PHOTONICS NEWS

Volume 24 | February 2022

International School of Photonics
Cochin University of Science and Technology

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Photonics News 2022 in Short...

FEBRUARY 2022

Editorial

Dr. Pramod Gopinath

Dr. Priya Rose T

Dr. Rehana P Ummer

Jose Antony V J

Harikrishnan P V

Mitty George

A K Sooraj Vishwam

Mubeena Rafi

Syammohan V

Mayur Anil Sathe

Inside...

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International Conference on Recent Trends in Photonics (NPS 2022)

International School of Photonics, established in 1995, has been conducting Annual Photonics Workshop, a national event which brings together leading scientists, academicians, industrialists and young researchers for active discussions and fruitful interactions on various aspects of Photonics, for last several years. This annual event was conducted in the form of National Photonics Symposium (NPS) from 2017 onwards. This year, NPS will be conducted as an international event in all-virtual mode. The aim of NPS is to enlighten the budding scientists to find newer directions for research through active discussions and collaborative research. We hope to provide the best platform for all participants to exchange the latest and advanced research with other specialists and scholars in the field by bringing in the best scientists in India and abroad to deliver invited lectures and plenary talks apart from contributed papers. On 28th February, there will be a special session to celebrate National Science Day.

List of Speakers

Prof. G. Ravindrakumar
TIFR, Mumbai, India

Prof. Franz X. Kärtner
University of Hamburg, Germany

Prof. V M Murukeshan
NTU,Singapore

Dr. Kazuhiko Maeda
Tokyo Institute of Technology, Japan

Dr. Pablo Albella
University of Cantabria,
Santander, Spain

Dr. Tatyana Sizyuk
Argonne National Laboratory, USA

Dr. Radhakrishna Prabhu
Robert Gordon University,
Aberdeen, UK

Dr. Swapna Nair
Central University of Kerala, India

Dr. Renilkumar M
Motion Imager, Twente,
The Netherlands

Dr. Sonia Mary
The Jackson Laboratory, USA

Dr. Madhu Veettikazhy
Technical University of Denmark, Denmark

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Dr. Bikas C. Das	IISER, Trivandrum
Dr. Mandip Singh	IISER, Mohali
Dr. M. Suheshkumar Singh	IISER, Trivandrum

Director's Message

Prof. (Dr.) Pramod Gopinath

The International School of Photonics has been advancing its forefeet into various disciplines of hardcore photonics research for past 25 years. Last year, the School witnessed the Silver Jubilee celebrations, through a series of webinars by eminent scientists contributing to state of the art photonics technology, from different parts of the world. This year, marks the Golden Jubilee of Cochin University of Science and Technology, that is being celebrated through various programmes focussing on cutting–edge research and academic programmes in inter-disciplinary areas. The International School of Photonics was one of the major organizing departments in the conduct of the Golden Jubilee International Conference NANOicon 2022 during Jan 11-15, 2022.

Despite the constraints posed by the COVID-19 pandemic, the academic and research activities of the school never felt a sway. The School has managed to sail through the tough times, by being consistent with its academic and research activities. It indeed elates me to find that the Masters students who have graduated from the school have managed to carry forward their journey by occupying research as well as professional placements at various esteemed institutions within and outside our country.

This year, the School is all set to organize its prestigious annual event, National Photonics Symposium, in the form of an online International Conference entitled "The International Conference on Recent Trends in Photonics (NPS-2022)" during February 27 - March 01, 2022 as part of the Golden Jubilee Celebrations of Cochin University of Science and Technology. The Conference will feature talks by many distinguished scientists round the globe, with one Keynote, three Plenary and Six Invited Talks. Prof. G Ravindrakumar, TIFR, Mumbai will be delivering the National Science Day Lecture on February 28, 2022. The Conference proceedings will be published in the IOP Journal of Physics: Conference Series (JPCS) after peer review. We are looking forward to the Conference being a success, helping young scientists and researchers in the field of Photonics to undertake novel directions of research, contributing to the overall development of the society and nation as a whole.

I am happy to see that the 24th issue of our annual souvenir highlighting the academic, research and other technical activities of the School, the Photonics News, is being released this year during the Conference. I congratulate the team led by Dr. Priya Rose T, for their commendable effort in preparing the same and releasing it on time.

Wishing all the very best for a great year ahead

Pramod Gopinath

Faculty Members at ISP

Prof. (Dr.) Pramod Gopinath
(Director)

Dr. A Mujeeb
Senior Professor

Dr. M Kailasnath
Professor

Dr. Sheenu Thomas
Professor

Dr. Saji K J
Assistant Professor

Dr. Manu Vaishakh
Assistant Professor

Mr. Muhammad Rishad K P
Assistant Professor

Dr. Priya Rose T
Assistant Professor

Dr. Praveen C S
Assistant Professor

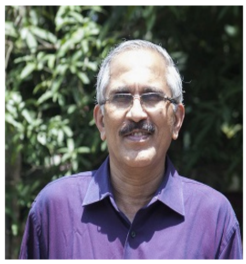
Dr. Mohamed Ameen
Assistant Professor

Visiting Professors

Dr. C P Girijavallabhan

Dr. V P N Nampoori

Dr. V M Nandakumaran



Dr. P Radhakrishnan

Prof. A Varadarajan

Dr. Reethama Thomas

Dr. S K Sreenivasan Nair

Dr. Lalitha Mathew

Administration

Siraj S
Section Officer

Rajasree P S
Technical Assistant

Aneesh P B
Assistant

Kesia Salimon
Assistant

Beema Beegum A M
Store keeper

Gaseena K M
Computer Assistant

Yadhavkrishnan K S
Computer Assistant

Saritha
Professional Assistant

Jude Varghese K S
Technical Assistant

Reshma Pusphakaran
Technical Assistant

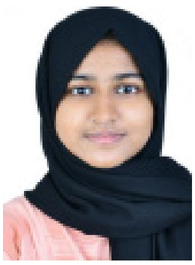
Shiny Dileep
Office Attendent

Asha A P
Sweeper Cum Cleaner

Awards

Fathima R

Best Researcher Award
(Highest Cummulative Impact Factor)
&
Best Research Scholar Award
(Single Peer-Reviewed Journal with Highest Impact Factor)



Hiba
Nalanda Award for Highest CGPA
1st semester M.Sc.

Asapanna Rajesh
Prof. Legget Award
Highest CGPA
M.Sc. 10th semester

Chandini Chandran
PSI Award
for M.Tech(OE & LT)
Topper

Ahmed Lafeef E N
Satish John Award
Best project in M.Tech
(OE & LT)

Aiswarya V Nair
C.V Raman Award
Best Project Thesis M.Sc.

Riswan Asif
C.V Raman Award
Best Project Thesis M.Sc.

Best Paper Awards

Shilpa S.
Best paper Award
ICRAPS 2022

Lakshmi B
Best Paper Award
NPS 2021

Cicily Rigi V J
Best Paper Award
NPS 2021

FRSC to Prof. Pramod Gopinath

Prof. Pramod Gopinath, Professor and Director, International School of Photonics has been admitted as a Fellow of the Royal Society of Chemistry (FRSC). Hon. Vice-Chancellor of CUSAT, Prof. K N Madhusoodanan awarded a Letter of Appreciation to Dr. Pramod Gopinath, in the presence of Dr. Meera V, Registrar, CUSAT

Achievements

Vineetha Ashok
PhD Student
ECE Department
Boston University

Asapanna Rajesh
Graduate Engineer Trainee
Optical Engineer
Zentron Labs Pvt Ltd
Bangalore

Sisira S
PhD Student
Fresnel Institute
Aix Marseille University, France

Anoop Varghese
Optical Engineer
Augur AI Pvt Ltd, Tamil Nadu

Rizwan Asif
Optical Engineer, Augur AI Pvt Ltd,
Tamil Nadu

Warrier Sreeraj Rajan
PhD Student
Department of Physics
Mahindra University
Hyderabad

Adarsh N M
Post Graduate Engineer
Trainee, Optical Engineer,
Hella India Lighting Ltd, Punjab

Aishwarya V Nair
PhD student, Karlsruhe School of
Optics and Photonics
Karlsruhe Institute of technology
Germany

Achievements

Neena Johnson
Verification Engineering Tech Analyst
Ribbon Communication

Fathima
Infosys
System Engineer

Midhun George Joseph
GoPhotonics

Pramitha P Kamath
Doctoral Researcher
Okinawa Institute of Science and Technology
(OIST), Japan

Ajmal Thottolli
Doctoral Student
DEI
Politechnico di Bari, Italy

New Doctorates from ISP

Pseudo binary chalcogenide glass for the realization of IR photonic devices

Ajina C

Under the supervision of
Prof. Sheenu Thomas and Prof. V.P.N. Nampoori

Surface-enhanced infrared spectroscopy (SEIRA) is a powerful sensing scheme for the identification of unknown organic species. In this, an enhancement in IR absorption is provided by the surface plasmon resonance character of the metal nano/microstructures introduced over the IR transparent substrate. The degree of enhancement obtained is a function of many factors such as metal type, its size, density, morphology and the optical and dielectric property of the substrate material etc. Even though the dependence of substrate material on the SEIRA response is evident and reported, the majority of research work in SEIRA is done by tuning the metal type and its morphologies.The availability of a substrate material with flexible fabrication routes and easily tuneable property will be a windfall when it comes to the development of integrated photonic sensor platforms. In this work, we tried to extend the SEIRA substrate choices to an amorphous chalcogenide system.

Chalcogenide glasses are glasses containing any of the chalcogen group element S, Se or Te. The low absorption in the characteristic absorption regions of the organic molecules along with its chemical compatibility with metals like Silver makes chalcogenide glass a promising alternative to the existing substrate choices. At present, commercially available chalcogenide glasses have toxic constituents like As or Sb in it. So the study aimed to identify a greener chalcogenide composition for SEIRA with device fabrication flexibilities. For this, a pseudo-binary chalcogenide glass system of GeSeTe was selected and a series of studies were conducted in its bulk form, solution form and film forms.

The bulk glass characterisation on a series of GexSe(90-x)Te10 systems revealed the moderate glass transition and stable glass-forming property of Ge20 Se70Te10 which can offer a low-temperature moulding during device realisation. From the solution based studies ethylene diamine-GeSeTe was found to be the best fit for solution processing. The thermal and photo-stability studies of thermally evaporated films were conducted by transient transmission measurement and it showed good environmental stability. The compatibility of the film to the incorporation of Silver nanostructures was also analysed with different experimental systems and a wavelength selective photo structural modification was identified which has the potential to be employed as an inorganic photoresist. The silver columnar structure developed by oblique angle deposition and silver islands formed by a novel sandpaper template-assisted micro-contact printing were used for analysing the SEIRA response of the self-assembled monolayer of anchor molecules on the Silver chalcogenide system .The results of this study point out the fact that the GeSeTe system is a potential candidate for a SEIRA substrate with many fabrication flexibilities.

Polymer optical fiber based active and passive whispering gallery mode resonators for microlasing and sensing applications

Under the supervision of

Prof. M Kailasnath and Prof. P Radhakrishnan

Anand V R

Compared to liquid, silica, and semiconductor-based WGM cavities, polymer-based WGM cavities have many advantages including mechanical flexibility, ease of fabrication, low manufacturing temperature and cost-effectiveness. The polymer is an ideal host material for organic dyes due to its low manufacturing temperature. Dye doped polymer WGM cavities have shown great promise for flexible photonic circuits. There are several methods for fabricating dye- doped polymer fiber including direct drawing from dye-doped polymer solution, electro spinning and heat drawing from dye doped polymer preform.

Different types of dye doped PMMA based polymer optical fibers including step index, graded index, hollow and microring embedded hollow polymer optical fibers can be fabricated using the fiber drawing technique. Hollow polymer optical fiber has attracted increasing attention due to its special tubular geometry and application in optofluidics.

The undoped polymer optical fiber can produce passive WGM with the evanescent coupling of light with a tapered optical fiber. Dye doped polymer optical fiber can generate narrow linewidth, low threshold lasing upon suitable optical excitation. The remote excitation and collection make dye doped polymer fiber an interesting candidate as an active sensor. Moreover, at low pumping energies, these dye doped polymer optical fibers can emit amplified spontaneous emission. The main focus of this thesis is to investigate the tuning the passive and active WGM's from polymer optical fiber and realizing efficient sensors with them.

