Confluentia 2023

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Abstract Book

First In-House Symposium

Department of Physics

National Institute of Technology Calicut

KEYNOTE ADDRESS

Optics and Spectroscopy for Monitoring Atmosphere & Climate: An overview of R&D activities of Applied Optics & Instrumentation Laboratory

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Abstract: Aerosols gaseous constituents in the atmosphere have a direct impact on Earth's climate by scattering and absorbing solar radiation. As a result, characterizing the optical properties of aerosol and gases has recently become an important research topic in our climate forecasting and air pollution studies. Applied Optics and Instrumentation (AOI) has over the years developed methods to monitor gaseous and pollutant constituents for pollution as well as climate monitoring applications. The talk will include basic needs for such research, problem statements, methods developed and the results obtained.

TALKS

1. Quantum measurement problem, decoherence and quantum to classical transition

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Abstract: According to the standard formulation of quantum mechanics, the state of the system can change in two ways: 1. a unitary time evolution and 2. an abrupt non-unitary change during a measurement usually called the 'collapse of the wave function'. If one thinks of system + apparatus as a single quantum system which we call the universe, the measurement process itself should be a unitary evolution of the universe. The problem of understanding the collapse of the system wavefunction from the unitary evolution of the universe is the quantum measurement problem. Understanding how quantum mechanics approximates to classical mechanics in certain domains

of applicability is the problem of quantum to classical transition. In this talk, we will discuss these two problems emphasizing its connection with quantum decoherence and with each other.

2. A peek into aspects of quantum gravity

P. N. Bala Subramanian
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Abstract: In this talk, we will take a broad look at the advances in the search for a theory of Quantum Gravity. We will look at the motivations for the conjectured holographic description of gravity, and also discuss how it has been used in various contexts to help with computations of seemingly distinct physics. The unifying nature of the topic is also the reason why it is called Gauge/gravity duality, and we will discuss how and why this is power tool for analytical and numerical computations. We will discuss the implications, and large spin-off research in fields such as condensed matter physics, mathematics, etc.

3. Big world of small neutrions

Saurabh Gupta
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Abstract: We provide a brief overview of some open problems existing in the area of neutrino physics. We discuss the latest development and give a bird's-eye view on the current status of neutrino research. Finally, we discuss our contributions to answer few of these open questions.

4. ON-DEMAND ASSEMBLY OF Au NPs OVER SOLID SURFACES FROM SESSILE DROPLETS BY THERMOPLASMONICALLY-CONTROLLED LIQUID FLOW

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Background: Optically controlled assembly of suspended particles from evaporating sessile droplets is an emerging method to realize on-demand patterning of particles over solid substrates. Though dynamic control over the assembly of microparticles is possible, limited success has been achieved in nanoparticle patterning, especially in the case of metallic nanoparticles. This work demonstrates a simple light-directed patterning of Gold (Au) nanoparticles based on the thermoplasmonically-controlled liquid flow.

Method: The on-demand assembly of Au NPs was realized via thermoplasmonically- controlled liquid flow inside an evaporating sessile drop (3 µL, 0.8 nM Au NP droplet). A diode laser (532 nm, Power - 80 mW) focused into a circular spot radius of 75 µm was utilized to induce the localized heating. We performed optical microscopy and 3D profilometry to characterize the final particle deposit.

Results: The plasmonic excitation led to a temperature difference of about 18 °C between the irradiated region and the three-phase contact line of the pinned droplet, resulting in the particle assembly at the irradiation zone in response to the thermocapillary flow created inside the droplet. Particle streak velocimetry experiments and analysis confirm the existence of a strong thermocapillary flow which counteracts the naturally occurring evaporative convection flows (up to *t/tf ~0.8*, where *tf* denotes the total evaporation time). 3D profilometry analysis revealed a 102 times enhancement in the deposit height upon irradiation, in comparison to the size of individual NPs (~44 nm). To test the versatility of the developed method, we tried different illumination patterns using photomasks/sequential scanning, which led to various patterns, including off-center, two-spot, and line deposit.

Conclusions: We demonstrate an efficient optical strategy for realizing patterns of Au nanoparticles based on thermoplasmonically-controlled liquid flow. A variety of patterns such as central deposit, off-center deposit, multi-spot deposit, and lines could be inscribed by simply varying the illumination pattern.

