waveguides for red, green and blue wavelengths are shown in Fig. 2. This configuration will be further employed to design a full color waveguide with enhanced FOV.

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Holographic Modal Wavefront Sensing Using Spatial Intensity Distribution and Convolution Neural Network

Anitta Jomy, Aryan Chand, C. S. Narayanamurthy, Dinesh N. Naik and Biswajit Pathak*

Indian Institute of Space Science and Technology, Thiruvananthapuram, Kerala 695547, India

*E-mail: biswajitpathak@iist.ac.in

Abstract: We propose an improved holographic modal wavefront sensing (HMWS) technique with a quality metric parameter based on spatial distribution of intensity. The proposed technique is independent of pinhole diameter placed in front of the detector to measure on axis intensity and position of point spread function (PSF). We have also employed convolution neural network (CNN) technique for faster estimation of the wavefront.

Summary: Wavefront sensing and correction are integral parts of adaptive optics system to realize aberration-free beams. We propose an improved holographic modal wavefront sensing (HMWS) technique with optimised quality metric parameter (QMP) based on spatial distribution of intensity. The wavefront estimation using HMWS is mainly dependent on the bias value, pinhole diameter and the orthonormal polynomial basis used for representing the wavefront. The proposed techniques make the HMWS independent of the pinhole diameter placed in front of the detector to measure the on-axis intensity and position of PSF. Figure 1 (a) and (b) shows the sensitivity matrix corresponding to QMP based on spatial distribution of intensity and conventional QMP (that uses mean intensity), respectively. Sensitivity matrix is obtained for applied Zernike mode $0.5Z_a$ estimated using Zernike modes ranging from 4 to 30. Each row and column of sensitivity matrix corresponds to applied and estimated Zernike modes Z_a and Z_e , respectively. The root mean square error (RMSE) of sensitivity matrix is obtained as 0.041 rad and 0.128 rad, respectively. The results indicate that the proposed technique of HMWS based on the spatial distribution of intensity based QMP gives improved estimation of applied modes in comparison to the conventional technique of HMWS based on mean intensity QMP. Figure 2 (a) and (b) shows the predicted vs true values of Zernike coefficient using QMP based on spatial distribution of intensity integrated with CNN architecture for multi-parameter regression to predict applied Zernike modes. The result shows that predicted and true values of Z_7 and Z_{11} are highly correlated with a root mean square error of 0.42 rad and 0.47 rad, respectively. The model was trained with approximately 10000 images of PSFs with different combination of Zernike modes and tested to evaluate performances with completely new magnitude values which is in the range of the training data but is not directly present in it. Applied and corrected PSF with conventional and proposed techniques are shown in Fig. 3.

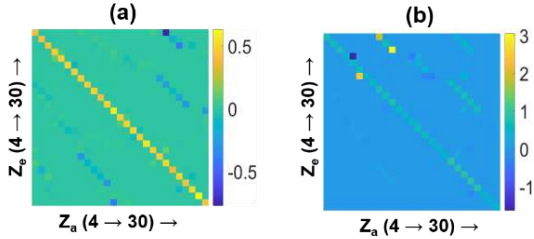


Fig. 1 The comparison of sensitivity matrix corresponding to the spatial distribution of intensity based QMP and mean intensity QMP.

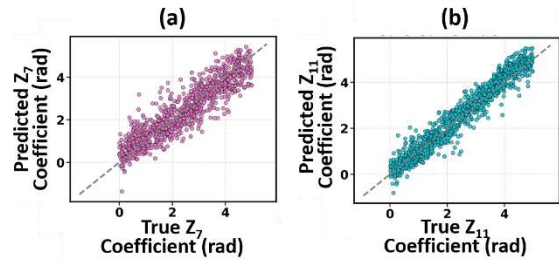


Fig. 2 The predicted vs true value of Zernike modes using spatial distribution of intensity based QMP integrated with CNN technique.

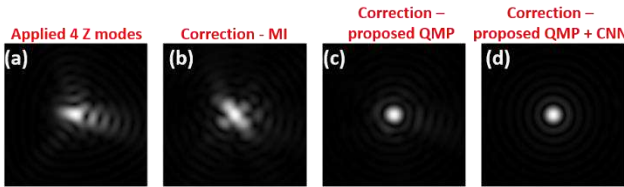


Fig. 3 The comparison of corrected point spread function with conventional mean intensity (MI), proposed QMP based HMWS and proposed QMP integrated with CNN.

The proposed HMWS and proposed CNN architecture integrated with QMP based on spatial distribution of intensity could efficiently estimate the aberration coefficients (Zernike coefficients). These techniques are independent of position of PSF and on-axis intensity of PSF which makes it a robust technique applicable to estimation of non-axially symmetric aberrations and wavefront estimation of wandering beams.

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Multi-GHz repetition rate, tunable ultrafast mid-IR source

Anirban Ghosh,^{1,2} Niladri Das,^{1*} S. Chaitanya Kumar,³ Kavita Devi,⁴ and G. K. Samanta¹

1. Physical Research Laboratory, Ahmedabad, Gujarat 380009, India

2. Indian Institute of Technology Gandhinagar, Ahmedabad, Gujarat 382424, India

3. Tata Institute of Fundamental Research, 36/P Gopanpally, 500046 Hyderabad, Telangana, India

4. Department of Physics, Indian Institute of Technology Dharwad, Dharwad, Karnataka 580011, India

*Co-author email address: niladri784.das@gmail.com

Multi-GHz ultrafast sources in the mid-IR region are essential for a wide variety of applications like sensing, optical clocks, time-resolved spectroscopy, and medical diagnostics [1]. To achieve a higher repetition rate conventional ultrafast laser source in mid-IR is very challenging due to the short cavity length, thermal management, dispersion, and mode locking stability [2]. To overcome those challenges, we demonstrate an innovative method to generate tunable ultrafast mid-IR source with higher repetition rate (RR) up to 100 GHz by continuous wave laser pumped optical parametric amplification in multi-GHz femtosecond optical parametric oscillator. The schematic of the experimental setup is shown in Fig 1(a) which describes, an ultrafast Yb-fiber laser ($\lambda=1040$ nm, $\Delta\tau=150$ fs, Rep. rate=80 MHz) which is used to generate the optical parametric oscillator (OPO) comprises with two crystal (NC1-2: 50 mm long MgO: PPLN with grating period $30.3 \mu\text{m}$), four curved mirrors (M1-4), and two plane mirrors (M5-6). Lenses L1 and L2 are used by both lasers to focus the beam with an identical spot size of $\sim 50 \mu\text{m}$ at the center of the two crystals into the grating period of $30.3 \mu\text{m}$. Using high harmonic and fractional incremental techniques [3], we translate M6 to get tunable repetition rate multi-GHz OPO. Continuous-wave (CW) Yb-fiber laser (50 W) emits 1064 nm, used as a pump source in NC2 to generate optical parametric amplification (OPA) using the ultrafast multi-GHz intracavity signal from OPO as a seed which resulting tunable mid-IR with multi-GHz repetition rate ultrafast source.