Investigations on synthesis and characterization of CdSe and CdSe-ZnSe nanostructures forphotonic applications

Under the supervision of

Prof. A . Mujeeb

Boni Samuel

The research is focused on the synthesis and characterization of CdSe and CdSe-ZnSe nanostructures for opto-electronic applications. The synthesis of nanostructures through the hot injection method was studied in detail to optimize certain synthesis parameters such as injection temperature, precursor molar ratio and growth temperature. Nanostructures synthesized through the optimized parameters exhibited improved optical characteristics. The broad emission spectra from smaller CdSe quantum dots (QDs) were investigated and found that a layer of these QDs can function as a phosphor layer in white LEDs. The method of synthesis and purification were investigated to obtain tunable spectra of different colour properties such as chromaticity coordinates, CRI and colour temperature. A series of purification methods were adopted to suppress the surface defects present in smaller QDs and to improve their quantum yield. The quantum yield was found to be increased up to 9% after purification.

Using the optimized conditions, CdSe-ZnSe nanotetrapod and core-shell morphologies successfully synthesized through the facile hot injection method. The anisotropic crystal growth in CdSe QDs triggered by zinc precursor causes the nanotetrapod morphology and Hexadecylamine is found to be a better capping ligand for the synthesis of CdSe-ZnSe core-shell by restricting the anisotropic growth. The quantum yield of the core-shell is found to be improved in comparison with core only QDs. Nonlinear absorption coefficients of core-shell were investigated using open aperture Z-scan experiment and nonlinear absorption coefficients were calculated.

Investigations on Ternary Ge-Se-Sb Chalcogenide Glass - A Potential Composition for Mid IR Photonics and Sensing Applications

Under the supervision of

Prof. Sheenu Thomas and Prof. V P N Nampoori

Anupama V

Wide Infrared transparency, low phonon energy, high optical nonlinearity, high photosensitivity, compositional tunability, high refractive index etc makes chalcogenide glasses an impossible option to ignore in the field of photonics and optoelectronics. This thesis addresses the fabrication, characterisation and practical applications of selected chalcogenide glass compositions.

Three potential combinations of chalcogenide glasses Ge20Se70Sb10, Ge25Se65Sb10 and Ge30Se60Sb10 were prepared and characterized using XRD, SEM, UV-VIS-NIR, DSC, EDAX, FTIR, XPS analysis. Nanocolloids of various concentrations were prepared by dissolving finely powdered bulk glasses in Ethylenediamine. Variation of band gap energy with solute concentrations and concentration dependent photoluminescence of chalcogenide colloidal solutions were studied. Thermal diffusivity analysis of ChG nanocolloids were done using Thermal Lens technique. Methods for the preparation of amorphous nanowires from solution processed ChGs using EDA and EA were undertaken.

Study on the possibility of deploying Chalcogenide glass materials for developing planar biosensors based on SEIRA effect were carried out. For the development of biosensor, Ge25Se65Sb10 chalcogenide glass and gold nanoparticles based planar heterostructures were fabricated by thermal evaporation technique. Enhancements of infrared intensities of molecules which are adsorbed to the metal surfaces were studied using FTIR-ATR analysis. Solution processed Ge25Se65Sb10 chalcogenide glass materials were efficiently deployed for developing a temperature sensor with solution processed ChG infiltrated PCFs using ARROW guiding mechanism. Different hybrid PCF structures were fabricated using PCFs LMA 10 and LMA 20 and a maximum sensitivity of 1.1nm/0C has been observed.The preparation of silver doped bulk GeSeSbAg Chalcogenide glass and a thorough comparative study of its structural, thermal and optical properties with undoped GeSeSb samples were also discussed in this work. Z-scan technique is employed to investigate optical nonlinearities of solution processed chalcogenide glass. It was found that these chalcogenide glasses possess high nonlinear refractive index n2 and large third order susceptibility $\chi(3)$, which increases with solute concentration and with silver doping.

Modeling and Detection of Certain Flooding Based Denial-of-Service Attacks in Wireless Ad Hoc Networks

Under the supervision of

Prof. A Mujeeb

Nishanth N

Wireless Ad Hoc Networks comprise of easily deployable and self-organizing mobile nodes that do not require the support of a predefined infrastructure. These networks are widely useful in non-traditional applications like military battle field, disaster management, and Internet of Things (IoT) based applications. However, the lack of centralized management and the absence of secure boundaries made the network prone to various types of security attacks. Moreover, the mobile nodes used in these networks have limited computational capability, memory, and battery backup which create additional constraints for the design of security measures for these networks. For a network with large number of nodes, availability of the network is an important requirement which refers to the tolerance of the network during various attacks. The risk to availability is Denial-of-Service (DoS) attack and is aimed at total depletion of resources like memory and battery backup of the mobile nodes which could further bring down the entire network.

SYN flooding and Route Request (RREQ) flooding attacks are considered for the present study in which a modified version of Adaptive Threshold Algorithm (ATA) is developed for the detection of flooding attacks. The mathematical model for SYN/RREQ traffic in the network is developed using Bayesian Inference and proposed an optimum algorithm for the detection of persistent SYN/RREQ flooding attack using the developed mathematical model. The algorithm is again refined for the detection of high rate and low rate pulsed form of SYN/RREQ flooding attack using Dempster-Shafer (D-S) evidence theory. The modified algorithm considered additional sources of evidence like consecutive violations of packet drop statistics in addition to consecutive violations of normal statistics of SYN/RREQ traffic in order to detect pulsed form of attack. The developed algorithm ensures sufficient sleeping time for the mobile nodes which further ensures the efficient utilization of battery resources. The developed method successfully defends any type of flooding based DoS attack in Wireless Ad Hoc Network with lower communication, computation and memory overhead.

The thesis also considered the modeling of DoS attacker traceback in Wireless Ad Hoc Network using Traffic History database. The presence of attack history database has identified the attack zone which in turn enabled to locate the attacker in an earlier stage without creating higher casualties in the network. The thesis is concluded by summarizing the major results from all the chapters and also highlights some of the future prospects.

Jessy Simon

Synthesis and optical characterization of certain metallic and bimetallic nanoparticles for biophotonic applications

Under the supervision of

Prof. M. Kailasnath and Prof. V P N Nampoori

Metal nanoparticles offer unique optical properties like surface plasmon resonance which make them suitable candidates for applications in nanotechnology. Control of size, shape, composition, structure, encapsulation, assembly and optical properties add to the advantages of metal nanoparticles. They can be synthesized by physical, chemical and biological methods. Gold and silver nanoparticles are the most widely studied owing to their specific applications. Bimetallic nanoparticles are composed of two different metals and offer enhanced optical, electrical, photothermal and biological properties compared to their monomeric counterparts. Parameters like shape, size, size distribution, surface functionalization, crystallographic nature, knowledge about the elemental composition and internal distribution of the individual elements are necessary for characterizing the bimetallic nanoparticles.

Metal nanoparticles like gold, silver and their bimetallic counterparts are extensively used in biological applications like cancer treatment, drug delivery and targeting, photothermal therapy and disease diagnosis. Conjugation of metal nanoparticles with biomolecular entities enhances the stability of the complex and results in better targeting of the drugs to the disease affected regions or cells. Today, one of the major challenges faced by the biomedical field is the emergence of a large number of novel diseases caused due to the bacterial activity and bacterial biofilm which are resistant to common antibiotics. It is at this point the development of newer, highly effective and cheaper antimicrobial agents that can fight these diseases attains vital importance.

The thesis describes the synthesis of metal nanoparticles like gold, silver and their bimetallic combination in various size, shape and composition using chemical reduction and laser ablation techniques. Interaction of the synthesized metal nanoparticles with biomolecules like proteins is also investigated. Linear and non-linear optical as well as thermal properties of the synthesized metallic, bimetallic and metal-bioconjugates are studied. The results suggest the potential application of the synthesized nanoparticles in biological sensing. Antibacterial and anti-biofilm studies of the synthesized nanoparticles against various Gram positive and Gram negative bacteria provide insight into their controlling factors and tunability.

Germanium Based Chalcogenide Glasses for Photonic Applications.

Under the supervision of

Prof. Sheenu Thomas

Musfir P N

Recent research developments in the Photonics industry demand new materials with high linear and nonlinear refractive indices having tunable properties. Chalcogenide glasses (main constituents being group 16 elements) exhibit outstanding properties such as wide optical transmission from visible to the far-infrared region of spectra, high refractive index, low phonon energies and high optical nonlinearity (over 100 times greater than the Silica glass). A better engineering tunability is possible with ternary/quaternary glasses which allows a large variety of atoms to be incorporated into the glass structure. For the present study stable glasses (Ge25Sb10S65, Ge20Ga5Sb10S65 and Ge20Ga5Sb10Se65) were prepared in bulk, thin-film, and nano colloidal form using melt-quenching, vacuum deposition, solution casting and other common techniques.

Our aim was to find chalcogenide materials that are both environment friendly and that which exhibit high optical nonlinearities. The prepared samples are thoroughly characterised by various methods. It is observed that as the sample changes from bulk to thin film and to nano colloids, the optical band gap increases and the value of linear refractive index decreases. The nonlinear refractive index calculated theoretically for the prepared thin films are found to be 100 times greater than the conventional silica glass. The quaternary Sulphur and Selenium based thin film samples show saturable absorption (SA) behavior whereas the ternary sample and all nano colloids show reverse saturable absorption (RSA) behavior. The RSA materials could be employed for protecting sensitive devices from high intense radiations. Saturable Absorbers are helpful for nonlinear filtering outside laser resonators which can clean up pulse shapes.

The thermal diffusivity of thin films studied are found to be one order lower than corresponding nano colloids which can be utilized for thermal insulator applications. The quaternary Selenium based glass possess low Tg, Eg and high value of refractive index. The 3rd order nonlinear susceptibility and nonlinear refractive index of Se based glasses are higher as compared to S based one. The low thermal diffusivity values of Se based glasses are attributed to high effective electron concentrations. These properties make Se based quaternary chalcogenide glasses potential candidates for Photonic applications.

Studies on Carbon dots and carbon dots decorated graphene oxide for nonlinear optical applications

Under the supervision of

Prof. Sheenu Thomas and Prof. V.P.N. Nampoori

Vijesh K R

In the last couple of years, carbon dots have emerged as a novel luminescent nanoparticle for applications in sensing, bioimaging, nanomedicine, catalysis, optoelectronics, and energy storage. The accidental discovery of fluorescent carbon nanoparticles takes much attention due to their high photoluminescence, biocompatible composition, and straightforward synthesis. Green synthesis with mild reaction conditions and non-toxic precursors promote carbon dots as the new sustainable material for optical applications.

In this work we have investigated the unexplored nonlinear optical behaviour of the carbon dots as well as carbon dots decorated with graphene oxide for thermal insulator, optical limiting, white light emission and optical switching applications. High quality carbon dots were prepared using simple microwave assisted pyrolysis using citric acid anhydrous as the precursor and ethylenediamine as the passivation agents. The highly sensitive dual-beam thermal lens studies show that the carbon dots behave like a thermal insulator. The thermal insulating properties of the sample are seen to enhance with the addition of DNA. A novel technique to synthesise highly fluorescent carbon dots decorated graphene oxide (CDs-GO) samples was resorted and the third-order nonlinear optical properties were studied. The optical limiting properties of these nanomaterials yield a low limiting threshold, enabling them to be strong candidates for optical limiting devices. A unique CDs-GO/Pyrromethene597 dye composite was effectively synthesised and the photoluminescence emission from the composite is found to cover the whole white light spectrum. Enhanced nonlinear optical properties of solution dispersed CDs-GO samples were observed with varying viscosity. Detailed nonlinear studies were carried out using spatial self-phase modulation and Z-scan techniques. We observed multi colour emission from phloroglucinol-derived carbon dots with different surface passivation. Tuning the emission spectra from ultraviolet to visible spectra is achieved by varying surface passivation. All-optical switching and OR gate realisation is achieved from the sample by using spatial cross-phase modulation. The present work showcases that the sample is highly beneficial for different optical devices like thermal insulator, optical limiter, white light emitting diode and all-optical switch.

Our New Faculty Members

Dr. Praveen C S

Dr. Praveen C S completed his Masters degree in Physics (Specialization in Applied Electronics) from the Department of Physics, Karyavattom Campus, at the University of Kerala. PhD from the Materials Research Laboratory at the University of Nova Gorica, Slovenia in Physics for developing materials for Photocatalytic Water-splitting applications. He was a Postdoctoral Fellow at the Condensed Matter Physics group of CNR-IOM hosted at SISSA, Trieste, Italy, wherein he worked mainly on 2D materials. Later he moved to ETH Zurich and worked initially at the Nanoscale Simulations group and later at the Laboratory of Inorganic Chemistry, ETH Zurich, Switzerland. During his assignment at ETH he has been working mainly on heterogenous catalysis.He joined International School of Photonics as a DST-INSPIRE Faculty Fellow in October 2018 and has been appointed as an Assistant Professor at International School of Photonics in March 2021.

Area of Resrearch : Electronic Structure of Bulk and 2D materials and their functionalization, Homogenous and Heterogenous catalysis , Materials for battery applications, and developing various functional materials.