Keywords: Directed assembly, Thermoplasmonics, Marangoni flow, Coffee ring effect.

5. Absorbing Phase Transition in Conserved Stochastic Sandpiles

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Abstract: Nonequilibrium phase transitions and scale-free structures are ubiquitous in nature. Sandpiles, a paradigmatic model for self-organized criticality (SOC), explain the scale-free system like mountain ranges, river networks, earthquake phenomena, etcetera. The sandpiles, defined on a lattice with non-negative particles, are threshold-activated, where the dynamics are governed by toppling events. The open-boundary sandpiles, with non-conserved total number of particles, show self-organization, whereas the conserved sandpiles, defined on closed-boundary, exhibit a transition between active to absorbing phase at a critical global particle density. In the talk, we will discuss the critical-properties of the conserved stochastic sandpiles. In particular, we will address

the long-standing issue with the universality class of the critical exponents, the recent advancement in this direction, and open issues.

6. Surface Plasmon Polariton Resonances for Terahertz Waveband Applications

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Abstract: Surface plasmon polaritons (SPPs) are the quanta of quasi-interaction between photons (incident electromagnetic wave) and plasmons (quanta of collective excitations of electrons) at the interface between plasmonic and dielectric material. It is one of the intriguing light-matter interactions in which one can explore SPP's localized fields for ultra-high confinement, sensing, and optical waveguiding. In this talk, the methods of obtaining SPPs at terahertz (THz) frequencies using bulk Dirac semimetal (BDS) and their applications will be presented. Especially, the confinement of THz wave along curved/bending geometries, and THz waveguiding are demonstrated. The realization of THz logic gate functions such as OR, AND, NOR, and NAND using SPP waveguiding will also be highlighted in this talk.

Keywords: Surface Plasmon Polaritons (SPPs), Terahertz (THz), Waveguides, and Bulk Dirac Semimetal.

References

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2. T. M. Blessan, and N Yogesh, "Terahertz surface plasmon polariton resonances and microparticle sensing in bulk Dirac semimetal with spatially perturbed geometries" **J Opt Soc Am B 38 (8)**, 2261-2266 (2021)

7. Near surface nitrogen delta doping

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The negatively charged nitrogen-vacancy centers (NV^-) is one of the most significant color centers in diamond due to their spin dependent fluorescence and exceptionally long coherence times. One of the key challenges for NV^- based magnetometry applications is to create an ensemble of NV centers in the near surface region. Recently, we reported an innovative delta doping technique to fabricate an ensemble of NV^- centers at shallow depths in (100) diamond [1]. This method produces a nitrogen delta-doped layer with a concentration of ~1.8 x 1020 atoms·cm-3 with abrupt interfaces. To the best of our knowledge, this is the thinnest nitrogen delta doping profile with abrupt interfaces in a single crystal diamond reported to date. Herein, we report an in-depth secondary ion mass spectroscopy (SIMS) analysis of nitrogen delta doped layer in diamond. The SIMS profile of the delta layer exhibits a positive concentration gradient of 1.9 nm/decade and a negative gradient of 4.2 nm/decade with a full width at half maximum (FWHM) of 7.5 nm. The broadening of the nitrogen profile (FWHM=7.5 nm) is partly attributed to the diffusion of nitrogen as well as to the depth resolution of SIMS measurements (ion mixing and surface roughness effects). Nitrogen delta doping in polycrystalline diamond revealed the diffusion of nitrogen through grain boundaries as well as the influence of surface roughness on the broadening of SIMS profile.

Keywords: Diamond, NV^- centers, Nitrogen, Delta doping, Magnetometry

Reference

1. M. Chandran *et. al*., Appl. Phys. Lett. **109**, 221602 (2016).

8. Inverse Problems in Natural Science and Engineering

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Abstract: The inverse problems are generally represented by the Fredholm equation of the first kind, which expresses a function in two different domains. There are few methods to solve such a typical equation analytically. The discretization of this equation leads to rank-deficient and ill posed numerical problems. On the other hand, we get limited observations in natural science and engineering, making it more difficult to invert the source function, such as determining the seismic moment tensor from the far-field seismic waves. In this presentation, we will discuss a few examples and numerical methods to solve such problems using analytical and numerical methods.