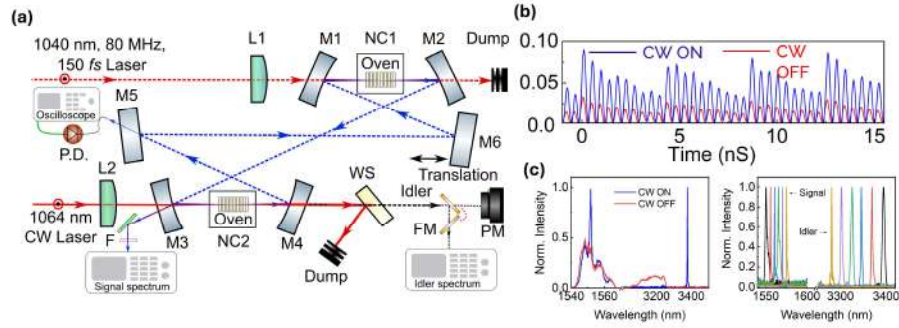


Fig 1: (a) Schematic of the Experimental setup; (b) Verification of parametric amplification; (c) Wavelength tuning of high RR signal and idler at different crystal temperatures;

Fig. 1(b) explains that the OPO is designed for operation at 2.4 GHz, which is achieved by tuning the cavity length from 1253 mm (3rd harmonic) to 1283 mm (30th harmonic). Although the ultrafast signal is traced with low intensity (red line) due to the losses of the multiple round trips in the cavity but turning on the CW laser, the signal gets amplified (blue line) for the gain factor of CW radiation and generates mid-IR ultrafast Idler due to parametric process with the same repetition rate of the resonant signal, this architecture verifies the parametric amplification. From Fig. 1(c), we observe the changes of the spectral bandwidth of the intracavity signal from 14 nm ($\lambda_c \sim 1550$ nm) to 4 nm ($\lambda_c \sim 1552$ nm), and the ultrafast idler has a significant change of spectral width from 153 nm centered at 3160 nm to 3 nm centered at 3384 nm, which is more clearly indicating phase-matched parametric amplification. We optimized the temperatures of two crystals to achieve phase matching for OPA and get ultrafast signal and idler wavelengths of 1550-1555 nm and 3394-3369 nm. Our measurements indicate that high repetition rate ultrafast mid-IR source has an output power exceeding 60 mW at 240 MHz, which can be adjusted to about 21 mW at a 100 GHz repetition rate by minimal changes of cavity length. In conclusion, we demonstrated high repetition rate mid-IR pulses using parametric amplification in a multi-GHz OPO. The detailed results with full characterization of this parametric oscillator and amplifier will be presented.

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Nonlinear compression of laser beam spot via two-wave mixing

Bhavesh Pant* and G. K. Samanta

Physical Research Laboratory Ahmedabad, Navarangpura, Gujarat 380009, India

*bhavesh.pant619@gmail.com

Abstract: A theoretical study is demonstrated on controlling and drastically reducing the laser beam spot size via two-wave mixing of Laguerre–Gaussian beams in a nonlinear medium. A more than 10-fold size reduction of the laser beam spot is achieved.

1. Introduction

Controlling laser beam profiles at fine spatial scales is critical in modern optics, with applications in microscopy, micromachining, and optical trapping. Conventional beam shaping relies on linear optical components or diffractive techniques, which often face limitations in real-time tunability and resolution. Nonlinear optical effects, particularly those in nonlinear media, offer a compelling route for dynamic beam control [1]. Structured light, particularly Laguerre–Gaussian (LG_{pl}) beams, has emerged as a versatile tool for optical manipulation and high-precision applications [2]. In this work, we theoretically investigate how LG beams can be harnessed to achieve extreme beam confinement of laser beams via nonlinear two-wave mixing (TWM) in a nonlinear media.

2. Methodology

We consider the codirectional TWM geometry: a Gaussian (LG_{00}) beam as a pump beam and a Laguerre–Gaussian (LG_{pl}) beam as a signal beam are incident on the nonlinear medium, as shown in Fig. 1(a). A coupled-wave theory is adopted based on Maxwell's wave equation to analyze the TWM process inside the nonlinear media [3]. The coupled-wave equations are solved analytically by using the average total intensity in the medium.

3. Results

Simulation results reveal that the nonlinear mixing of a pump Gaussian (LG_{00}) and a signal (LG_{pl}) beams leads to the emergence of a highly confined intensity distribution in the interaction region, as shown in Fig. 1(b). The main spot undergoes a dramatic compression, achieving a spot size that is over 10 times smaller than the original pump beam width, as shown in Fig. 1(c). The degree of compression is found to be highly sensitive to the radial (p) and azimuthal (l) index of the signal (LG_{pl}) beam. The generated localized structure exhibits sub-diffraction features and a sharply peaked core, emerging purely from nonlinear interactions.

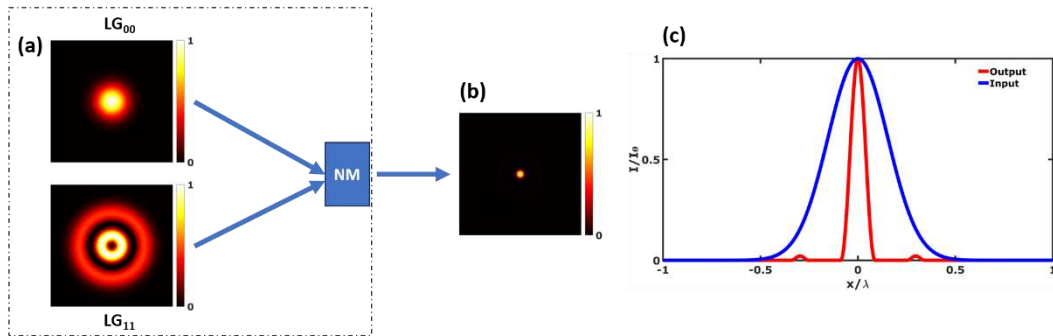


Figure 1: TWM in a nonlinear media (NM) (a), compression of beam spot (b), comparison of pump beam and output beam (c).

4. Conclusion

This study demonstrates a purely theoretical yet practical route to achieving extreme beam confinement via nonlinear TWM. The results indicate that wave mixing of structured beams in nonlinear media can serve as an all-optical, tunable method for beam shaping, with potential applications in high-resolution imaging, optical lithography, and light–matter interaction studies.

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Efficiency Improvement of Silicon Solar Cells with Embedded Cross-Shaped Nanostructures

Sanket Kumar, Praveen C Pandey*

Department of Physics, Indian Institute of Technology (BHU), Varanasi, U.P. 221005, India

* Corresponding author, Email: - pcpandey.app@iitbhu.ac.in, Tel: - (+91)5427165473

Abstract: A cross-shaped Ti nano-rod enhanced silicon solar cell with $\text{SiO}_2/\text{Si}_3\text{N}_4$ coating achieves 85% visible and 94% near-IR absorption, delivering 60.32 mA/cm^2 current via optimized FDTD design for next-gen high-efficiency photovoltaic.

Keywords: Solar cell; cross-shaped Nano-rods; Surface Plasmon; Absorption;

Introduction: Improving the efficiency of thin-film silicon solar cells is a key challenge in advancing next-generation photovoltaic technologies[1]. Due to their reduced thickness, these cells often suffer from limited light absorption, particularly in the longer wavelength regions of the solar spectrum[2][3]. To address this limitation, plasmonic nanostructures have emerged as a powerful solution. By incorporating metallic nanoparticles in the silicon layer, localized surface plasmon resonances (LSPR) can be excited, enhancing light scattering and trapping within the active region[4][5]. This not only boosts absorption but also increases photocurrent generation. In this work, we explore a plasmonic-enhanced thin-film silicon solar cell design that integrates optimized metal cross-shaped nano-rod and anti-reflection coatings, aiming for significant improvements in light harvesting and overall device efficiency.