Dr. Mohamed Ameen joined the International School of Photonics as Assistant Professor in 2021. He obtained a PhD from the University of the Basque Country, San Sebastian, Spain in 2015 for the studies on the optical response of several materials with an aim of optimising them for controlling light-matter interaction at nanoscale. During this period Ameen worked in Donostia International Physics center and Center for Materials Physics at San Sebastian, Spain. After the PhD, Ameen worked as Assistant Professor at SRM University, Kattankulathur, Chennai.

Dr. Mohamed Ameen P

Area of Resrearch : Theoretical modelling of the optical response of nanostructures and light-matter interaction at nanoscale.

Newcomers

PhD Scholar	Area of Research	Guide
K P Muhammad Rishad	Metamaterials	Prof. (Dr.) Mujeeb A
Athira T Das	Laser Propagation	Prof. (Dr.) Pramod Gopinath
Arun Pappacahan	Metamaterials	Prof. (Dr.) Sheenu Thomas
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Interdisciplinary Applications of Thermo Optic effect with special reference to Thermal Lens Spectroscopy

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1. Introduction

As Oscar Wilde puts it "light is the messenger of the Universe". Light and light related phenomena are responsible for important turning points in the forward march of human progress and civilization. Invention of fire, invention of electric bulb, theories and experiments described by Newton and Huygens, description of solar spectrum by Fraunhofer, Planck's theory of energy quantization and explanation of black body spectrum, Einstein's theory of relativity and his theory of light quanta and photoelectric effect, Bohr's theory of hydrogen spectrum, Einstein's theory of spontaneous and stimulated emission of radiation, development of quantum mechanics, invention of optical fibre, invention of Maser and Laser, development of nonlinear optics and related phenomena, discovery of gravitational waves and their detection are some of the prominent peaks in the wide range of light related developments.

One of the major achievements in the field of science and technology during the second half of the twentieth century was the invention of lasers in 1960. Laser, which generates coherent, monochromatic, intense and directional light beams, is the dream source of spectroscopists and optical scientists. Initial phase of laser research, known as the period of solution in search of a problem, has triggered a number of advancements in almost all fields of human knowledge and activities - Physics, Chemistry, Biology, Archeology, Geology, Medicine, Entertainment and Consumer devices and the list expands day by day.

Invention of various type of Lasers gave birth to another revolution in the field of Communication and Information Technology. Capabilities of photons to compute, to transmit information and to get guided through optical fibre have opened up a new branch of technology, the technology of the 21st century called Photonics. Photo thermal spectroscopy and its applications form an important part of photonics. Intersections of Photonics with other branches of knowledge have resulted into new interdisciplinary fields of studies as shown in Fig. 1. The capabilities of optics based computers in high speed parallel processing and in ultrahigh dense connectivity have made Photonics an integral part of the fifth level computers, which fuses IT with logical processing. Breakthrough in optical computing was possible due to the development of Non Linear Optics (NLO) that made lasers a wonderful source of light. Hence, synthesis and characterization of NLO materials form an integral part of Photonics based research. There exist a number of techniques to characterize optical and thermal properties of materials of which the Thermo-Optic method is one of the prominent one.

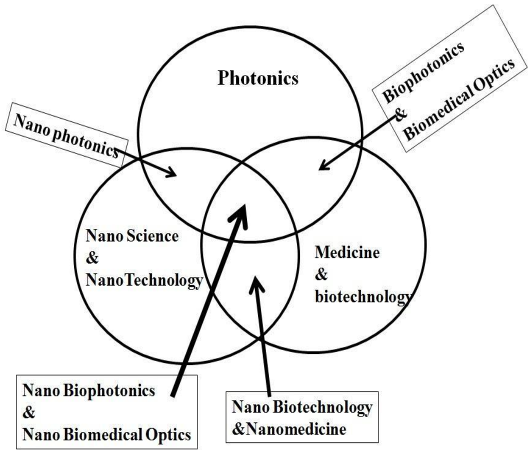

Fig.1

The entire process of nonradiative relaxations involved in light – matter interactions were not directly monitored in conventional spectroscopic techniques due to the fact that during this process heat energy is produced instead of light energy.

During the second half of the twentieth century, advances in theoretical and experimental studies related to light matter interactions, novel techniques based on photo acoustic (PA) effect , photo thermal deflection (PTD) effect and laser induced thermal lens (TL) effect were developed to monitor non radiative relaxations of atoms and molecules. These are the techniques in which the detection and monitoring of the phenomenon are followed without the conventional light detection spectroscopy apart from another procedure called optogalvanic spectroscopy (OGS). This article outlines theory, experiment and applications of PTD and PTL spectroscopy. It was the inventions of various types of lasers and developments in detection techniques that made possible the emergence of spectroscopy based on effects like OG, PA, PTD and PTL.
Developments of nanoscience and nanotechnologies have enhanced the utility of thermo optic techniques as efficient tools in interdisciplinary research. Use of PTD and PTL techniques to study the science, technology and applications of nano materials will also be described in following sections.

2. Physics of Photo-thermal effects

Light – matter interaction is one of the oldest branches of studies and research starting from Newton (discovery of light dispersion) expanded by Fraunhoffer, Kirchoff, raised to new heights by Bohr & Sommerfeld following Einstein discussing two types of light matter interactions namely spontaneous and stimulated emission of radiation and later on by Quantum Mechanical descriptions by Heisenberg, Schrodinger and Dirac. When atoms or molecules are excited to higher energy levels through optical excitations they get relaxed back to the ground states through radiative and nonradiative de-excitation processes. In the case of radiative relaxations, the monitoring of excitation and deexcitation processes are monitored using light detection techniques as is the procedure followed in the conventional spectroscopic techniques from the time of Newton till the first half of the twentieth century. The entire process of nonradiative relaxations were not directly monitored due to the fact that during this process heat energy is produced instead of light energy. It should be noted that the OG effect is the rediscovery of the Joshi effect discovered by S. S. Joshi of Banaras Hindu University, India. Joshi observed fluctuations in the discharge current for a variety of atomic and molecular vapours in a discharge tube (Nature155,1945,483; Curr Sc.8,1939,548). In the case of Photo acoustic and OG spectroscopy even the output signals are obtained through non-photo detectors like microphone (for PAS) and impedance analyser (for OGS).

When the energy of radiation matches with that of a transition between the ground state and an excited state of the molecule a photon is absorbed. The excited molecule can eventually return to the ground state by radiative or nonradiative transition as illustrated in the figure. The nonradiative de-excitation causes local heating in the sample along the beam path. The heating results in the creation of a refractive index gradient which, based on the geometry, causes either thermal lens effect or photo-thermal beam deflection in the medium. In the case of Photo acoustic and OG spectroscopy the output signals are obtained through non-photo detectors like microphone (for PAS) and impedance analyser (for OGS). For example using a specially designed PAS cell, Ravikumar et al (Pramana 63,1989, L621) recorded two photon absorption spectrum in gas phase formaldehyde using pulsed dye laser as the pump source Sasikumar et al. observed chaotic oscillation and Hopf bifurcation in photoemission optogalvanic spectrum and recorded rotational fine structure of nitrogen gas using OG technique (Phys Lett A198(1994)191, Pramana 42, 1994, 231).

3.1 Photo-thermal deflection spectroscopy (PTDS) : Out Line of the Theory

Light beam deflection by thermally induced changes on the surface of materials causes refractive index variation in the medium like air that is in contact with the material surface, causing deflection of the incident light. This is similar to the well known phenomenon called mirage effect experienced in deserts or in highway roads
Mirage is the oldest thermo-optic phenomenon known to us. During the second half of the twentieth century, mirage effect has been made use of to study optical and thermal properties of materials and the coupling media. Nonradiative de-excitations of atoms and molecules on the surface of materials using a high power laser beam (pump beam) will generate heat which will be transferred to the adjacent medium that is in close contact with the surface. This causes refractive index variation in the coupling medium like air in a direction normal to the surface. A low power laser beam (probe beam) just skims over the surface normal to the pump beam, and will experience deflection normal to the surface. Magnitude of the beam deflection depends on the power of the pump beam, the optical absorption coefficient of the material and thermal diffusivity of the coupling medium.

By monitoring the magnitude of the beam deflection using a position sensitive detector, one can record the photothermal deflection (PTD) spectrum of the material by changing the wavelength of the pump laser beam. The amount of thermal energy transferred to the coupling medium will depend on the absorption coefficient of the material as well as the thermal diffusivity of the coupling medium. In other words, photothermal deflection spectroscopy will provide the same information as that of the conventional optical absorption spectroscopy together with thermal property of the medium as a bonus.

Depending on the magnitude of the refractive index gradient, the probe beam will experience deviation and the angle of deviation can be measured by using a position sensitive detector or by standardizing the intensity variation of the probe beam using a sensitive photo detector like photomultiplier tube. . Transfer of heat to the coupling medium from the sample surface, generated due to the pump beam, will make the coupling medium optically inhomogeneous and laser beam propagation through the spatially varying refractive index can be represented by the equation

$$\frac{d}{ds}\left(n_0 \frac{dr_0}{ds}\right) = \nabla_\perp n(r,t)$$

where, r_0 is the perpendicular displacement of the probe beam from its initial position and n_0 is the uniform refractive index of the medium prior to the generation of thermal gradient in the medium, on integrating equation over the path length s we get beam deflection angle.

3.2 Thermal Lens Spectroscopy (PTLS): Theory

Consider a laser beam with circular cross section having Gaussian distribution of intensity so that the intensity along the beam axis is maximum and goes on decreasing away from the beam axis. When atoms or molecules absorb radiation and get into a higher excited state, they de-excite to their respective ground states through radiative or non radiative relaxations. Radiative relaxations cause fluorescence emission while non radiative relaxation generates heat energy causing a rise in temperature in the medium. Hence, the medium along the beam axis will have maximum temperature which goes on decreasing away from the beam axis. Thus, we can write temperature distribution of the medium along the circular cross section of the laser beam as a Gaussian function with maximum value along the beam axis causing temperature dependence of the refractive index of the medium as $\frac{dn}{dT} = \frac{\partial n}{\partial r}\frac{\partial r}{\partial T} + \frac{\partial n}{\partial T}$ Since the temperature of the medium decreases away from the beam axis, causing a corresponding increase in refractive index of the medium away from the beam axis. Temperature distribution as a function of radius and time when the source of heat is a beam of radius w_0 will be $T = T_0 e^{-t/t_c}$ where tc is the characteristic response time for the stabilization of temperature variation in the medium. The response time will depend on the beam radius and thermal diffusivity of the medium and is given as $t_c = \frac{w_0^2}{4D}$ where D is

the thermal diffusivity of the medium which is given as $D = \frac{k}{\rho c}$ with k = thermal conductivity of the medium (calories/cm sec. K), ρ=density (g/cm³), c= specific heat of the medium (calories/g K).

Due to the temperature distribution as described by the above equation, the medium will have refractive index variation causing it to behave like a diverging lens and is called thermal lens (TL). Optical path length of the beam inside the medium (eg. Glass) can be changed either by increasing or decreasing the thickness of the glass plate from the centre to the rim. In the case of a usual glass lens, the thickness is varied while the refractive index is constant while in the case of thermal lens thickness is kept constant (thickness of the cell) with refractive index continuously increasing from the beam center to the edges of the cell so that the liquid in the cell will behave like a diverging lens with a focal length depending on the beam spot size, thickness of the cell and change in the refractive index.

The effect of the TL can be observed as the continuous expansion of the laser beam cross-section. The beam spot size as a circle of time dependent spot size w(t) which will stabilize as t tends to infinity with time constant $t_c = \frac{w_0^2}{4D}$

and thus by knowing the time constant of the temporal variation of TL development, and the laser beam spot size, we can calculate thermal diffusivity D of the medium which is an important thermal parameter of the medium with valuable applications.

Optical absorption coefficient is the parameter which describes the strength of light – matter interaction. By monitoring input and output intensities of the laser beam one can evaluate optical absorption coefficient. If α is the absorption coefficient of the medium at laser wavelength λ, we write

$$I(x,y,l) = I(x,y,0)e^{-\alpha l}$$
$$or$$
$$I(l) = I(0)e^{-\alpha l}$$

where *l* is the optical path

length in cm, α is the absorption coefficient or absorptivity of the medium, so that for small values of absorption coefficient and path length, the total absorbance will be

$$I(0) - I(l) = I_0 - I_0 e^{-\alpha l} = I_0(1 - e^{-\beta l}) \approx I_0 \alpha l$$

From the above equation called Lambert Beer equation, we can calculate the absorption coefficient of the medium. If the medium is a solution of absorbing species with concentration c, then the Lambert Beer equation will be modified to $I(0) - I(l) = \Delta I = I_0 \alpha c l$ and is useful for trace analysis in absorbing media. Detailed theoretical analysis provides the expression for the focal length of thermal lens as

$$\frac{1}{F} = \frac{P_{abs}\left(\frac{dn}{dt}\right)l}{\pi k w^2\left(1 + \frac{t_c}{2t}\right)} \quad where\ t_c = w^2/4D = \frac{w^2 \rho c}{4K}$$

For small values of 'αl'. with ρ = density of the medium (g/cm³) and c = specific heat of the medium (J/g⁰c) power absorbed by the liquid is P α I. The TL strength builds up from zero at t=0 to the steady state value as t-->∞ from which we can calculate TL response time tc and hence the values of thermal diffusivity and thermal conductivity of the medium using the expressions given above. In the experimental procedure there are two methods to investigate TL spectroscopy namely, single beam and dual beam TL techniques. Thus by studying thermal lens response of the medium we can evaluate thermal diffusivity and optical absorption coefficient which are important parameters in light – matter interactions.