9. Symplectic reformulation of particle on a torus knot as a gauge theory

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Abstract: We explore the deduction of constraint spectrum and the symplectic approach of quantization for the particle constrained to move on a (p, q)-torus knot in a geometrically motivated way. We discern all basic brackets and establish the gauge non-invariance of theory. Further, by making use of symplectic methodology, we reformulate the system as a physically equivalent gauge theory in the original phase space variables. To quantize the newly reformulated gauge theory, we employ the BRST scheme of quantization to ascertain the symmetries and the corresponding generators with the consistent physicality condition.

10. Simple and Continuous Production Janus Liquid Marbles Based On Controlled Droplet Impact

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Abstract: Liquid marbles (LMs), droplets encapsulated with micro-/nanoparticles, have attracted significant attention owing to their potential applications in various fields, ranging from micro-bioreactors to sensors.[1,2] The capabilities of LMs can be enhanced by enwrapping the marble with multi-particles, referred to as Janus liquid marble (JLM).[3] However, their fabrication process remains a challenge. Here we present a simple and fast approach for the fabrication of JLMs based on the controlled droplet impact on particle beds. The fabrication process involves collection of PVDF particles (particle type 1) by a water drop, followed by its impact over an uncompressed bed of BTP (particle type 2). The drop impact and condition required for JLM formation were explained based on the Weber number and maximum spread analysis.

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11. Computational study of Nb-doped TiO_2 as an Effective Oxygen Reduction Reaction Catalyst

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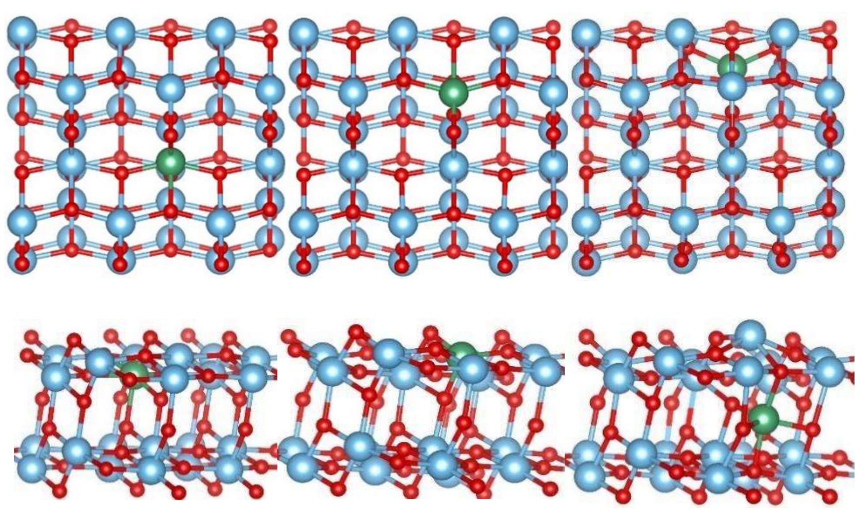
Abstract: The design and development of low-cost, highly efficient, and platinum-free electrocatalysts for oxygen reduction reactions (ORR) are crucial to the large-scale commercial application of fuel cells. We investigated the mechanism of the ORR on Nb-doped TiO_2 using density functional theory (DFT) computations to explore Nb-doping at the substitutional and interstitial sites to activate the basal plane of (101) TiO_2. We elucidated the possible ORR mechanism on Nb-doped TiO_2 by calculating the activation energy for all of the possible elementary reaction steps in ORR. Our finding suggests that ORR in Nb-doped TiO_2 follows the H_2O_2 dissociation mechanism. Nb-doping at the 6c site exhibits improved ORR activity than 5c and interstitial sites, which may be attributed to the optimal balance between the electron transfer and the adsorption/desorption kinetics. Our finding provides insight into the design and optimization of Nb-doped TiO_2 electrocatalysts for fuel cell applications.
Keywords: Oxygen reduction reaction, Density functional theory, Doped TiO_2



12. Tamm Plasmon Cavity Enhanced Nonlinearity and Efficient Optical Limiting Action of Graphene Quantum Dot Prepared by Laser Ablation