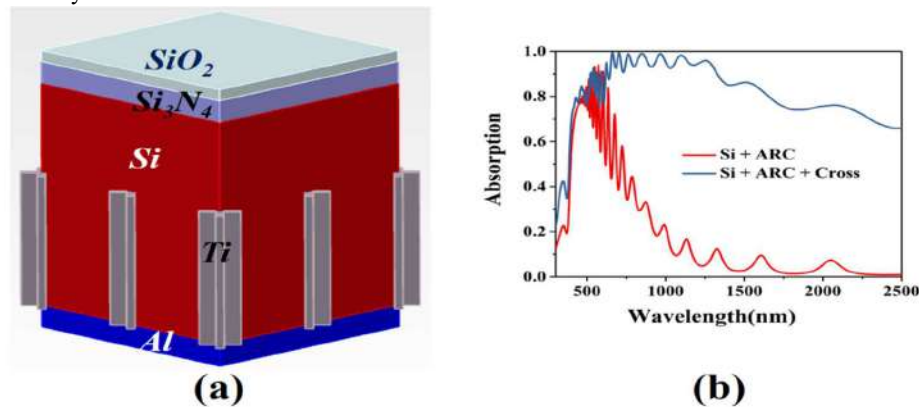


Fig.1. (a) proposed solar cell structure, **(b)** Absorption vs. wavelength graph for the cross-shaped embedded rod with anti-reflection coating (ARC)

Results: Figure 1(b) clearly highlights the exceptional optical performance of the proposed structure, demonstrating a remarkably high average absorption of 85% in the visible spectrum (400–700 nm), where solar irradiance is most intense. Furthermore, the design maintains superior absorption efficiency in the near-infrared region (700–1800 nm), achieving an impressive 94% average absorption. This broad-spectrum enhancement underscores the effectiveness of the plasmonic and anti-reflective features integrated into the device architecture.

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Structural, vibrational (FT-IR & FT-Raman), optical and nonlinear optical properties of 2-Methylimidazole for NLO applications

M.Nagulan^{1*}, M. R. Kannan¹, S. Manvizhi¹, R.G.Tharun¹ and T. Vijayakumar^{1*}

¹ Futuristic Material Research Centre for Planetary Exploration, Department of Physics and Nanotechnology, College of Engineering and Technology, Faculty of Engineering and Technology SRM Institute of Science and Technology, Kattankulathur, Tamilnadu, India, 603203

* Corresponding Author email: nm2319@srmist.edu.in and vijayakt1@srmist.edu.in

Abstract

2-Methylimidazole is a structure related to imidazole containing heterocyclic compound of simple nitrogen, and a ligand in coordination chemistry. It is a precursor to several members of Nitroimidazole antibiotics where selected for its antibacterial property and used to compact anaerobic bacterial, antifungal [1-3]. The structural and vibrational spectroscopic features of 2-methylimidazole have been studied using experimental and tools derived from quantum chemical calculations. The Spectroscopic properties of 2-Methylimidazole were examined by FT-IR and FT-Raman. The complete vibrational assignments of the vibrational modes have been made on the basis of potential energy distribution. The optimized structure of the compound was interpreted and compared with reported experimental values and investigated for further analysis using NBO, HOMO-LUMO, UV and hyperpolarizability.

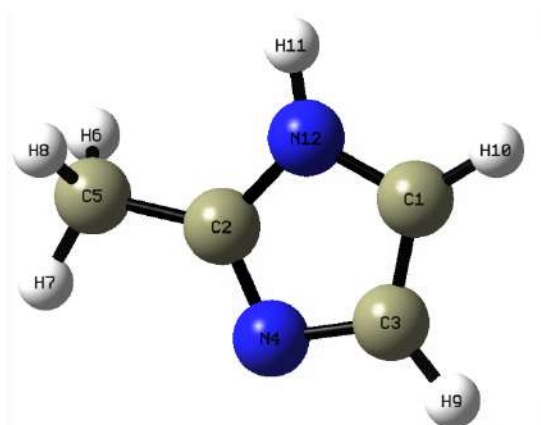


Fig 1: Optimized structure of 2-Methylimidazole

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Computational Study of the Impact of Device Imperfections on Integrated-photonic Gaussian-Boson-Sampling based QRNG

Bhushan Ravi Kape¹, Ravi Sadananda Hegde¹

¹Department of Physics, IIT Gandhinagar, Gandhinagar, India 382355. kapebhushan3872@gmail.com

¹Department of Electrical Engineering, IIT Gandhinagar, Gandhinagar, India 382355. hegder@iitgn.ac.in

Unlike conventional photonic QRNGs that yield at most a single bit per detection, the multi-mode interference statistics of Gaussian Boson Sampling encode several bits of entropy per event, enabling compact, high-entropy generation on a scalable integrated-photonic platform. In this work, we simulate a 4-mode, 2-photon integrated photonic GBS QRNG with carefully optimized squeezing parameters and interferometer phase settings. Figure 1 illustrates the overall block structure and operation of the GBS-based QRNG system, encompassing the entropy source, measurement, and post-processing modules which is simulated using the SYMPHONY python package. Our idealized system which also includes Von Neumann extraction followed by robust HMAC-256 hashing reaches a Shannon entropy close to the theoretical maximum of 3.32 bits per sample and passes the comprehensive NIST suite, affirming near-perfect quantum randomness.

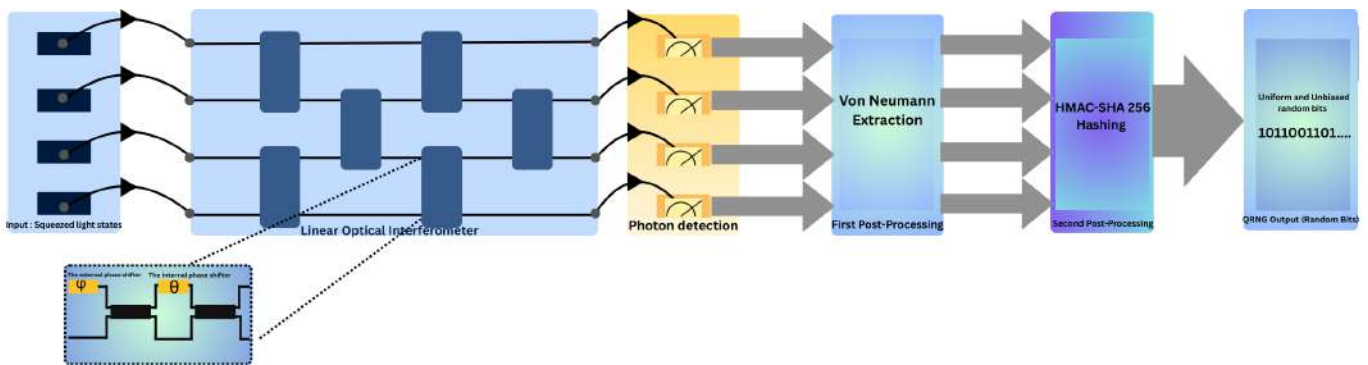


Figure 1: Block diagram of the Gaussian Boson Sampling-based quantum random number generator (QRNG), showing the entropy source, photonic interferometer, photon detectors, and randomness post-processing pipeline.

We then systematically model prevalent device-level imperfections—including waveguide photon loss, beam splitter ratio fluctuations, phase shifter noise, and squeezing parameter variability—both individually and combined to emulate realistic integrated photonic hardware. The quantified effects of these noise sources on the entropy of the QRNG output are depicted in the following three diagrams. Our study establishes design constraints which are critical for experimental realization of GBS based on-chip photonic QRNGs.