Photothermal deflection or mirage technique is employed to characterize solids and liquids so as to get the direct knowledge of one of the important thermal parameters namely thermal diffusivity of materials as well as an alternate technique to study phase transitions in solids. Thermal diffusivity is an important parameter since it describes how far thermal energy will diffuse into the materials as well as from what depth of the material the thermal wave originates. The point of generation of photothermal signal inside the materials depends on the penetration depth of light into the material. This knowledge has applications in analyzing subsurface images of a solid.

4. Detection of phase transitions in solids using PTD effect

Rajasree et al. (Materials Lett 36, 1998, 76) made use of the mirage effect to detect phase transitions in solids. As the thermal properties of the sample undergo drastic variation at the phase transition temperature, phase transition is bound to affect the deflection signal in a measurable way due to the consequent changes produced in the refractive index gradient (RIG). Near the transition temperature, wide fluctuations in the signal are observed which is the usual critical fluctuations observed near the phase transition temperature. Soumya et al (Eur J Phys.136 ,2021, 187) discovered that more than 50% reduction in thermal diffusivity values in MoO_3 films with respect to the bulk form by annealing the thin film to 450^0 C due to phase transformation from monoclinic to Rhombohedral form in molybdenum oxide films. They also found a similar reduction in the values of thermal diffusivity in molybdenum film consisting of nanowires (Opt.Laser Tech.139 ,2021, 106993).

George et al. (Apply Phys B 77 ,2003, 633) used PTD effect to determine thermal parameters of InP doped with Sn, S and Fe as well as intrinsic InP. They found that thermal diffusivity values depend on the doping concentration. This method can be used to tune the thermal diffusivity values by using appropriate concentrations of the dopants. Photothermal beam deflection effect using pump–probe method, was applied by George et al. to investigate the effect of impurity densities on the effective thermal diffusivity of thin epitaxial layers of GaAs grown on semi insulating GaAs substrates (Phys Rev B68 ,2003, 16539).

Swapna and Sankararaman (J. Biomed. Opt. 22 ,2017, 068001) studied the diffusion of drugs into water and found that the diffusion rate increases linearly with the concentration of drugs within a range of drug dosage In their experiment, they set up a liquid medium with layers of different solution concentration below and above the correct dosage, the linearity of the variation as a function of time is lost and the diffusion coefficient becomes very small, thereby reducing the diffusion efficiency of the drug so that the recovery from illness will be slow. Thus doctors will have to prescribe the dosage of the drugs so as to fall within the linear range of the diffusivity plot.

5. Experimental Techniques for TLS

There are two modes of experimental techniques to investigate thermal lens effect, namely, single beam and dual beam experimental setup. In the single beam setup the pump beam is used both to generate refractive index variation and to probe beam divergence and the resulting thermal lens effect. The single beam setup can be used to measure thermal diffusivity of the medium which is an important thermal parameter of the material for practical applications. However, this setup cannot be used to investigate thermal lens spectra, In the dual beam setup, the thermal lens effect is probed by a low power laser beam with wavelength far away removed from the resonant absorptions of the medium. Thus, the probe beam will not perturb the refractive index variations in the medium, and will provide TL spectra and accurate results for the optical and thermal parameters of the medium. The pump beam is focused into the liquid sample in a cell using a long focal length converging lens so that the beam is converging type before the focal point and diverging type after the focal point. Thermal lens effect will result in additional divergence beyond the focal point causing enhancement in the beam spot size at far field point. One can measure this beam spot size and can calculate the focal length of the thermal lens generated in the medium. Stronger the thermal lens effect shorter will be the focal length causing larger beam spot size.

Because of the divergence, the beam intensity will be diminished at the beam-spot centre. Thus, in order to study the TL effect one need not calculate the focal length but just monitor the variation in the intensity at the beam centre Ibc using an appropriate photo detector. For this a pin hole is placed at the centre of the beam spot in front of the photodetector. One can monitor the variation of light intensity at the beam centre as a function of time so as to get the information about the variation of beam spot from t= 0 to the time at the stabilization of beam spot size (t-->∞) . From the time evolution of the thermal lens formation, one can calculate the thermal lens response time and hence the value of thermal diffusivity and thermal conductivity of the medium. Figures show the nature of the time response of TL signal.

In the case of CW pump laser source, modulation of the beam intensity is achieved by making use of a mechanical chopper and detection is made using lock-in amplifier and high frequency storage oscilloscope. Pulsed thermal lens technique using a pulsed laser as the pump source has allowed a number of spectroscopic applications involving the study of radiationless de-excitation processes. The high irradiance at the focal point can induce nonlinear optical absorption effects in the medium. Thus, the absorbed energy is proportional to the integrated irradiance raised to the power of the number of photons absorbed. The dual-beam technique is more advantageous since only a single wavelength, related to that of the probe beam, is always detected irrespective of the wavelength of the pump beam, and there is no need for correction for the spectral response of the optical elements and detector. Moreover, the dual beam TL setup can be used to record TL spectrum unlike in the case of single beam setup.

6. Applications of Photo-thermal Lens Spectroscopy

Soon after the discovery of thermal lens effect in liquids by Gordon et al.(J. Appl Phys36 (1965)3) several researchers started to apply the newly available technique to monitor non radiative de-excitations of excited atoms and molecules to lower states. Majority of works in the literature were related to extracting spectroscopic information like vibrational overtone spectra of molecules (Abdul Rasheed et al. Pramana, 33, 1989, 391), estimation of absolute quantum efficiency of fluorescent materials and evaluation of thermal parameters like thermal diffusivity and thermal conductivity of liquids (Bindu et al Opt Engg 37,1998,2791.) . Some of the works reported are related to the use of TL effect in realizing logic gates (Achamma Kurian et al. Laser Chem. 20, 2002,705925) and Bessel like optical beam (Santhi et al. J Opt Soc Am.B27,2010,1361).

During the 21st century, researchers all over the world started to use TL techniques for many interdisciplinary applications. Reports started coming out from several laboratories on the use of TL effect and associated techniques in diverse fields like medicine and health sciences, green pathways to develop materials for various applications, spatial phase modulation and its use to understand nonlinear optical property of liquids and designing of all optical diode (Vijesh et al, Optik, 248,2021, 168049), time series analysis of TL signals to investigate molecular dynamics in liquids (Swapana et al Int J Thermo Phys., 41,2020,93), graph theoretical applications of time series extracted from thermal lens (Sankararaman et al. Appl .Opt. 60,2021,6409) etc. There are reports in which the TL effect along with other techniques like Raman scattering can be used as a tool to study different pathological conditions. Such works find importance during this time of the global pandemic condition and some of such works are adapted to the archives of the WHO library

The progress in science and technology of nano materials have opened up another window of interdisciplinary applications of TL effect since material properties at nanoscale depend on the size of the nano materials. One can have some useful applications of TL effect at nanoscale in finding new effects in material properties. In the following sections we will include some of the representative works in this direction also. In this section we review some of the works reported in the literature including those which are of interdisciplinary nature of TL spectroscopy.

Determination of Fluorescence quantum efficiency using TLS

Knowledge of fluorescence quantum yield (FQY) is an important parameter in choosing fluorescing materials for photonic applications. Conventional method of the evaluation of FQY is to compare the fluorescence efficiency of materials with that of standard materials like rhodamine 6G. Advancement in TLS has provided us with a tool to evaluate the absolute value of FQY.

Fluorescence efficiency of a material depends on its radiative and nonradiative de-excitation cross-sections. The limitation of the conventional method is that it cannot provide first hand knowledge of non radiative relaxation cross-section unlike in the case of thermo-optic techniques. Basic principle of the evaluation of FQY is that the fluorescence emission and non-radiative relaxation processes are complementary to each other.

It is well known that the fluorescence emission intensity of the solution of a fluorescing solute shows a quenching effect in the fluorescence emission intensity above a certain concentration, thereby increasing the probability of non radiative relaxation process, a phenomenon called concentration quenching. At a critical concentration, emission is completely quenched and one can safely assume that the absorbed radiation is completely contributing to the non radiative de-excitation, causing an enhancement of the temperature in the medium and its saturation above the critical concentration. Plotting graphs of concentration dependent fluorescence emission intensity and that of the strength of photothermal signal strength, we can evaluate FQY of the solution at various concentrations.

Determination of Thermal diffusivity using TLS

The refractive index variation in the medium, generated due to the pump beam can be probed by a second beam called probe beam wavelength of which is far away from the absorption region of the medium. Variation of the power at the beam centre of the probe beam (Ibc) can be measured using a photo detector in the far field and monitoring the intensity variation with time till the intensity at the beam centre becomes steady. Thus, the experimental data will be the values of intensity at the beam centre as a function of time till the intensity becomes steady, ie., from Ibc (t=0) to Ibc Ibc(t-->∞). The plot of the data as a function of time will be of exponential form proportional to $e^{-\frac{t}{t_c}}$. The slope of the plot 'ln (lbc(t))' as a function of time t will provide the value 1/tc which will be equal to $4D/w^2$ where tc is the thermal lens response time, D is the thermal diffusivity of the medium, and w is the beam spot size. Hence, by measuring the beam spot size w, we can evaluate D from which thermal conductivity k can be calculated. The knowledge of D will help us in using the medium to design devices for various practical applications.

Energy transfer mechanisms in fluorescing liquid mixtures

An interesting case may be considered when the solution contains two different types of molecules A and B such that A has a resonant optical absorption at frequency ν and the resulting fluorescence emission from A is absorbed by B, which emits its characteristic fluorescence in a higher wavelength range. This type of energy transfer (ET) quenches the fluorescence emission from one class of molecules (donor), and sensitizes the fluorescence emission from the other class called acceptor. This mechanism of ET may enhance the range of the emission spectrum to the whole of visible and near infrared regions. This process is useful in identifying laser media to increase the working range of spectral output of a laser device.

Kurien et al.(Spect.Chim.Acta A59,2003,487) recorded and analyzed thermal lens spectra of organic dyes using dual-beam TL technique They studied TL techniques to investigate the effect of pH values on electronic energy transfer in organic dye mixtures (Spect.Chim.Acta A61,2005,2794).

Dual-beam thermal lens technique is an effective method to evaluate fluorescence quantum yield and photo degradation characteristics of laser dyes (Laser Chem.,20,2002,99). Bindhu et al.(Opt Engg. 37,1998,2791 measured and tabulated thermal diffusivity of different organic liquids using pulsed dual-beam TL techniques. Thermal diffusivity of liquids is an important parameter for various thermal engineering applications. Kurien et al. have employed dual-beam thermal lens technique to study energy transfer processes in organic dye mixtures, and have evaluated the critical molecular distance $R_0(A^0) = \frac{7.35}{(C_0)^{1/3}}$ between donor and acceptor molecules where C0 is the critical concentration at which the ET is 50% efficient (the donor fluorescence is half quenched), and evaluated absolute fluorescence quantum yields of laser dyes (Mod.Phys.Lett.B13,1999,563) .

Dual-beam photothermal lens spectroscopic technique can be used to study overtone spectra of large molecules due to the highly sensitive character of the technique. For example Abdul Rasheed et al. (Pramana,33,1989,391) made use of TLS technique to detect sixth overtone spectra of styrene and polystyrene. They also studied the CH local mode excitations in trichloro-ethylene and have detected Fermi resonance between pure overtone and stretch-bend combination state (J.Phys. Chem.,91,1987,4228).

7. Spatial Self Phase modulation (SSPM)

Study of optical non linearity of a medium, using the new technique of spatial self phase modulation (SSPM), was made by Wu et al.(Nano Lett.11, (2011) 5159-5164) Vijesh et al. employed SSPM and Z-scan techniques to study nonlinear optical response of solution dispersed with carbon-dot decorated graphene oxide (Opt.Laser Tech.,121,2020,105776). They observed enhanced nonlinearities with increase in input pump power and viscosity of solvents. This change in the optical path length across the beam spot generates spatial self phase modulation (SSPM). If the phase difference between two points on the observation screen is mπ, m being an even or odd integer, constructive or destructive interference occurs resulting in the ring diffraction pattern on the observation screen.