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Abstract: Miniaturisation of optical materials is the focus area of the photonic community of all time. Light confinement in the nanoscale regime has opened new doors to the miniaturisation of devices required for future integrated photonics. Recently, Tamm Plasmons (TP) have attracted research interest as they possess various advantages over conventional surface plasmons. In this work, we report the enhanced nonlinear optical response of graphene quantum dot (GQD) prepared by laser ablation, aided by a TP cavity. The spacer layer containing GQD is sandwiched between a silver film and a DBR made of TiO_2 and SiO_2 alternative layers. The photonic bandgap of the DBR is centred around 532 nm and the final structure is characterized by a prominent transmittance peak around 532 nm, indicating the TP cavity mode. The open aperture z-scan results, shows a decreased transmittance at the focus characteristic of Reverse Saturable Absorption (RSA) behaviour, which becomes steeper for the TP cavity structure compared to the bare GQD reference film. It is also showing best optical limiting threshold value. This giant enhancement in the absorptive nonlinearity arises from the enormous energy concentrated in the spacer layer due to the presence of localized TP mode allowing stronger light-matter interaction.

13. CORONAL SEISMOLOGY

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Abstract: Coronal seismology is a tool to understand the physical properties of coronal plasma by analysing the waves and oscillations in different coronal structures. Thereby, these waves and oscillations play a crucial role in the dynamics and heating of the corona, and understanding their properties is important for predicting solar flares and other space weather events. Using high-resolution observations such as Atmospheric Imaging Assembly (AIA) onboard Solar Dynamic Observatory (SDO), we explore the coronal seismology in detail.

POSTERS

1. Computational Modeling of Janus SnSSe as a material for NO, NO_2 and NH_3 gas sensing

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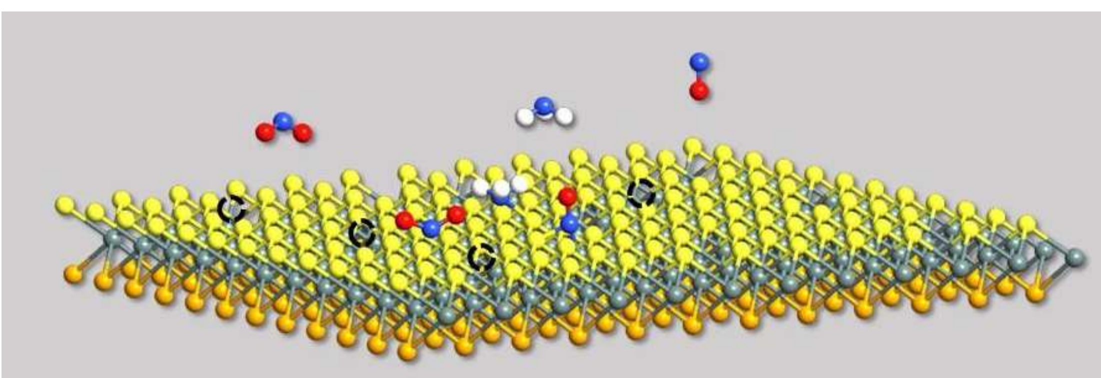
Abstract: Janus transition metal dichalcogenides (TMD) are a class of 2D materials that have recently attracted significant attention due to their unique electronic and optical properties. The quest for suitable materials to capture toxic gases, such as NO, NO_2, and NH_3, is of paramount importance as they are known to have detrimental effects on human health and the environment. Using DFT, we systematically investigate the ability of Janus SnSSe to sense these toxic nitrogen-containing gases (NCG). Our studies reveal that the three gases are adsorbed on the sulfur and selenium defectsof Janus SnSSe with significant adsorption energy ($\sim 1.7\ eV$).Specifically, it was found that the presence of a single chalcogen defect could significantly improve the adsorption energy. The electronic structure, charge transfer, and work function after adsorption areanalyzed. Results showed a significant change in work function after adsorption as well as a decrease in energy gap ($\sim 0.5\ eV$), indicating an improved conductivity.It is found that a significant amount of charge is transferred from the molecules to the monolayer.The results indicate that the material has high sensitivity for these gases, making it an excellent candidate forsensing applications.



2. Batalin-Fradkin-Vilkovisky quantization of Christ-Lee model

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Abstract: We analyze the constraint structure of Christ-Lee model by the means of Dirac formalism. Further, we quantize the system using systematic Batalin-Fradkin-Vilkovisky formalism and obtain the BRST invariant gauge-fixed action in Cartesian as well as polar coordinates.

3. Radiative transfer equation & Applications

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Abstract: Radiative transfer equation (RTE) is a fundamental equation in physics that describes the propagation of electromagnetic radiation through a medium. The RTE relates the intensity of radiation at a given point in space and time to the properties of the medium through which the radiation is traveling.