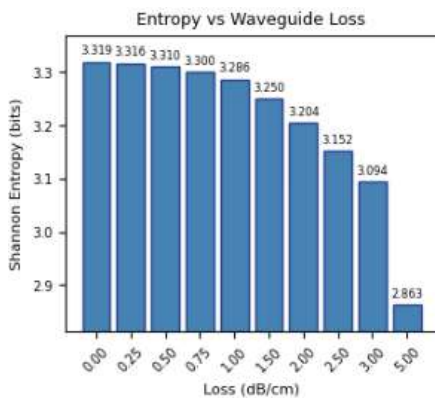


Figure 2: Shannon entropy vs. waveguide photon loss.

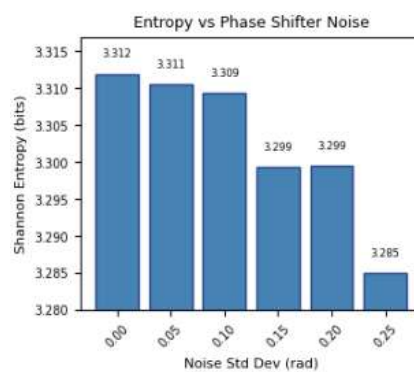


Figure 3: Shannon entropy vs. phase shifter noise.

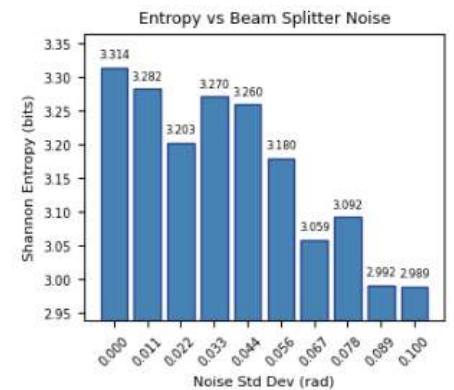


Figure 4: Shannon entropy vs. beam splitter noise.

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Probing Dynamical Phase Transitions via Loschmidt Echo in Quantum Many-Body Systems

Shruti Prakashan¹, S. Kannan², C. Sudheesh¹

¹*Department of Physics, Indian Institute of Space Science and Technology, Valiamala, Thiruvananthapuram-695547, Kerala, India.*

²*Department of Quantum Science and Technology, Research School of Physics, The Australian National University, Canberra, ACT 2601, Australia.*

Understanding the behavior of quantum phases and phase transitions lies at the heart of many-body quantum systems and is crucial in advancing quantum information processing and quantum technologies. In this work, we investigate the dynamical phase transition of a disordered Bose-Hubbard model with the Hamiltonian,

$$H = \sum_i [-J[b_{i+1}^\dagger b_i + b_i^\dagger b_{i+1}] + h_i n_i + \frac{U}{2} n_i(n_i - 1)]. \quad (1)$$

Here, L is the number of lattice points, $b_i^\dagger$ and b_i are the creation and annihilation operators at the site i . n_i is the number operator that gives the number of bosons at i^{th} site. The strength of the hopping amplitude between the neighboring sites is given by J , and that of the on-site random disorder by h_i . U represents the interaction energy.

We start by preparing the system in the ground state ($|\psi_0\rangle$) of an initial Hamiltonian (H_0). The non-equilibrium dynamics of the system is studied by implementing a sudden quench by abruptly changing the disorder parameter h_i [1]. We are particularly interested in the dynamical quantum phase transition (DQPT). To study this, the well-known Loschmidt echo is used. The Loschmidt echo quantifies the return probability of a quantum system to its initial state after unitary time evolution under a quenched Hamiltonian [2]. It is defined as,

$$\mathcal{L}(t) = |G(t)|^2 = \langle \psi_0 | e^{-iH_f t} | \psi_0 \rangle^2 \quad (2)$$

where $G(t)$ is the Loschmidt amplitude, and $|\psi_0\rangle$ is the initial ground state of the pre-quench Hamiltonian H_0 . A vanishing Loschmidt echo indicates the signature of dynamical phase transition.

To further analyze the dynamics, we define the rate function, which is analogous to a dynamical free energy density:

$$r(t) = -\frac{1}{L} \ln \mathcal{L}(t), \quad (3)$$

where L is the system size. The rate function often exhibits non-analytic behavior at critical times, which is interpreted as a dynamical counterpart to equilibrium phase transitions [3].

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Single-shot Phase-stepping Common-path Digital Holographic Microscopy with Multiplexed Grating

Deepak Kumar, Biswajit Pathak, Dinesh N. Naik, C.S. Narayanamurthy

*Applied and Adaptive Optics Laboratory, Department of Physics,
Indian Institute of Space Science and Technology,
Thiruvananthapuram - 695547, India*

We present the design, implementation, and experimental demonstration of a single-shot phase stepping common-path digital holographic microscopy (SPC-DHM) system based on a spatially multiplexed phase grating. In this configuration, a programmable spatial light modulator (SLM) displays a multiplexed grating pattern that generates four spatially separated, phase-shifted replicas of the object beam, together with a common reference beam [1,2]. Precisely tailored phase delays are imparted to the diffracted orders of the multiplexed grating, enabling the simultaneous acquisition of four independent off-axis holograms within a single camera exposure. The recorded hologram is subsequently computationally processed further, and a modified phase-shifting algorithm is applied to get the reconstructed phase information of the sample under test. Experimental and simulation results validate the proposed SPC-DHM system, demonstrating its capability for single-shot phase reconstruction and exceptional robustness to environmental perturbations. The architecture supports real-time quantitative phase imaging without mechanical phase shifting, making it highly suitable for dynamic biological specimen observation and for high-speed, high-stability optical metrology applications.

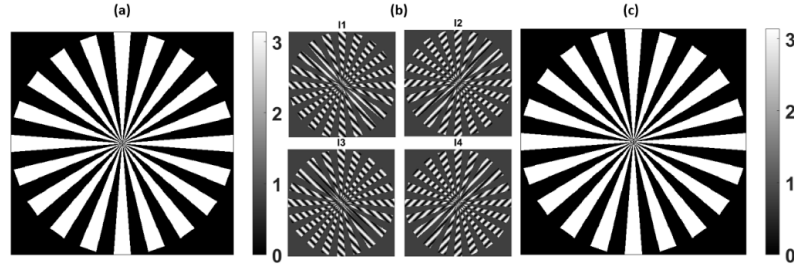


Fig. 1 Simulation results of the Siemens star: Panel (a) shows the simulated Siemens star, panel (b) depicts the numerically generated hologram with phase shifts of 0 , $\pi/2$, π , and $3\pi/2$, respectively, and panel (c) presents the reconstructed amplitude.

The proposed method was first validated through numerical simulations using a Siemens star as the test object, Fig. 1(a). To implement our proposed system numerically, four discrete phase shifts— 0 , $\pi/2$, π , and $3\pi/2$ are applied to the four copies of the object beam. Each phase-shifted object wave interfered with a common reference wave, generating four spatially separated off-axis holograms within a single frame as depicted in Fig. 1(b). These holograms are processed further by applying a modified phase shifting algorithm to reconstruct the phase information of the samples, as shown in Fig. 1(c). Following the simulation results, the technique is experimentally implemented using the same phase-stepping scheme. The hologram is recorded in a single shot in the image plane using a complementary metal oxide semiconductor (CMOS) camera, and phase information of the sample under test is reconstructed using a modified phase shifting algorithm. Preliminary experimental results are shown in Fig. 2 (see caption for more details), demonstrating the method's robustness against environmental error and its suitability for real-time, single-shot, high-stability quantitative phase imaging.