Refractive index variation in the medium due to interaction between the pump laser beam and the medium, produces thermo-optic coefficients resulting in spatially distributed self phase modulation. This spatial distribution of self phase modulation (SSPM) is similar to self phase modulation in electronic signal processing in the time domain. SSPM is a coherent 3rd order nonlinear optical effect due to optical field induced local refractive index changes. The phase of the output beam depends on the input intensity .Variation of refractive index creates a phase shift in the far field diffraction pattern. This phenomenon has been used by Wu et al to study nonlinear optical effects in condensed matter. Following the work of Wu et al. , $\chi(3)$ can be calculated by observing the number of rings as a function of laser intensity I using the equation $\chi^{(3)} = \frac{c\lambda n_0}{2.4\times10^4\pi^2 l}\frac{dN}{dI}$

with N as the number of rings, I is the input intensity of the excitation, λ is wavelength, n_0 is the refractive index of the medium and *l* is the length of the cell.

8. TLS in Nanoscience and Nanotechnology

Many researchers have applied PTLS in the field of nanoscience and nanotechnology. One of the important branches of such studies is green synthesis of nanomaterials. In the following paragraphs we describe some of the representative works in this field. Swapna and Sankararaman synthesized sodium carbide from the leaves of Aloe Vera (Int. J. ThermoPhys. 41 , 2020, 93). They describe how sodium carbide based nanofluid exhibits enhanced thermal diffusivity values for the base fluid which suggests the nanofluid applications in heat transfer applications. Fathima and Mujeeb studied the tailoring of thermo-optical properties of eosin B dye using surfactant free gold-silver alloy nanoparticles , (Spect. Chim. Acta. A 228, 2020,117713). They were able to quantify composition dependent changes in thermo-optical properties of eosin B- nanoparticle system Remya et al. (Appl. Phys. B,125, 2019 181) observed increase in thermal diffusivity values as a function of both particle size as well as concentration in ZnO nanofluids using dual beam TL technique. Jancy et al.(J. Molec. Liquids. 279 , 2019, 63) discussed biosynthesis of copper nanoparticles using mimosa pudica leaf extracts as reducing and stabilizing agent and its application in the study of third order optical nonlinear coefficient and thermo-optical properties of copper nanoparticle colloidal solution using Z-scan and dual-beam TL technique. Sony et al. (J. Luminesc. 194 ,2018, 428) employed TL technique along with fluorescence lifetime measurements for monitoring viscosity of samples using styryl 7 dye in different solvent and with DNA-CTMA complex . Nideep et al. studied thermal-diffusivity of CdTe colloidal quantum dot samples using TL technique and found that the water based colloidal solution of CdTe quantum dots is less than that of water and that the colloid can act as a good thermal insulator (Physica E: Low dimensional systems and nanostructures, 116 ,2020, 113724) Pathrose et al. (Spect.Chim.Acta, A128,2014,522) prepared basic fuchsin dye solution incorporating silver sol and using femtosecond laser ablation to evaluate absolute FQY of the dye- silver sol mixture solution using TL method.

9. The Variety of Interdisciplinary Applications of Photothermal Spectroscopy

During the second half of the 20th century the theoretical and experimental works in respect of PTLS resulted in one of the powerful techniques for interdisciplinary applications in diverse fields like photonics, bio-photonics, image processing, quantum biology, environmental science, biology and agriculture, Chaos, health sciences etc . In the following paragraphs we briefly describe some of the salient works on TLS as applied to interdisciplinary fields. Kurien et al. have worked on optical logic gates using low power CW Lasers as the pump source to design logical functions such as XOR and NAND (Laser Chem.,20,2002,705925). Santhi et al. employed TL technique to generate Bessel beams and to realize fast all optical switching in gold nano sol prepared by pulsed laser ablation (J.Opt.Soc.Am.B35,2018,1661) . Hussain Ali Badran demonstrated TL based all optical switching effects with low background and high stability (Res. Phys.,4,2014,69).

One of the most important works in the interdisciplinary applications of TLS is the use of graph theoretical approach by Sankararaman (Phys.Fluids,33,2021,07710) to separate transient thermal lens signals into correlated and uncorrelated segments. He has shown how Graph Theory can pinpoint the time when the transition occurs from correlated to uncorrelated signals . This work is a seminal one in the field of heat flow analysis in thermal engineering. Swapna et al. (J.Opt.Soc.Am.B35,2018,1662) used thermal lens analysis of drugs during pre formulation study which is an important study since temperature variations can induce structural changes of constituents of drugs which sometimes may become fatal. They found that the concentration of a drug in liquid form decides its thermal stability which can be monitored by the variation of thermal diffusivity with concentration. Thus it provides information about the optimum value for the concentration of drugs for which the thermal stability is high. For example, the terbutaline will be thermally stable above 60% concentration. Raj et al.(Mat. Res.Exp.,5,2018,155504) carried out TL based studies to evaluate heat trap mechanisms of coconut oil with repeated heating, and it was found that thermal diffusivity values fall by about 74% of its initial values on cooling. Thus the oil gets denatured which may adversely affect health.

The time series analysis has been used to investigate the complex molecular dynamics involved in thermal lens systems by variation of duty cycle. Raj et al. (Optik,212,2020, 164720) studied molecular dynamics by making use of fractal dimension, phase portraits, sample entropy and Hurst exponent for different duty cycles. It is found that as the duty cycle value increases, fractal dimension and sample entropy values indicate that molecular dynamics becomes more complex and less deterministic. Swapna et al (Chaos,30,2020,073116) used time series analysis of TL signals for the chaotic dynamics involved in carbon allotropic nanofluids, and observed a lowering of sample entropy and thermal diffusivity which improves the efficiency of the thermal system.

Goswami and co-workers have conducted many interesting experiments with thermal-lens spectroscopy to investigate intermolecular interactions, even with a femto second laser as the excitation source (J Mol. Liq. 336, 2021,116322) .Dual-beam pump probe thermal lens spectroscopic technique has been employed to investigate heat dissipation in binary mixtures of liquids involving methanol and polar and non polar solvents. An increase in TL signal strength was observed as the volume fraction of methanol increased. Convective heat transfer mechanism was found to be large when methanol component increased in the liquid mixtures. Heat diffusion is strongly dependent on intermolecular interactions between clusters of methanol and the co-solvents, proving that TL technique is a sensitive method to study intermolecular interactions in liquid mixtures.

Thermal lens techniques have great potential in revealing the morphology and structure related changes in materials. Studies on ceria nanoparticles synthesized by co-precipitation technique, reveal that particle size and thermal diffusivity increase with annealing temperature. The enhancement in the particle size enhances the closed pore volume in the sample resulting in increased absolute porosity. Natural pyrrhotite have become important in recent years due to their interesting electronic, antimicrobial and chemical properties, and their morphology-induced modifications due to aging has been explored by thermal lens technique (J Phys Chem.,C123,2019,23264).

The studies on the size and morphology of gold nanoparticles embedded in proteins, may have important applications for photothermal therapy in the treatment of cancer. The mechanism of heat diffusion, in nanofluids as well as in solutions dispersed with nanoparticles of silver and gold, has been an area of much research activity. Techniques of photothermal spectroscopy have been applied to conduct a variety of experiments. It has been found that nano silver in rod shaped morphology greatly enhances thermal diffusivity and nano gold in water dissipates heat with four-fold efficiency.

Conclusion

Intersection of Photonics with varied branches of knowledge generation and their applications has created new branches of research and developments. To conclude Photothermal spectroscopy with its two broad categories, of Photothermal deflection and Photothermal lens, techniques has been employed with great success in revealing molecular properties and a great deal of

Topological Insulators for Photonics

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One of the major research thrusts of photonics research at present aims at creating chip-scale photonic devices which can ideally work in the quantum regime. This is important towards realizing all-optical architectures for data handling operations to replace the currently used electronic or hybrid optoelectronic platforms, yielding several advantages particularly in terms of speed, data capacity as well as security. Realizing such systems require a combination of approaches both from the perspective of photonic materials as well as nanophotonic architectures. Topological insulators (TIs) are an extremely versatile material platform for such nanophotonic architectures.

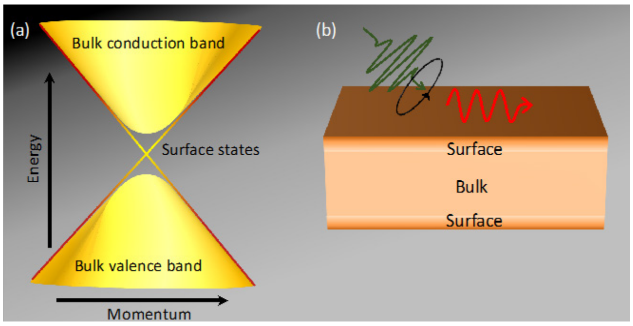

Figure 1. Schematic representation of a topological insulator material in (a) momentum space and, (b) real space. The material is characterized by parabolic dispersion of the semiconducting bulk and a linear Dirac dispersion of the topological surface states. Spin plasmons can be potentially excited by coupling circularly polarized light with the latter.

TIs are a novel quantum state of matter featuring highly conducting surface states encapsulating an insulating or semiconducting bulk. They exhibit extraordinary features such as the presence of free carriers on the surface which are topologically immune from scattering, spin-momentum locking wherein the spin of the electrons are correlated with their direction of motion as well as high polarizability of the bulk [1]. These features arise as a consequence of the nontrivial topology of the Hilbert space of the bulk which leads to band inversion resulting in the p-orbital band being pushed energetically above the s-orbital band. Normally, for a band insulator, the p-orbital bands lie below the s-orbital bands and the inversion can be brought about by the presence of heavy elements such as Bi or Sb which creates strong spin-orbit coupling.

Chalcogenide 3D topological insulators belonging to the BSTS $Bi_xSb_{(2-x)}Te_ySe_{(3-y)}$ family are excellent candidates for photonic applications. Firstly, their semiconducting bulk exhibit very high polarizability which translates to extremely high refractive index values (n ~ 6 to 8) in the near-to mid-infrared frequencies making them highly suitable for dielectric metamaterial architectures [2]. Secondly, the topological protection & immunity to scattering of the surface state carriers can be potentially exploited to create surface plasmons with long propagation lengths (in the mid-infrared region & THz frequencies) for plasmonic applications [3–6]. Finally, the spin-momentum locking feature of the bulk can be utilized to create spin plasmons which can be controlled optically by changing the helicity of the incident electromagnetic field. The same feature can be exploited together with nanostructuring to create strategies for chiral photodetection at optical frequencies [7].

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Introduction to line laser technology for material processing applications

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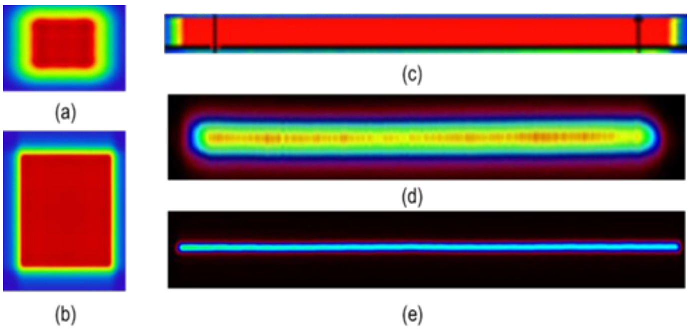
High power lasers have undergone rapid and exciting developments in numerous applications during the past decades. Even though a wide variety of systems are available, high power diode lasers are the fore-running systems in material processing applications. The major advantages of diode lasers are their high efficiency, low running cost, high reliability, compactness etc ; but, their beam quality is relatively poor. The combination of diode lasers, micro-optics and beam shaping technology enables them to be developed as line laser systems to be employed for various applications.

As the name implies, a line laser system generates a laser beam profile which has the dimensions of length and width. A typical line laser system encompasses photon generation, photon control and beam shaping technology. The line shaped beam can be called as narrow line, line, rectangle or square beam with different aspect ratios and different homogeneity distribution along the length and width directions. Line laser systems can provide a very large range of aspect ratio from 1:1 to 50,000:1. This characteristic offers extremely broad application range.



False colour diagram of different profiles (1)

The components of a typical line laser system can be outlined as below.

1. Photon Generator-Light sources.
Laser sources which generate photons are the driving forces for a line laser system. These laser sources could be direct diode lasers, fiber coupled diode laser modules, fiber lasers, solid state lasers, excimer lasers etc. and the mode of operation could be continuous wave, quasi continuous wave or pulse.

2. Photon control technology

Developments in micro-optics enables us to control and deliver photons emitted by light sources to the right place at the right time. Properly designed cylindrical free-form micro-optics/arrays/diffusers are available to control the photons for line laser systems meant for numerous material processing applications.