The general form of the RTE can be expressed mathematically as:

$$\frac{dI_\nu}{ds} = -\alpha_\nu I_\nu + j_\nu$$

where I_ν is the specific intensity of the radiation at a frequency ν, s is the path length travelled by the radiation, α_ν is the absorption coefficient of the medium at frequency ν, and j_ν is the emission coefficient of the medium at frequency ν.

The first term on the right-hand side of the equation represents the absorption of radiation by the medium, while the second term represents the emission of radiation by the medium. The left-hand side of the equation represents the change in intensity of the radiation as it travels through the medium.

The RTE is used in a variety of fields, including astrophysics, atmospheric science, and remote sensing. It is essential for understanding the behaviour of radiation in these systems and for interpreting remote sensing data obtained from satellite or airborne sensors. It plays a crucial role in solar astrophysics, as it provides a theoretical framework for understanding how energy is transported through the Sun's interior and atmosphere.

4. Band-edge induced nonlinear absorptive dynamics of platinum nanocluster doped photonic crystal structure

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Abstract: The suppression of group velocity at the photonic band edges can induce significant changes in the optical nonlinearity of a material. Herein, we explore the contribution of band-edge effect in the enhanced absorptive nonlinearity of an all-polymer Distributed Bragg Reflector with platinum nanoclusters dispersed in its high index layers. Atomically precise platinum-17 metal nanoclusters are synthesized by polyol reduction method and the third order nonlinear optical properties are studied using standard z-scan technique. Moreover, the high angular tunability at the band edge can be exploited in the design and fabrication of low power, compact photonic devices.

Keywords: Photonic band edge, slow light, platinum nanoclusters, nonlinear absorption, z-scan

5. Use of Image Processing in Solar Astrophysics

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Abstract: Image processing techniques have played a critical role in advancing our understanding of the universe. In astrophysics, images captured by telescopes and other instruments contain vast amounts of information but often require advanced processing techniques to extract meaningful insights. This poster presents an overview of various image processing techniques and their applications in astrophysics. The poster will begin by discussing the importance of image processing in astrophysics, and the challenges that arise in dealing with large and complex data sets. It will then present various image processing techniques, such as image filtering, enhancement, segmentation, registration, and classification. Each technique will be accompanied by specific examples of their application in astrophysics, such as the detection and analysis of supernovae, galaxies, and other celestial objects. Overall, this poster will demonstrate the crucial role of image processing techniques in advancing our understanding of the universe, and the potential for future discoveries through continued development of these techniques.

6. Light-Controlled Assembly of Binary Colloids from an Evaporating Sessile Droplet

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Abstract: The controlled assembly of colloidal particlesis of particular interest in view of its applications inphotonic devices[1] and biomedical devices,[2] etc. The conventional assembly techniques are based on bottom-up approaches such as LB assembly,[3]LBL deposition,[4]and evaporation of sessile droplets.[5] Among them,evaporation-based assembly is promisingdue to its scalability and ease of implementation. Herein we demonstrate light-controlled assembly of binary colloids (Gold and polystyrene particles) by exploiting thermocapillary flow inside an evaporating droplet.

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7. Plasmonic-Photonic Interactions in Polymer Microcavities for Enhanced Excited State Absorption in Cobalt Phthalocyanine-Gold Nanocomposites

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Abstract: Light-matter interaction in sub-wavelength scale optical confinement structures is a hot topic in both basic science and the photonic industry. Materials experiencing high electric field strength can change their optical properties according to the intensity of light. In this paper, we investigate the linear and nonlinear optical behaviour of Cobalt Phthalocyanine (CoPc) placed in the combined local fields of plasmonic and photonic cavity modes. We create a planar all-polymer

microcavity and incorporates the cavity layer with CoPc-Au nanocomposite. The large field strengths caused by the cavity photon-plasmon coupling lead to a significant enhancement in the nonlinear optical absorption of the CoPc. The photon-plasmon-exciton interactions in the hybrid microcavity results in an enhancement of the excited-state absorption of the system, even at low excitation intensities. The degree of light coupling can be altered by tuning the angle of light incidence, thereby varying the nonlinear transmittance of the structure. The proposed system can act as an angle-dependent optical switch that works for laser pulses, with high attenuation at normal incidence and high transmittance at oblique incidence. Our findings provide a comprehensive understanding of resonant light-matter interactions in tailored photonic crystal structures and how they nonlinearly modulate the optical properties for photonic applications.