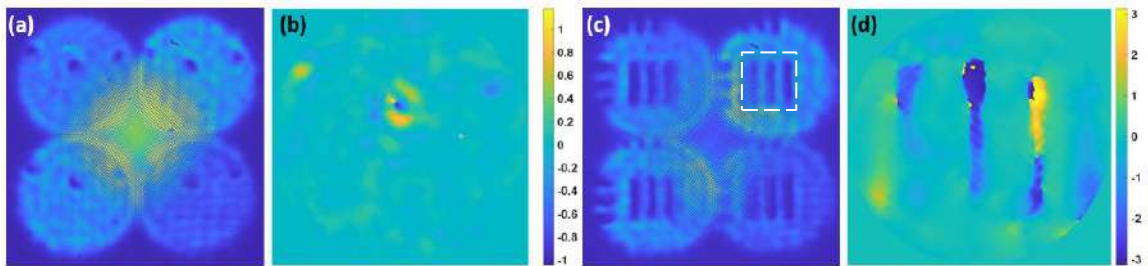


Fig. 2 Experimental results of the vortex phase and USAF target: Panel (a) and (c) show the recorded holograms for the vortex phase and USAF target, respectively; panels (b) and (d) depict the reconstructed phase using a modified phase-shift algorithm for both objects—phase in radian.

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Generation of Squeezed Light for High-Resolution Quantum Bioimaging

Vishal Navani¹, V. Narayanan¹

1. Department of Physics, Indian Institute of Technology Jodhpur, NH-62, Nagaur Road, Karwar, Jodhpur, Rajasthan 342030, India

We present a **theoretical investigation of Kerr-based squeezing at 515 nm for quantum-enhanced bioimaging**. We observe that squeezed light as the illumination source can suppress the noise below the shot-noise limit, which enables a higher signal-to-noise ratio without increasing the optical power [1].

The nonlinear phase shift accumulated by an optical beam propagating through a nonlinear fiber of length L is expressed as follows [2]

$$\varphi = \gamma L_{\text{eff}} P = \frac{2\pi n_2}{\lambda A_{\text{eff}}} L_{\text{eff}} P,$$

where $\gamma = \frac{2\pi n_2}{\lambda A_{\text{eff}}}$ is the nonlinear Kerr parameter, λ is the wavelength, P is the peak optical power, n_2 is the nonlinear refractive index of the medium, and A_{eff} is the mode field area. The effective interaction length L_{eff} , which incorporates fiber attenuation, is given by $L_{\text{eff}} = \frac{(10 - 10^{(1 - \alpha L/10)})}{\alpha \ln(10)}$ where α represents the fiber attenuation coefficient in dB/km. To model quadrature noise under the influence of nonlinear phase shift and optical loss, the variance of fluctuation in one quadrature is defined as [3, 4]

$$V(R) = (1 - R) \left[1 - 2\varphi \sqrt{1 + \varphi^2} + 2\varphi^2 \right] + R,$$

where R is the total loss factor. To relate this to experimental parameters, the loss factor is defined as $R = 1 - 10^{-(\alpha L + \kappa)/10}$ with κ representing additional system losses in dB. The degree of the quadrature squeezing is expressed in decibels as

$$\text{Squeezing(dB)} = -10 \log_{10}(V(R)).$$

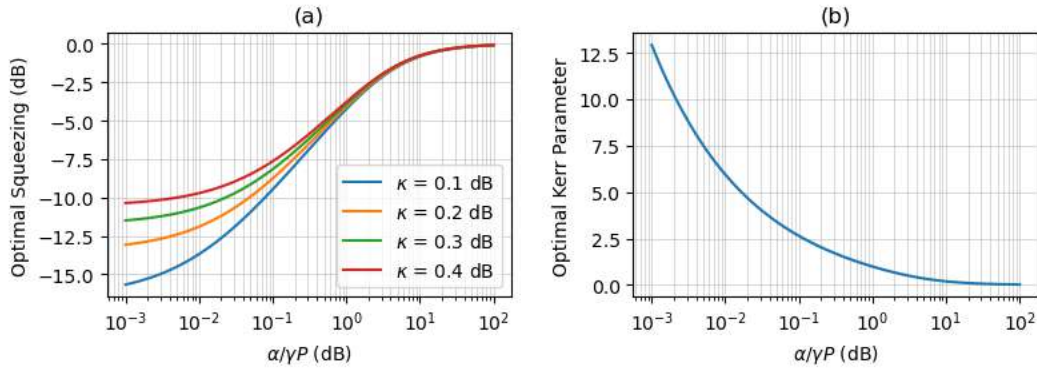


Fig. 1. (a) Optimal squeezing as a function of $\alpha/\gamma P$, for various values of the additional loss parameter κ . (b) Corresponding optimal Kerr nonlinearity as a function of $\alpha/\gamma P$.

A commercially available single-mode fiber, such as the 460HP [5] with a mode field diameter of approximately $3.5 \mu\text{m}$ and an attenuation coefficient of $\alpha = 30 \sim \text{dB/km}$. The nonlinear refractive index of silica at a wavelength of 515 nm is approximately $n_2 \approx 3.2 \times 10^{-20} \text{ m}^2/\text{W}$ [2]. These parameters yield a nonlinear coefficient of $\gamma \approx 40 \text{ W}^{-1}\text{km}^{-1}$. Assuming an input power of $P \approx 1 \text{ W}$, the normalized attenuation parameter $\alpha/\gamma P$ becomes 0.75. According to Fig. 1. (a), this corresponds to an optimal squeezing of approximately 5 dB for an additional loss of $\kappa = 0.1 \text{ dB}$. The corresponding Kerr parameter is found to be approximately 1.15, which translates to a required fiber length of 28 m.

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Beam Engineering for Free Space Optical Communication Channel using Stress Engineered Optical Elements

Sakshi Dubey¹, Kedar Khare¹, Abhishek Dixit²

1. Optics and Photonics Centre, Indian Institute of Technology Delhi, New Delhi, 110016, India

2. Department of Electrical Engineering, Indian Institute of Technology Delhi, New Delhi, 110016, India

Free Space Optical (FSO) communication systems provide a cost-effective, high-speed alternative to conventional wireless radio frequency (RF) methods [1]. FSO systems offer high bandwidth and do not face constraints associated with wires and radio frequencies, effortlessly integrating with existing optical fibre technologies. However, FSO systems face significant challenges, when light beams travel through randomly fluctuating atmospheric conditions. As an optical beam travels through the atmosphere, its quality deteriorates due to time-dependent refractive index variations and scattering by particulates, resulting in scintillations, beam spreading, and beam wandering. Applications such as, free space optical communication (FSOC), LIDAR systems, laser-guided defence mechanisms, and medical imaging through tissues, all demand robust beam propagation through random media. In this work, we report structured light beams engineered via stress induced birefringence in a glass flat by using a custom-built stress engineered optical element (SEOE), as shown in Fig.1. The beam profile is shaped by the SEOE to yield a C-point polarization singularity structure and is subsequently transmitted through a random phase screen that simulates atmospheric turbulence [2]. The C-point singularity contains the 0 and 1 orbital angular momentum (OAM) states in orthogonal polarizations of the beam that are known to produce speckles with negative intensity correlations [3]. Notably, we observe that the engineered beam generates a smoother far-field speckle patterns as compared to the scalar Gaussian beam, as shown in Fig.1. These far field speckle patterns are characterized by the on-axis scintillation and intensity probability distribution measurements. Thus, our concept of structured light generated using a low-cost SEOE is valuable for improving the performance of free space optical communication systems.