3. Beam shaping technology

Appropriate beam shaping technique has to be employed to match the photon generator and photon controller to take full advantage of their high quality In general, beam shaping involves changing the beam geometry and intensity distribution before and after passing the optical system. Phase shifting, beam transformation and beam mixing are the methods used to design and produce the optical beam shaping elements.. These methods can be used separately or together depending on the final output beam performances and manufacturing process requirements.

To sum up , line laser system can shape laser sources such as diode lasers, fiber lasers, excimer lasers and solid state lasers to form a line shaped beam with high uniformity level both in length and width directions. High aspect ratio, high process efficiency and high beam homogeneity are the advantages offered by these systems.

Semiconductor wafer annealing, low radiation glass annealing, bonding in display industry, plastic welding, laser soldering are some of the prominent material processing applications for which these line lasers can be employed efficiently.

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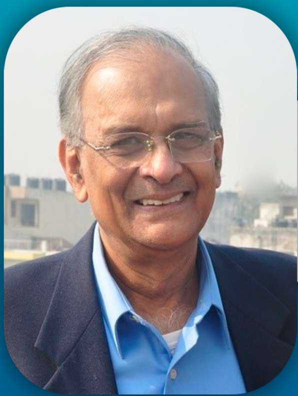

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Chief Guest
Prof. Carmen Menoni
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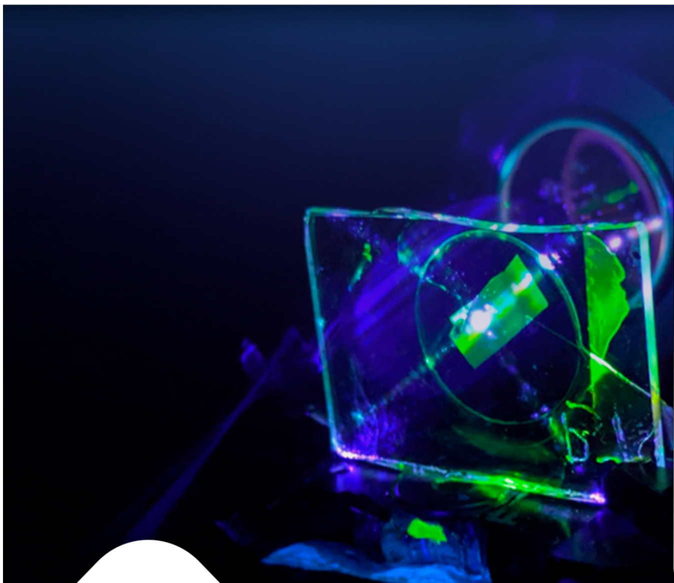

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The IEEE Kerala Section, with over 10,000 members, 14 societies, 4 affinity groups, and over 80 student branches, aspires to provide its student members an advantage over their peers by developing their technical and management acumen through a wide range of initiatives and flagship events. While serving as a bridge for members to engage with the global community, the Section keeps its members up to date on the latest scholarships, conferences, and membership benefits, as well as hosts regular membership development sessions and creative events.

With continuous support and encouragement from the IEEE Kerala section, the faculty members and researchers of the International School of Photonics, took the initiative to form a Photonics Society chapter. On August 24, 2021, the first IEEE Photonics Society in the state was formally inaugurated. Prof. Ajoy Ghatak, a renowned physicist from IIT Delhi, delivered the inaugural address. Prof. Carmen Menoni, President of the IEEE Photonics Society, presided over the event and delivered a noteworthy speech about the society's efforts and their benefits to humanity. Ms. Sarada Jayakrishnan and Dr. Suresh Nair spoke to the audience and shared their unique insights.

A webinar was organised on September 17th and the topic was "Smart and Intelligent Microscopy: Clinical Applications". In this lecture, Prof. Renu John, of IIT Hyderabad, gave an interesting presentation on Optical Microscopy, 3D imaging of biological and living cells. He discussed how to apply AI and machine learning to diagnostic applications. The webinar drew a large number of IEEE members, students, industry participants, and academics. On November 22nd, a technical demonstration was organised for graduate students and researchers. This seminar included actual demonstrations of experiments, which aided students in self-learning the principles of optical communication.

A talk was organised on December 21st on "Changing Phases of Optical Communication" by the expert speaker, Dr. Deepa Venkitesh, of IIT Madras . In a highly motivating and interesting lecture, Dr. Deepa presented the details of the evolution of optical communication and the different phases involved in it. IEEE members, industry professionals, along with the researchers, participated in this event.

In the year 2022, the society intends to organise a variety of professional and student activities, such as career and skill development programmes with a focus on optical design software, monthly expert talks, and Optics to School. At ISP, M.Tech (OE&LT) students have joined IEEE and a photonics students chapter has been started in CUSAT. In addition, the society decided to institute three best paper awards for the National Photonics Symposium organised by the International School of Photonics, CUSAT. The IEEE Photonics Society has also proposed establishing a hub in CUSAT for nurturing start-ups and entrepreneurship in photonics.

Scientific research involve large amount of data produced that need to be analyzed, interpreted, presented and communicated in a systematic fashion. This requires, in addition to scientific knowledge, acquisition of several additional skills and trainings in the fields of research methodology, data analysis, and science communication. As a beginner to scientific research, many of us are haunted by several questions like; what exactly is scientific research? Why do we need to do research? What methodology to be followed in research? How to read a research article critically? How to select an appropriate journal while submitting your article? How to draft a paper? Which tense is to be used in writing a journal paper? How to manage references? How to write a cover letter? How to do effective scientific presentations for different occasions like group meetings, conferences and seminars, thesis defence etc.? What are the procedures to be followed in Chemical, Electrical and Optical laboratories to avoid causalities? To help the early carrier researchers to find answer to these questions, at the International School of Photonics, we conducted a workshop from 22.11.2021 to 30.11.2021 entitled, "Workshop on Rendering Your Scientific Output (RYSO-21)" "The not so frequently discussed topics: from basic research to communication in science" Visualizing complex and interrelated results in simple and comprehensible manner is an inevitable part of presenting results. Knowledge in the effective use of plotting and visualization tools makes researchers to convey the results as well as the message at the same time. Several open source tools are available and widely used in scientific research community. A basic level training to such software will enable the students explore further and master in it. With the advent of visualization and graphic tools, scientific results and ideas and even imaginations are being presented in artistic fashion. Gaining an exposure to elementary ideas in graphic tools will support one in expressing imaginations and results in an appealing style and fashion. Artistic graphical images are inevitable in modern scientific publications. RYZO-21 offered an extensive training on the usage of Blender, a free and open-source 3D computer graphics software toolset, to design impressive and informative cover pages, graphical abstracts and table of content figures. There were 44 registered participants for the workshop. The scientific sessions were handled by expert faculties including Dr. M T Sebastian, Prof. Pramod Gopinath, Prof. Honey John, Dr. Saji K J, Dr. Priya Rose T, Dr,.Praveen C. S., Dr. Sasidevan Vijayakumar, and Mr. Vinod V Nair. The tutorials on visualization using Blender software was given by Mr. Rafeeq Mavoor, founder of Scidart accademy.

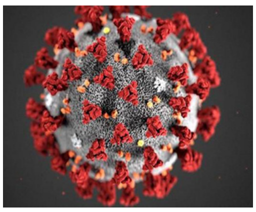
Raman fingerprint for the detection of current and past SARS-CoV-2 infections

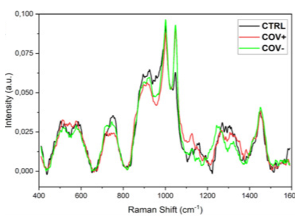
Dr. Vineesk Kumar T V

UGC-DSK Post Doctoral

Can SERS be really influential in effectively detecting the COVID-19? Discovery of Surface Enhanced Raman spectroscopy (SERS) has a surprisingly short history. It was accidentlly discovered by Fleishmann and Co-workers in 1974 during measurements of the Raman scattering of pyridine on rough silver electrodes. Since its discovery over 40 years, it has enjoyed a steady growth of interest in the research community, and it has spawned a variety of other spectroscopic techniques that take advantage of enhanced local fields that arise from plasmon excitation. Even if the Raman process is a weak effect, the use of SERS caused a billion-fold increase in the intensity of Raman signals. This provides a substantial assistance in trace analysis or sensing of molecules adsorbed onto corrugated hotspots.

The coronavirus outbreak came to light on December 31, 2019, when China informed the World Health Organisation of a cluster of cases of pneumonia of an unknown cause in Wuhan City in Hubei Province. Subsequently, the disease spread to more provinces in China, and eventually to the rest of the world. The disease 2019 (COVID-19) became a public health emergency of international concern as declared by the World Health Organization (WHO) and turned out to be a pandemic. The world even came to a standstill with fewer travellers, economic crises, and more restrictions.





The gold standard method for detection of SARS-CoV-2 infection is Real Time reverse transcription Polymerase Chain Reaction (rRT-PCR) on respiratory specimens such as nasopharyngeal and oropharyngeal swabs. However, the collection procedure is relatively invasive, causing discomfort that occasionally induces coughing and bleeding. The close contact between healthcare workers and patients poses a risk of transmission of the virus to nurses and physicians, even with full personal protective equipment. Moreover, the analytical protocol for the detection of SARS-CoV-2 through rRT-PCR requires time, specialized laboratories, expensive reagents, and adequate personnel. Hence, these nasopharyngeal and oropharyngeal swabs are not desirable for serial monitoring of viral load and for massive screening.

Considering that the primary routes of diffusion for SARS-CoV-2 are respiratory droplets and aerosols, saliva was proposed as a valid alternative to nasopharyngeal swabs. Saliva is an easily accessible biofluid that can be collected without invasive procedures and by non-specialized personnel. To overcome the rRT-PCR methodological limitation, an immunological method has been developed, but its sensitivity varied from 0% to 94% (average 56.2%). False negative results also can occur if samples don't have a sufficient amount of viral protein to yield a positive test. The immunological method circumvents the extraction of virus nucleic acid and shortens the detection time. However, it is not applicable for the early diagnosis of COVID19 due to the low antibody concentration at the beginning.

In the current scenario, vibrational spectroscopies like Raman spectroscopy (RS) are promising alternatives in molecular diagnostics. These techniques have already demonstrated their utility in the diagnosis of infections at the point-of-care, with promising results leading to the early diagnosis and monitoring of a variety of human diseases. Taking advantage of Surface Enhanced Raman Scattering (SERS), RS challenges current fluorescent based detection methods in terms of both sensitivity and multiplexing ability, detecting multiple components in a mixture, including viruses, in point-of-care platforms

The research group from IRCCS S. Maria Nascente and the University of Milano-Bicocca (Italy) has been actively involved in the use of SERS to identify a Raman fingerprint of SARS-CoV-2 in the saliva of patients affected by COVID-19. They reported a Raman-based approach for the analysis of saliva, able to significantly discriminate the signal of patients with a current infection by COVID-19 from healthy subjects and/or subjects with a past infection. Interestingly, the data obtained showed that the saliva of patients with current SARS-CoV-2 infection contains a biochemical signature that allows for rapid detection and differentiation from people with previous SARS-CoV-2 infection and from healthy subjects, with an accuracy, precision, specificity, and sensitivity of more than 90%. The sample preparation technique eliminates the need for filtering, allowing for a faster, more cost-effective, and more informative analysis. With a few modifications to the Raman acquisition parameters, this approach allows for the safe collection of saliva while limiting sample handling and passages that are difficult or complex. The overlapping average spectral characteristics and spectral variations highlight the three different test groups. Spectral variation is attributed to the changes in the molecular structure of glycoprotein, tryptophan, phenylalanine, and glucose/ glycogen in the saliva of these three different groups.

The discrimination ability of the RS relies on the wide range of information that can be obtained from a single analysis, with the lowest concentration detectable up to 10–15 M in a specific SERS regimen. With this SERS approach, all information about the analysed biological fluid can be collected, namely its density, environment, chemical nature, modifications, mutations, changes, and interactions. A complete signal can be obtained from all existing biochemical species based on the above routes.In the case of a rapid and continuous increase in severe COVID-19 cases, the SERS can identify the threat of Covid 19 over time by comparing the amounts of biological molecules contained in the saliva. In addition, it is also a good way to detect current and past SARS CoV-2 infections by analysing variations in the levels of biological molecules. Thus, the drawbacks in the currently used RT-PCR and antigen tests can be remedied by the fast and sensitive SERS technique with minimal invasive procedure. In the same way, the identification of subjects with a past infection (with or without symptoms) could be fundamental to creating epidemiological maps useful for infection confinement. Hence, SERS proposes to provide information regarding the presence, concentration, and modification of molecules of interest, including nucleic acids and proteins, all with a single fast analysis of saliva.