8. Role of Weak Measurements in Quantum to Classical Transition

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Abstract: The idea of quantum to classical transition has been studied for a long time. It has been identified that the interaction with the environment plays the most crucial role in the emergence of classical behaviour. But, classicality can mean (1) the absence of interference terms in the pointer bases, (2) the simultaneous measurability of “classical” observables. How, can the various quantities like position, momentum, etc be simultaneously measurable? How do these conjugate variables even exist simultaneously in well-defined values? The answer lies in weak measurements. Through weak measurements, we sacrifice the precision on one of the variables to gain some information about the other. Thus, through weak measurements, the environment would be able to monitor both the position and momentum of the system, albeit approximately. But with time, the environment would be able to discern both the position and momentum accurately. The system would now exist in astate that locally seems to exist in distinct values of position and momentum.

9. Advanced Spectroscopic Instrumentation for Atmospheric and Climate Monitoring

Salma Jose and M. K. Ravi Varma

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Abstract: Scattering and absorption of light by atmospheric gases and aerosols have significant influence on the visibility of the atmosphere, affects weather and plays a vital role in climate

forcing and pollution monitoring. Incoherent broadband cavity enhanced absorption spectroscopy (IBBCEAS) is a recently developed method to detect and quantify atmospheric trace gases with high sensitivity. A nephelometer is an instrument which can measure the scattering of gases and particles and consequently gives the idea about the concentration of the same. Developing innovative instruments based on the principle of the conventional IBBCEAS and Nephelometer, by improving the sensitivity and compactivity can be an asset for the climate and atmosphere monitoring advancements.

Keywords: IBBCEAS, Scattering, Absorption, Nephelometer.

10. Bioinspired *5*-caffeoylquinic acid capped silver nanoparticles using *Coffee arabica* leaf extract for high-sensitive cysteine detection

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Abstract: Along with health concerns, choosing of plants as a bioactive phytochemical source to synthesize nanoparticles is highly demanding due to the biocompatibility, nontoxicity, and cost-effectiveness over other available physical and chemical methods. Here, for the first time, *Coffee arabica* leaf extracts (CAE) were used to produce highly stable silver nanoparticles (AgNPs) and the corresponding bioreduction, capping and stabilization mechanism mediated by *5*-caffeoylquinic *acid (5-CQA) is discussed.* UV-Vis, FTIR, Raman spectroscopy, TEM, DLS and Zeta potential analyzer measurements were used to characterize these green synthesized NPs. The affinity of 5-CQA capped CAE-AgNPs to thiol moiety of amino acid is utilized for the selective as well as sensitive detection of L-cysteine (Cys) to a low detection limit of 0.1nM. Hence, the proposed novel, simple, eco-friendly, and economically sustainable method can provide promising nanoplatforms in the field of biosensors which is compliant with the large-scale industrial production of AgNPs without aid of instruments.

11. The comparison of the nonlinear optical response of Poly(vinylidene fluoride) (PVDF)/reduced graphene oxide (RGO) and PVDF/graphene oxide (GO) nanocomposites

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Abstract: In this work, we compare the third-order nonlinear optical properties of Poly(vinylidene fluoride) (PVDF)/reduced graphene oxide (RGO) and PVDF/graphene oxide (GO) nanocomposites. The nanocomposites were produced by mixing different concentrations of RGO or GO as the filler with PVDF. The third-order nonlinear optical properties were investigated at 532 nm using the Z-scan technique under seven nanosecond excitation [1]. The results showed that both PVDF/RGO and PVDF/GO nanocomposites exhibited nondegenerate two-photon absorption in the nanosecond regime. Linear optical properties of the nanocomposites were studied using UV-visible absorption spectroscopy. This study highlights the importance of incorporating RGO and GO in designing efficient optical limiting devices. Additionally, the results from the FTIR study provided information about the chemical interactions between PVDF and the fillers.