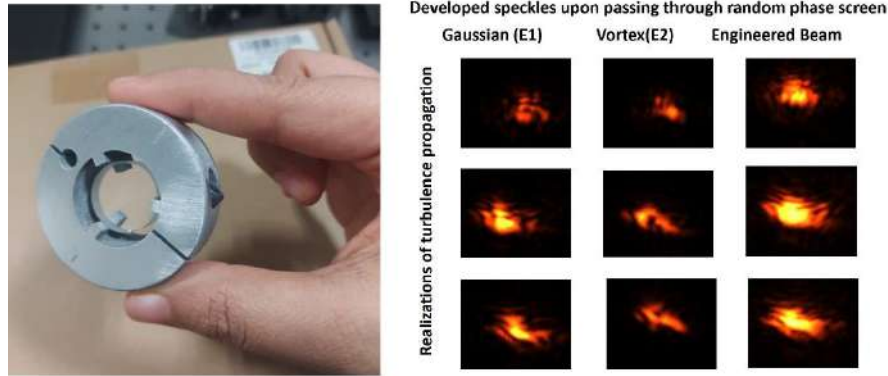


Fig. 1 Left: Stress engineered optical element (SEOE). Right: Zoomed camera frames in back-focal plane after turbulence mimicking phase screen (3 out of 60 realizations).

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Femtosecond laser pulses with extended depth-of-focus for high-throughput micromachining

Aditya Narayana Jena^{1, *}, Rajesh Menon², Kamal P. Singh³, and Vishwa Pal¹

1. Department of Physics, Indian Institute of Technology Ropar, Rupnagar 140001, Punjab, India.

2. Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, Utah 84112, USA.

3. Indian Institute of Science Education and Research Mohali, SAS Nagar, Mohali 140306, Punjab, India.

Achieving non-diffracting beams with an extended depth-of-focus (EDOF) is essential for various optical applications, including imaging [1], high-precision fabrication, laser processing, and nonlinear optics. Conventional approaches often rely on bulky refractive optics with limited control over beam propagation and experience from wavelength sensitivity, restricting their application to broadband and ultrashort pulse regimes. In this work, we employ a thin and flat multi-diffractive lens (MDL) to produce tightly focused femtosecond pulses with a remarkable EDOF, providing a compact and effective substitute for existing conventional optics [2]. The ability of MDL-generated beams to maintain their shape and size over extended propagation distances not only relaxes alignment tolerances but also enables high-throughput, robust laser-based material processing.

Furthermore, we experimentally demonstrate tunable EDOF using different MDL designs, achieving on-air laser filamentation [3], which is beneficial for optical and plasma waveguides as well as laser-induced breakdown spectroscopy. In comparison to traditional lenses, we demonstrate a fourfold increase in plasma channel length using MDL, indicating better energy localization and stability. Furthermore, we display its potential for precise laser marking in glass, ensuring great spatial resolution over an extended range of propagation, required for industrial micromachining. Note, the laser marking in the original experiment is obtained using EDOF fs-laser pulses with pulse energy $E = 1$ mJ, pulse duration $t_p = 25$ fs, repetition rate $f_{\text{rep}} = 1$ kHz and exposure time $\tau \approx 1$ sec.

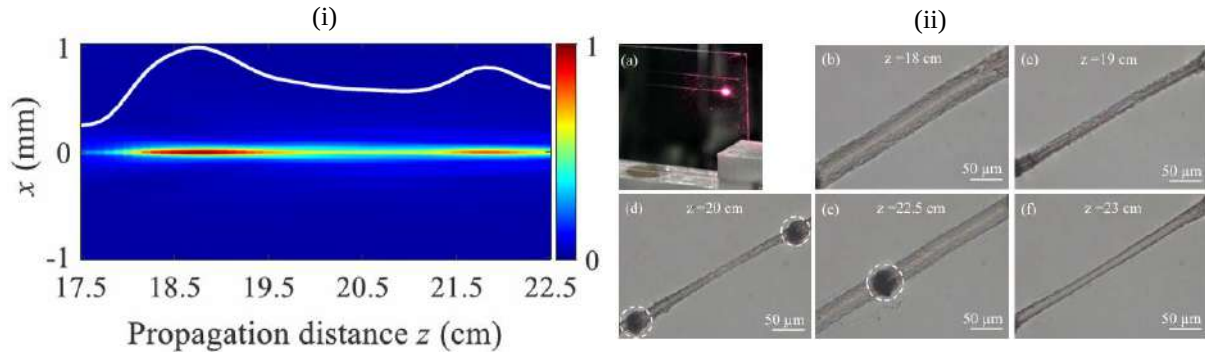


Fig. 1: (i) Intensity evolution in the x - z plane. (ii) (a) Image of fs-laser marking on the glass sample. (b-f) Optical microscope images of marking at different z values.

These findings offer a compact and robust solution for high-power ultrafast beam shaping strategy which holds strong potential for high-throughput, in-line processing in micro-optics, microfluidics, and nanosurgery.

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Real-World trial of long-distance entanglement distribution using a field-deployed quantum source

Gourav Singh Rawat¹, Khushboo¹, Vivek Venkataraman^{1,2}, Joyee Ghosh¹

¹Quantum Photonics Lab, Department of Physics, Indian Institute of Technology Delhi, New Delhi, 110016, India

²Department of Electrical Engineering, Indian Institute of Technology Delhi, New Delhi, 110016, India

¹Email: joyee@physics.iitd.ac.in ²Email: vivekv@ee.iitd.ac.in

Entangled photon pair sources at telecommunication wavelength are key source for diverse quantum applications, such as quantum key distribution (QKD), quantum communication, quantum cryptography and information processing over existing fiber-optic networks. To generate these sources, there are prominent technologies such as spontaneous parametric down-conversion (SPDC), spontaneous four-wave mixing (SFWM), integrated photonic chips, quantum dots, and atomic ensembles. Out of these, SPDC is the most effective and widely used technique. [1] The source's compatibility and potential for entanglement distribution to real users over the existing fiber networks can be tested by a field demonstration of the source. Our first trial for long-distance entanglement distribution was for 100 km using a fully-fiber-integrated multiuser efficient quantum source [2]. Here we show the field demonstration of the photon source by using deployed dark optical fiber between Quantum Photonics Lab in the Main building and SIT Building within the Indian Institute of Technology Delhi (IITD) campus.

In this work we employ a customized Zn-indiffused MgO:PPLN ridge waveguide, which is type-0 phase-matched. The waveguide has a poling period of $\sim 18.3 \mu\text{m}$ [?]. For field demonstration of entangled photon source we used 2 km length of fiber (0.8 km of total dark fiber in one channel with two fiber spool of 0.5 km each).

We characterize the source performance by measuring two-photon interference visibilities in different polarization bases. This was a first trial with an achieved raw visibility for H-V basis and D-A basis (without any background or noise subtraction) as 59% and 56% respectively, with a corresponding fidelity of 58% for generated state $|\Phi^+\rangle$ [3]. After subtraction (as we feel that the on-field dark fiber had leakages at several places with imperfect fiber-to-fiber connections and was not spliced properly) the visibility were much better which was 77.18% and 79.47% respectively in H-V basis and D-A basis that gives the fidelity of 78.32% for generated state $|\Phi^+\rangle$. The possible reason for the low visibility (less than 90%) is loss in the field-deployed dark fiber used in this experiment. The total loss that we have obtained due to field-deployed dark fiber between the SIT building and Main building was around 28 dB.