Furthermore, the simple approach, the reliable and repeatable analytical protocol, and the low cost of the Raman substrate suggest that this could be a good method for discriminating COVID-19 and comparable onset.

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Rare-Earth Elements as a Potential Candidate to Overcome Limitations of Solar Cells in Clean Energy Solutions

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Perovskite solar cells have advantages over current solar cell technology. They have the potential to be more efficient, are lightweight, and cost less than other competitors. In a perovskite solar cell, the layer of perovskite is sandwiched between a transparent electrode at the front and a reflective electrode at the back of the cell. Electrode transport and hole transport layers are inserted between cathode and anode interfaces, which facilitates charge collection at the electrodes.

There are four classifications of perovskite solar cells based on morphology structure and layer sequence of the charge transport layer: regular planar, inverted planar, regular mesoporous, and inverted mesoporous structures. However, several drawbacks exist with the technology. Light, moisture, and oxygen can induce their degradation, their absorption can be mismatched, and they also have issues with non-radiative charge recombination. Perovskites can be corroded by liquid

The Applications and Functions of Rare-Earth Ions in Perovskite Solar Cells.

electrolytes, leading to stability issues. To realize their practical applications, improvements must be made in their power conversion efficiency and operational stability. However, recent advances in technology have led to perovskite solar cells with a 25.5% efficiency, which means that they are not far behind conventional silicon photovoltaic solar cells.

To this end, rare-earth elements have been explored for applications in perovskite solar cells. They possess photophysical properties that overcome the problems. Using them in perovskite solar cells will therefore improve their properties, making them more viable for large-scale implementation for clean energy solutions.
There are many advantageous properties that rare earth elements possess that can be used to improve the function of this new generation of solar cells. Firstly, oxidation and reduction potentials in rare-earth ions are reversible, reducing the target material's own oxidation and reduction. Additionally, the thin-film formation can be regulated by the addition of these elements by coupling them with both perovskites and charge transport metal oxides.Furthermore, phase structure and optoelectronic properties can be adjusted by substitutionally embedding them into the crystal lattice. Defect passivation can be successfully achieved by embedding them into the target material either interstitially at the grain boundaries or on the material's surface.Moreover, infrared and ultraviolet photons can be converted into perovskite-responsive visible light owing to the presence of numerous energetic transition orbits in the rare-earth ions.The advantages of this are two fold: it avoids the perovskites becoming damaged by high-intensity light and extends the material's spectral response range. Using rare earth elements significantly improves the stability and efficiency of perovskite solar cells

As mentioned previously, rare earth elements can modify the morphologies of thin films consisting of metal oxides. It is well-documented that the morphology of the underlying charge transport layer influences the morphology of the underlying charge transport layer influences the morphology of the perovskite layer and its contact with the charge transport layer. For example, doping with rare-earth ions prevents aggregation of SnO2 nanoparticles that can cause structural defects, and also mitigates the formation of large NiOx crystals, creating a uniform and compact layer of crystals. Thus, thin layer films of these substances without defects can be achieved with rare-earth doping.
Additionally, the scaffold layer in perovskite cells that have a mesoporous structure plays an important role in the contacts between the perovskite and charge transport layers in the solar cells. The nanoparticles in these structures can display morphological defects and numerous grain boundaries.This leads to adverse and serious non-radiative charge recombination. Pore filling is also an issue. Doping with rare-earth ions regulates the scaffold growth and reduces defects, creating aligned and uniform nanostructures. By providing improvements for the morphological structure of perovskite and charge transport layers, rare earth ions can improve the overall performance and stability of perovskite solar cells, making them more suitable for large-scale commercial applications.

The importance of perovskite solar cells cannot be understated. They will provide superior energy generation capacity for a much lower cost than current silicon-based solar cells on the market. The study has demonstrated that doping perovskite with rare-earth ions improves its properties, leading to improvements in efficiency and stability. This means that perovskite solar cells with improved performance are one step closer to becoming a reality.

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Recent Publications

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Conference Proceedings

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Books/Book Chapters Published

1. Dr. Mohammad Zaheer Ansari, Thermodynamics and Thermal physics: A brief analysis (ISBN:9798885211949) published on 2021-11-26.

2. Dr. Praveen C S, Prof. (Dr.) Pramod Gopinath , Proceedings of the National Photonics Symposium 2020, INSC International Publishers , ISBN:978-1-68576-133-2

3. Meera Sathyan , Nisha T Padmanabhan , K V Vijoy , K J Saji , and Honey John , 2D nanomaterials and their heterostructures for hydrogen storage applications in “2D Materials for Energy Storage and Conversion” ISBN 978-0-7503-3319-1 (ebook), ISBN 978-0-7503-3317-7 (print); IOP Publishing, Bristol, UK

4. Viji Vidyadaran, Kamal P Mani, Cyriac Joseph, M Kailasnath , Phosphors : A Promising Optical Material for Multifunctional Applications, Optical and Molecular Physics : Theoretical Principles and Experimental Methods, 301,2021, ISBN:978-1-00315-005-3(ebk)

Ongoing Projects

1. Dr. Saji K J : Ultrafast laser beamlines for Multidisciplinary, Multitasking Research Programmes (one among 8 Investigators), Funding under Chancellor’s Award 2019, (Total outlay Rs. 400 Lakhs)

2. Dr.M. Kailasnath: Photothermal and nonlinear oprical characterisation of rare earth doped nano particles for bioimaging applications (Principal Investigator), Funding by DST-SERB, (Total outlay Rs 34,99,000)

Patent Filed

Honey John, Divya Jose, Saji K J, Vijoy K V, Jelmy E J, Manoj N,'Polydimethyl siloxaine composites of Graphene oxide hybrids with conducting polymers, pocess for preparation, and energy harvesting applications as smart devices',Filed with Indian Patent application No: 202041006974, dated February 18, 2020.

THURSDAY SEMINARS

SEMINAR TOPIC	PRESENTED BY
Familiarizing the diffraction pattern in SSPM	Jayaprasad KV
SiO2 @ TiO2 core @ shell nanoparticles deposited on 2D layered ZnIn2S4 to form ternary hetero structure for simultaneous photocatyltic hydrogen production and organic pollutant degradation.	Amrutha Thomas
Super capacitors as energy storage devices	Divya Krishnan
Propagation of laser beam in underwater turbulence	Athira T Das
Plasma-mysterious and powerful state of matter	Shilpa S
Handheld laser speckle imaging devices	A K Sooraj Viswam
Investigation on dielectric behavior of carbon based high k-composites	Vijoy K V
Recent advances in spatial self phase modulation with 2D materials and its applications	Titu Thomas
Speckle free laser imaging using random laser illumination	Anugop B

Dynamic light scattering theory and particle size measurement using Horiba nanoparticle analyzer SZ-100	Safna Saif
Enhancement in Non-linear optical properties by growth of CdS shell over PbS cation exchange method	Syammohan V
An integrated hollow-core photonic crystal fiber transverse optical trapping system optical manipulation and detection.	Mayur Anil Sathe
Memristor size scaling down to single defect in MoS2 sheet	Praveen P
Fourier transforms for fast and quantitative laser speckle imaging	Keerthana S J
Forming van der-waals metal contacts to two-dimensional semiconductor approaching the schottky mott limit	Cicily Riji V J

Workshops/Conference/Schools organised

Rendering Your Scientific Output (RYSO-21), 21-30 Nov 2021
Co-ordinators : Dr. Saji K J & Dr. Praveen C S

Advanced Molecular Dynamics Simulations', jointly organised with Katmandu University, Nepal, and Scidart academy, 6 .09.2021 to 17.09.2021
Co-ordinator: Dr. Praveen C S

Pre-conference workshop organized jointly with Inter-University Centre for Nanomaterials and Devices (IUCND), CUSAT , 7.01.2022
Co-ordinator : Dr. Praveen C S

International Conference on Recent trends in Photonics (NPS 2021), Feb 27-2021-March 01-2021.
Co-ordinator: Dr Priya Rose T

Special Talks by Experts

PRESENTED BY	TOPIC
Prof. Robert Boyd	New Results in Nonlinear Optics
Dr. Anisha Gokarna	ZnO as a multifunctional photonic material
Prof. John T Costello	AMO physics VUV and X-ray FEL'S
Dr. Anil K Patnaik	Ultrafast laser based light matter interactions:Sensing and beyond
Prof. Jean Michel Nunzi	Perovskite, graphene and hot electron photodetectors
Dr. Rajesh P Nair	Controlled light emission in photonic structures (order to tailored disorder)
Dr. Yogeshwar Nath Mishra	Advanced optical imaging for engine research
Dr. Sreekanth Perumbilavil	Lasing in Nanostructures

Mechanism and Applications of Aggregation Induced Emission Luminogens

Lakshmi R

Research Supervisor- Prof. Dr. Pramod Gopinath

The widely used conventional luminophores have suffered decreased or completely quenched fluorescence once they are aggregated and this notorious Aggregation Caused Quenching (ACQ) effect adversely affect the concentration dependent sensing applications and solid state device fabrication. Ben Zong Tang in 2001 coined the concept of Aggregation Induced Emission (AIE) for a phenomenon in which a series of non-emissive molecules in solution state are induced to emit strongly in aggregate or solid state. AIE is exactly the opposite effect of ACQ. An excited luminophore decay either radiatively or non-radiatively. AIE luminogens (AIEgen) decay mainly through radiative photohysical pathways. Since the discovery of AIE molecules,researchers are continuously exploring the real mechanism behind AIE. There are many hypothesized mechanism behind the working of AIEgens like J- aggregate formation,conformational planarization, restriction of twisted intramolecular charge transfer (TICT), E/Z isomerization, excited state intramolecular proton transfer etc. The most accepted standard mechanism among common AIEgens is Restriction of Intramolecular Motion (RIM). This special photophysical phenomenon can also be due to the structural rigidification. When the intramolecular motion is restricted, a dramatically decreased non-radiative decay rate is observed. Thus radiative relaxation channel become favourable. AIEgens finds applications in various field like AIE based polymers, AIE-induced chirogenesis, Room-temperature phosphorescent in AIE molecules, Liquid crystalline AIE molecules, AIE materials for energy devices, AIEgens for explosives detection, New chemo- and biosensors with AIE molecules, Cell structure and function imaging with AIE molecules, AIE nano-probes for multi-photon bioimaging, AIE materials in drug delivery and therapy. AIE-related research is booming, which has permeated a large number of research disciplines with a wide-spread influence. There are many opportunities as well as challenges on this platform. Grasping the opportunities and overcoming the challenges will deepen our understanding and create innovative light- based technologies.

An Amalgam of Machine Learning and Density Functional Theory

Maneesha M

Research Supervisor- Dr. Praveen C S

Carbon dioxide (CO_2) is one of the notorious greenhouse gases whose imbalance in earth causes possible global warming issues. One best route to mitigate the effects of carbon dioxide is to convert carbon dioxide into useful energy. Various methods used for the conversion of CO_2 is chemical, photochemical, electrochemical, photoelectrochemical method and so on. Our research focuses on ELECTROCHEMICAL REDUCTION(ECR) of CO_2 . It is the reduction of CO_2 into organic feedstocks using electrical energy. Because of its easily controllable nature, this method found to be the most promising approach in the conversion of CO_2 . Significant advances in electrocatalysts are needed to enhance the rate of reduction process. But there exists some hinders in the practical application of CO_2 conversion, includes requirement of high energy for CO_2 conversion, lack of industrial commitment for developing carbon based materials and so on. We are aiming to discover novel electrocatalyst which have much better Faradaic efficiency and selectivity than the ones developed so far by a meld of Machine Learning and Density Functional Theory(DFT) which provide an amplifying insights into catalyst discovery.

Employing Machine Learning and DFT techniques for producing Carbon Free Energy by Phtocatalytic Water Splitting

Jose Antony V J

Research Supervisor- Dr. Praveen C S

Fossil fuel in the form of coal, oil and natural gas has powered human society for years. Increasing population and energy consumption is exhausting our non-renewable resources and also a threat to our environment because of the pollutants created by the fossil fuels. Consumption of fossil fuel will produce a potentially significant global issue. Inspired from nature i.e. how green plants produce oxygen by photosynthesis Akira Fujishima & Kenichi Honda have developed artificial photosynthesis where nano material dispersed in water produces oxygen and hydrogen by using sunlight (Photo Catalytic Water Splitting).