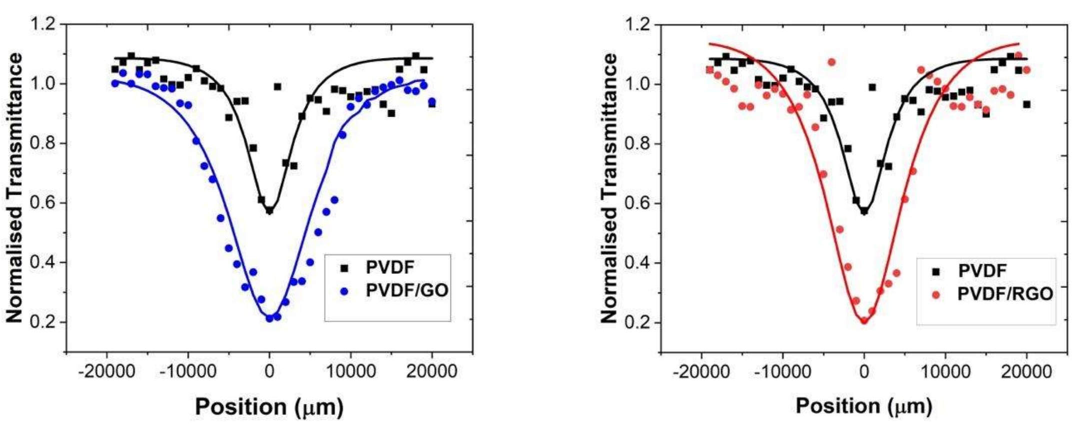

Figure 1 Open aperture z-scan traces of (a)PVDF, PVDF/GO nanocomposites, (b)PVDF and PVDF/RGO nanocomposites

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12. Nearly Perfect Cross- and Circular-Polarization Conversion Using Ultra-Thin Bi-layered Chiral Metamaterial at Microwave Frequencies

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Abstract: A bi-layered chiral metamaterial (CMM) with giant optical activity and strong circular dichroism is reported in this work. The proposed CMM functions as a nearly perfect cross-polarization converter (i.e 90° polarization rotator) at 7.288 GHz and a wide-band circular-polarization converter (i.e a transverse electric linearly polarized wave is converted into a left-circularly polarized wave) in the frequency range of 6.36 GHz to 7 GHz, respectively. The realized CMM is ultrathin, in which a CMM's thickness of λ/19.8 and λ/21.6 is sufficient for the cross- and circular-polarization conversions, respectively. The mechanism for the cross- and circular-polarization conversion by the designed CMM is explored through surface current analysis and field distributions. We anticipate that our realization expands the possibility of creating miniaturized ultra-thin polarimetric instruments for microwave applications.

Keywords: Chiral metamaterial, giant optical activity, cross-polarization converter, and circular polarizer.

13. Beating the Optical Resolution Limit with Negative Refractive Index Material: Numerical Demonstration of Sub-Wavelength Focusing by a Negative Index Slab

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Abstract: The electrodynamics of negative refractive index medium is fascinating in which the material with the simultaneous negative values of relative dielectric permittivity and relative magnetic permeability exhibits exotic optical properties including negative refraction, double focusing, and sub-wavelength imaging. In this poster, we highlight the interesting optics of negative index medium by solving electromagnetic wave propagation in negative index medium numerically. Especially, how the imaging by the negative index slab overcomes the Rayleigh diffraction limit is demonstrated numerically. The challenges and limitations associated with negative index-based imaging are also highlighted.

Keywords: Negative Refractive Index, Double Focusing, Sub-wavelength imaging and Rayleigh Diffraction Limit.

14. STUDY AND FUTURE PROJECTION OF AEROSOL PARAMETERS USING OBSERVATIONAL DATAS AND CLIMATE MODELS

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Abstract: Aerosols may seem tiny and insignificant, but they play a vital role in shaping our planet's climate. From affecting radiation balance to cloud formation and precipitation, these minuscule particles are like the invisible architects of our atmosphere. But how do we measure and understand these elusive particles? Enter parameters like aerosol optical depth, single scattering albedo, and effective radiative forcing - which offer insights into the distribution, composition, and energy imbalance caused by aerosols.

However, there's more to this story. To truly unravel the mysteries of aerosols, we need to look beyond just observations and reanalyses. That's where cutting-edge models like those from the CMIP6 come in. By simulating these complex processes, we can gain a better understanding of how aerosols impact our planet. But even with the latest models, there are still challenges - from uncertain aerosol emission and deposition to inter-model diversity. So, while we've come a long way in our understanding of aerosols, there's still much work to be done. By tuning and improving these models, we can unlock a brighter, more informed future for our planet.