Source	Case	Raw Fidelity	Detectors used (Q.E., CDW)
Ref. [2]	Alice: no fiber Bob: 100 km fiber spool	95%	SPD (10%, 512 ps)
This work	Alice: no fiber Bob: 0.8 km Dark fiber and 0.1 km fiber spool	78.33%	SPD (20%, 512 ps)

Table 1: Performance comparison of our polarization-entangled photon source with previous Sagnac-loop-based implementations for generating the $|\Phi^+\rangle$ state.

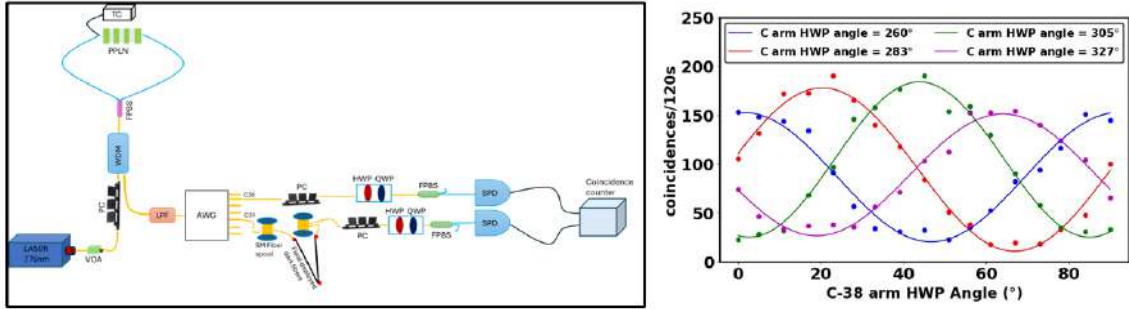


Figure 1: Experimental setup for field demonstration of entanglement distribution for long-distance quantum communication. VOA: Variable optical attenuator, PC: Polarization controller, WDM: Wavelength division multiplexer, FPBS: Fiber polarization beam splitter, TC: Temperature controller, LPF: Long pass filter, HWP: Half wave plate, QWP: Quarter wave plate, AWG: Arrayed waveguide grating, SPD: Single photon detector

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Laser-Assisted Surface Modification of Obturator Materials to Minimize Microbial Adhesion

K K Anjali¹, Kishore Ginjupalli², Runki Saran², Raghu Chandrashekar³, V K Unnikrishnan^{*1}

1. Manipal Institute of Applied Physics, Manipal Academy of Higher Education, Manipal, Karnataka-576104, India
2. Department of Dental Materials, Manipal College of Dental Sciences, Manipal Academy of Higher Education, Manipal, Karnataka-576104, India
3. Department of Pharmaceutical Biotechnology, Manipal College of Pharmaceutical Sciences, Manipal Academy of Higher Education, Manipal, Karnataka-576104, India

*Email: unnikrishnan.vk@manipal.edu

Obturator prostheses, commonly made of polymer-based materials like poly(methyl methacrylate) (PMMA), are used to restore maxillofacial defects caused by oral neoplasms, trauma, or congenital anomalies [1]. These materials are susceptible to adhesion and colonization by various microorganisms, leading to biofilm formation and, therefore, pose a risk of local or systemic infections, affecting patient care [2, 3]. Since the adhesion of microbes is highly influenced by the surface characteristics of the obturator materials, such as topography, roughness, and wettability, surface modification without affecting the bulk properties of the material is an effective way to reduce microbial adhesion [4, 5]. Of late, laser-induced surface modification has gained great importance in creating antimicrobial surfaces due to its high precision and accuracy by creating surface micro/nano structures [6]. With this background, nanosecond laser-based surface microstructures have been created on PMMA-based materials as a preliminary study to evaluate their effect on minimizing microbial adhesion.

A Q-switched Nd: YAG pulsed laser (Quantel Q-Smart 450) with 532 nm wavelength, 10 Hz repetition rate, and 6 ns pulse duration was utilized for surface texturing on three commercially available heat-activated PMMA denture base materials, namely, DPI Heat Cure, Acrypol, and Trevalon Denture Base material (Figure 1 (a)). The first set of patterns (Pattern 1) was made by focusing the laser beam on the specimen through a lens of focal length 10 cm with 80 μm vertical spacing (Figure 1 (b)). The second set of patterns (Pattern 2) was made by focusing the laser beam on the specimen through a lens of focal length 5 cm with 100 μm vertical spacing (Figure 1 (c)). For both sets of patterns, the energy of the laser beam was set to 2.3 mJ, and the specimens were scanned at a speed of 600 $\mu\text{m}/\text{s}$.

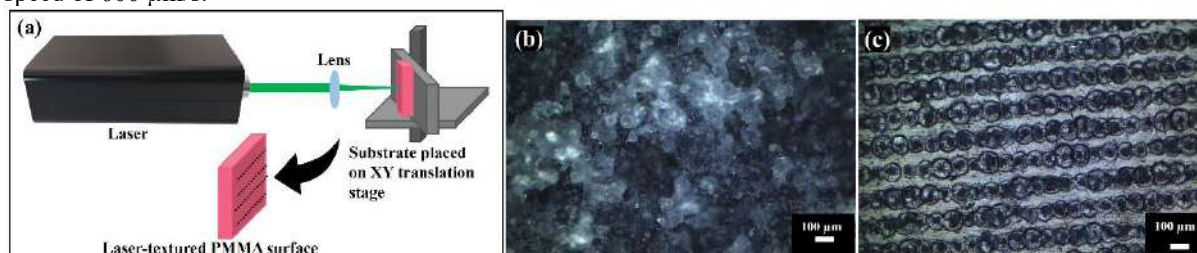


Fig. 1 (a) Schematic of the experimental setup. Microscope images of laser-ablated surface patterns on Trevalon Denture Base material made with (b) 80 μm spacing using a lens of 10 cm focal length and (c) 100 μm spacing using a lens of 5 cm focal length, at 10x magnification.

The observed water contact angle values of the patterned surfaces were slightly higher than those of the bare surface. Microbial adhesion tests have been carried out on the laser-textured specimen surfaces by the colony counting method for 24-hour exposure against two different microbes, namely, *Staphylococcus aureus* (Gram-positive) and *Escherichia coli* (Gram-negative), and have been compared with those of the bare surface. Pattern 1 of Trevalon and Acrypol and patterns 1 and 2 of DPI material exhibited a lower number of CFUs of *S. aureus* compared to their respective controls. Pattern 1 of Trevalon and Acrypol materials exhibited a lower number of CFUs of *E. coli* compared to their respective controls. As these are our preliminary observations, which provided satisfactory results, further studies will be carried out to investigate the effect of various patterning parameters on microbial adhesion.

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Digital holographic microscope with a synthetic wavelength

Amit Yadav¹, Nishant Chhiller², Gyanendra Sheoran², Rakesh Kumar Singh^{1*}

1. Laboratory of Information Photonics and Optical Metrology, Department of Physics, Indian Institute of Technology (Banaras Hindu University), Varanasi, 221005, Uttar Pradesh, India.

2. Advanced Research in Optical and Microwave Application (AROMA) Lab, Dept. of Applied Sciences, National Institute of Technology Delhi, India 110036;

*krakeshsingh.phy@iitbhu.ac.in

Abstract: We present a common-path synthetic wavelength microscopy to utilise the full spatial frequency bandwidth. Working principle of the technique is examined and initial experimental result is presented.

The capability of digital holographic microscopy (DHM) to reconstruct both amplitude and phase distributions of microscopic objects has made it a powerful tool [1]. Its ability to retrieve complex fields has enabled a wide range of applications, including biomedical imaging and optical metrology [2]. The DHM offers spatially resolved, quantitative phase images and facilitates accurate depth reconstruction of transparent and semi-transparent samples. The DHM with off-axis configurations is a commonly used approach for quantitative imaging due to its high flexibility. However, this scheme faces constraints like space-bandwidth and stability issues due to the angular separation between interfering beams. To overcome this problem, we demonstrate a common-path synthetic wavelength microscopy approach designed to utilize the available spatial frequency bandwidth fully.

Also in traditional microscopy systems, the maximum unambiguous optical path difference is constrained to within one optical wavelength due to the 2π periodicity of the interference fringes. This limitation leads to phase ambiguity when imaging thick or multi-layered specimens. Synthetic wavelength microscopy can solve this constraint by generating a synthetic wavelength, $\Lambda = \frac{\lambda_1 \lambda_2}{|\lambda_1 - \lambda_2|}$ which expands the measurable depth range to $[0, \Lambda]$ [3]. The synthetic phase $\Phi_\Lambda(x, y)$ is given as, $\Phi_\Lambda(x, y) = \Phi_{\lambda_1}(x, y) - \Phi_{\lambda_2}(x, y)$. This phase corresponds to the effective synthetic wavelength Λ , and the corresponding optical path difference (OPD) can be retrieved as : $OPD(x, y) = \frac{\Lambda}{2\pi} \Phi_\Lambda(x, y)$. Figure 1(a) presents the reconstructed amplitude, while Figure 1(b) displays the corresponding phase of Group 7 of the USAF resolution test target.

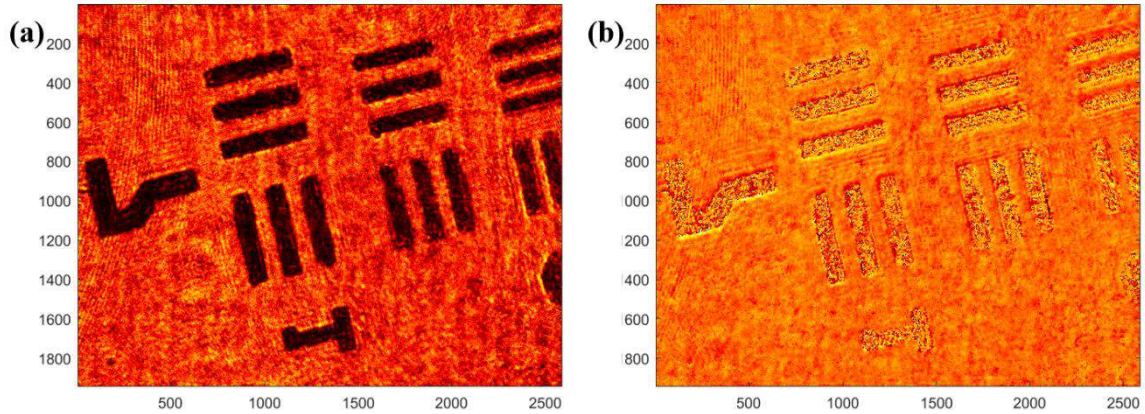


Figure. 1 Experimental results: (a) amplitude, and (b) synthetic phase of group 7 of the USAF resolution test target.

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Realization of De-multiplexing Operation via Photonic Integrated Circuit on SOI Platform

Manisha Sharma¹, Arindam Ishwar Behera¹, Vinod Parmar¹

1. Optics and Photonics Instrumentation, CSIR-Central Scientific Instruments Organisation, Chandigarh 160030, India.

Author email address: sharmamanisha199558@gmail.com, varindam22@gmail.com, vinodparmar.csio@csir.res.in

Abstract: A four-channel de-multiplexer PIC consisting of micro-ring resonators and couplers was designed using Lumerical MODE, achieving ~53% coupling efficiency. The MRRs exhibited distinct FSRs ranging from 28 nm to 33 nm with resonances in the 1500–1600 nm range.

Keywords: Photonic Integrated Circuit (PIC), Silicon Photonics (SiPh), Grating coupler, Tapered waveguide, Micro-ring resonator (MRR)

Introduction

Silicon photonics (SiPh) has become a pivotal technology for realizing compact, high-performance photonic integrated circuits (PICs), enabling scalable solutions for high-speed optical communication and signal processing [1]. In this work, we present the design and optimization of a four-channel wavelength de-multiplexer (DeMUX) using a silicon-on-insulator (SOI) platform. The device integrates key photonic components like grating couplers, tapered waveguides, and micro-ring resonators (MRRs)—all systematically optimized using Ansys Lumerical MODE simulations to enhance coupling efficiency, transmission, and spectral selectivity.

Design and Optimization

A light beam of NIR (1500-1600nm) is coupled vertically onto the surface of the grating coupler. The grating coupler (GC) design was refined by tuning the grating pitch and period, achieving an optimized coupling efficiency of approximately 52–53% [2]. A tapered waveguide with a length of 120 μm demonstrated transmission efficiency of up to 60%, facilitating efficient mode transition between input and output ports. The MRRs, optimized in terms of radius and coupling gap, exhibited high-quality resonance characteristics with minimal channel crosstalk and sharp wavelength selectivity [3].

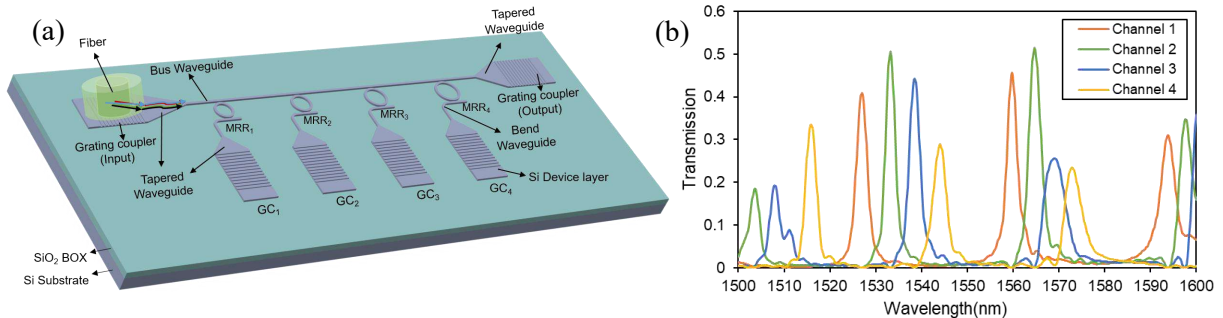


Fig. 1 (a) Schematic representation of spectral de-multiplexing via a single input source with a 4-channel output at GC1, GC2, GC3, GC4, respectively (b) Spectral characteristics measured from the drop port of ring resonators with different radii, (each with a difference of 0.15 μm) and coupling gap of 0.15 μm .

Results and Conclusions

In this work, the proposed PIC design using MRRs effectively filters specific wavelengths in the 1500–1600 nm range, acting as a wavelength de-multiplexer. The FSR was found to decrease with increasing MRR radius (33 nm at 3.1 μm , 31.45 nm at 3.25 μm , 30.24 nm at 3.4 μm , and 27.95 nm at 3.55 μm) [4]. This enables clear channel separation and demonstrates the device's efficacy in wavelength-selective filtering and de-multiplexing within integrated photonic circuits, paving the way for further advancements in SiPh-based high-speed communication technologies.

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