Main focus of our research work is to solve this global issue created by the pollutants ie “A paradigm shift to Carbon Free Energy” by using artificial photosynthesis proposed by Honda Et al. The driving energy of this hydrogen production is sunlight. Band Gap tailored nano material dispersed in water when irradiated with sunlight undergoes chemical reaction to produce hydrogen and oxygen. The existing methods developed so far is covering only a narrow region of solar spectrum with a very less quantum efficiency (< 10%).To obtain high solar energy – hydrogen conversion, the quantum efficiency of the photo catalytic reaction must be increased over a wide range of wavelengths and suitable new materials are to be discovered. Conventional methods are time consuming and expensive. To overcome the material challenge and experimental challenge DFT techniques is used. With High Performance Computing System it has become an easy task to do material simulations in the lab. New and efficient material for Photo catalytic water splitting can be obtained using Machine Learning and DFT techniques. With increased Quantum Efficiency these materials can solve the problem for energy crisis and global warming.

Investigations on Silica and Polymer waveguides for Micro-lasing Applications

Mitty George

Research Supervisor- Dr. M. Kailasnath

Optical waveguides are the structures that are used to confine and guide the light in the guided-wave devices and circuits of integrated optics. Micro-lasers have drawn considerable attention for applications in future optoelectronic nanoscience and nanotechnology, owing to the capability of scaling physical dimension of devices down to micro/nanometer level. Currently, the most popular optical gain micro-nanomaterials for microlasers are inorganic semiconductors, organic dyes and polymers, and organic-inorganic hybrid perovskites. The incorporation of metal nanoparticles in gain medium as well as in the structure has shown many remarkable advancements in optical sensing. Polymer and silica waveguides can be investigated for different sensing applications. Optical fiber biosensors have attracted extensive research attention in fields such as public health research, environmental science, bioengineering, disease diagnosis and drug research. Accurate detection of biomolecules is essential to limit the extent of disease outbreaks and provide valuable guidance for regulatory agencies to take timely measures. Among many optical fiber sensors, optical fiber biosensors based on specialty fibers have the advantages of biocompatibility, small size, high measurement resolution, high stability and immunity to electromagnetic interference. Whispering gallery modes (WGMs) is another phenomenon which can be used for a broad range of sensing applications. Random lasing studies on optical fibers is another area which has tremendous applications especially biosensing.

Development of low-threshold, tunable random lasers and high-sensitivity sensors is still an area which need to be studied. So it is proposed to study various configurations of silica and polymer waveguide structures for various micro-lasing applications.

Chalcogenide Glass Photonics at a Glance

Soumya S

Research Supervisor- Dr. Sheenu Thomas

Chalcogenide glasses are promising materials in the field of infrared photonics because of their unique physical, optical, thermal, and electrical properties. Their high transmission in the infrared (IR) spectral regime and the high refractive index makes them a prominent candidate for the fabrication of active and passive IR devices, especially for biochemical mid-IR sensor applications and in the field of fibre optics. Chalcogenide glasses have the advantages of a wide transparency window and high optical nonlinearity, makes them good candidates for mid-infrared supercontinuum generation. The high photosensitivity, including photo-darkening, photo-crystallization, and photo-expansion/contraction of chalcogenide glass, permits the direct writing of optical waveguides and photonic integrated circuits (PICs). Due to its high photosensitivity, it has application as phase change memories used in CD/DVD and memory chips. In addition to this, chalcogenide glasses offer attractive properties like high nonlinearity, low band gap, and good rare earth solubility, which can be exploited for making amplifiers and lasers in the IR regime. We can use metamaterials integrated with chalcogenides, known as meta-devices for various photonics applications. Research in this realm has been consistently and continually progressing, opening a way to the more compact integration of photonic circuits with high optical quality.
Our research group in ISP, mainly focuses on chalcogenide glasses for IR photonic applications. In particular, chalcogenide glasses-based MIR biosensors, polymer photonic crystal fibre (PCF) with infiltrated chalcogenide glass films, chalcogenide glass nano-photonics, chalcogenide meta-devices and nonlinear optics (NLO) are our core exploring areas. We synthesis glasses using conventional melt-quenching technique and have an excellent Photonics research laboratory to carry out the research. Recently, we have developed novel amorphous nanowires from solution processed chalcogenide glasses and also realized a hybrid metal-chalcogenide glass substrate for surface-enhanced infrared spectroscopy.

Fibre Optic Plasmonic Bio and Chemical Sensors

Priyamvada V C

Research Supervisor- Dr. P. Radakrishnan

Optical fibres are cylindrical waveguides designed for confining UV-VIS-IR electromagnetic radiation and propagate with minimal loss. In addition to the data transmission using optical fibres, development of sensing instruments is also gaining momentum in industrial and medical field applications. Based on the methodology implemented to make the confined radiation to sense, different sensor configurations are possible. In fibre optic plasmonic sensing, core of the optical fibre is coated with a nanometric layer of plasmonic material. The surrounding refractive index change is precisely captured by the sensor head and transfer it as the absorbing wavelength-shift at the output measured. Extremely sensitive sensor configurations are possible using this principle of Surface Plasmon Resonance. In addition to this, plasmonic sensing property can be tailored to match the analyte to be detected by using Localized Surface Plasmon Resonance (LSPR). Here instead of coating a plasmonic layer, noble metal nanoparticles are integrated with the core of the fibre and can be functionalized to capture the analyte more effectively. The sensors based on surface plasmon resonance are found to be effective in sensing chemical as well bio species reliably.

Colliding Laser Produced Plasmas– An Emerging Field of Plasma

Shilpa S

Research Supervisor- Dr. Pramod Gopinath

Laser-produced plasmas (LPP) are formed when a high-power pulsed laser is focused on a solid, dense target at an irradiance of more than $1 GWcm^{-2}$. Colliding laser-produced plasma is produced as a result of the collision of two rapidly expanding laser-ablated plasmas. Its characteristics are strongly dependent on many parameters, including the laser characteristics like intensity, laser wavelength, pulse duration, irradiation spot size, etc. The nature and geometry of target materials, ambient gas composition, ambient pressure, etc. When two plasmas collide, the outcome usually lies between two opposite scenarios where the plasmas can either interpenetrate each other or can stagnate at the collision front to form a dense localized region called 'stagnation layer'. When two streaming plasmas collide it may be collisionless type or collision dominated is determined by the collisionality parameter of plasmas which in turn depends upon density, temperature, ionic charge and relative velocities.

There are several diagnostic techniques for characterizing laser-produced plasma includes optical emission spectroscopy, mass spectroscopy, laser-induced fluorescence, Langmuir probe, faraday cup, etc. Spectrally filtered time-gated intensified charge-coupled device imaging was used to obtain information about the spatial dynamics and temporal evolution of the collision process. In contrast, time-resolved imaging spectroscopy was used to determine the spatial and temporal distributions of electron temperature and density within the interaction region.

Fig. Laterally colliding laser produced plasmas

Laser-produced colliding plasma has found potentially attractive applications in material science, analytical science, in the field of X-ray lasers, pulsed laser deposition, laser ion sources, for stimulated Raman scattering experiments, for indirect drive inertial confinement fusion, extreme ultraviolet (EUV) lithography, etc. Even though there are numerous experimental and theoretical progress in the dynamics of single laser-produced plasmas, attention towards collisional plasma is minimum. So, it is worth studying the nature and dynamics of laser-produced colliding plasma because of its several emerging applications.

Photonic Crystal Hydrogels

Karthika Sankar & Safna Saif

Research Supervisor- Dr. Priya Rose T

Photonic Crystals (PCs) is an emerging research field since 30 years. They are optical structures with periodic variation in refractive index. The signature property of a PC is the existence of a photonic bandgap, where frequencies within the band gap are not allowed to propagate through the structure resulting in complete reflection. A Photonic Crystal Hydrogel (PCHG) is a kind of responsive PC whose peak reflected wavelength can be tuned according to some external stimuli. So they are good candidates for sensing applications. Different biosensors, chemical sensors, humidity and pH sensors fabricated using PCHGs have been reported in literature. In this kind of sensors, selectivity is achieved by appropriate functionalization of the PCHG and wisely choosing the hydrogel precursor. Some hydrogel precursors are hydroxyethylmethacrylate (HEMA), polyethylene glycol diacrylate (PEGDA) and N-isopropylacrylamide (NIPAAm). HEMA is pH sensitive and NIPAAm is temperature sensitive. So if a hydrogel PC is made using NIPAAm, the PC is now sandwiched inside the hydrogel matrix. Hence, with respect to change in temperature, the HG swells or shrinks. As a result, the periodicity of the PC increases or decreases respectively, resulting in a change in the photonic bandgap. In other words, PCHGs are efficient colorimetric sensors. A major disadvantage is the angle dependence of the photonic bandgap. But this could be managed by properly choosing the constituents such that there is a remarkable refractive index contrast.

Investigations on devices based on silica

Reji Thankachan

Research Supervisor- Dr. M. Kailasnath

Optical fibers are structures that use total internal reflection for the confinement and guidance of light. These find major applications in the field of biological and chemical sensing. Optical sensors are broadly divided to Interferometric, grating based and distributed. Optical biosensors play an important role in the fields such as public health research, environmental science, bioengineering, disease diagnosis, and drug research. Precise spotting of viruses helps regulatory bodies to take preventive measures against disease outbreaks.

Micrometer sized dielectric structures doped with a gain medium generates whispering Gallery mode (WGM) lasing under optical pumping. Microcavity based WGM sensing is an important field of modern research for applications such as biosensing. Random lasers are a new class of fiber optic devices that exploits the structural properties of waveguides for lasing. A random laser is an optical device that depends on multiple light scattering and gain to provide the feedback mechanism and light amplification respectively. To enhance the emission efficiency, tailor the output spectrum, or control the emission directions of random lasing, gain materials and scatters of RLs may be embedded into optical waveguide structures, in which light amplification and scattering are confined and mediated by the waveguide, giving birth to partially regulated and still randomly formed positive feedback loops that support random lasing. The gain materials used for random lasing are inorganic semiconductors, organic dyes and polymers. Introduction of metal nanoparticles and its composites in gain medium and fiber structure provides considerable improvement for microlasing applications such as sensing.

INVITED TALKS BY OUR FACULTY MEMBERS

No	Title	Date	Faculty Name
1.	ATAL-FDP on Photonics Rajarshi Shahu Mahavidyalaya, Latur, Maharashtra. Hollow optical fibers for sensing.	24-09-2021	Dr. M. Kailanath
2.	Guest Speaker in the AICTE ATAL sponsored Faculty Development Program organized by Sree Shankaracharya Group of Institutions, Bhilai Chhattisgarg, delivered a talk on "Nanophotonics".	01.02 2022	Dr. A. Mujeeb
5.	Resource person in the AICTE ATAL sponsored Faculty Development Program organized by MES College of Engineering, Kuttippuram, delivered a talk on "Speckle Metrology".	23.09.2021	Dr. A. Mujeeb
6.	Resource person in the AICTE ATAL sponsored Faculty Development Program organized by MES College of Engineering, Kuttippuram, delivered a talk on "Optical NDT".	22.09.2021	Dr. A. Mujeeb
7.	Invited Speaker in the Online line session for the BSc honors Physics students of Punjab University, Chandigarh, "Developments on Interferomtery Techniques after Holography".	05.06.2021	Dr. A. Mujeeb
8.	"Photonic bandgap structures: Theory and applications, Department of Physics HHMSPB NSS College for Women,Neeramankara".	18.03.2021	Dr. Priya Rose T
9.	"Photonic bandgap materials and their applications", KCT- Online Faculty Development Programme On "Applied optics and Photonics", Department of Physics, Kumaraguru College of Technology, Coimbatore-641049, Tamilnadu .	11.08.2021	Dr. Priya Rose T
10.	"Ultrafast Laser-matter Interaction "AICTE-ATAL FDP, M E S College of Engineering, Kuttippuram.	22.09.2021	Dr. Priya Rose T
11.	"Unravelling the common glitches in data Extraction" RYSO-21 Workshop, International School of Photonics.	15.12.2021	Dr. Priya Rose T
12.	KSHEC Sponsored One Week E-Summer School	16.05.2020	Dr.Saji K J
13.	Annual Physics Symposium, St Theresa's College	18.02.2020 & 19.02.2020	Dr.Saji K J

14.	Instructor at the "MaX School on Advanced Materials and Molecular Modelling with Quantum ESPRESSO" organized by the Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste	17.05.2021 to 28.02.2021	Dr. Praveen C S
15.	Organizing Secretary and Teaching Assistant for the summer school on 'Advanced Molecular Dynamics Simulations', Jointly organized by the International School of Photonics, Cochin University of Science and Technology, Department of Physics, Department of Chemistry and green club of Thoughts, Katmandu University, Nepal, and Scidart academy	6 .09.2021 to 17.09.2021	Dr. Praveen C S
16.	Co-ordinator and Resource Person for the "Workshop on Rendering your Scientific Output(RYSO-21), organized by the International School of Photonics, Cochin University of Science and Technology	22.09. 2021 to 30.09. 2021	Dr. Praveen C S
17.	Coordinator and Resource Person for the NANO-icon-2022 pre-conference workshop organized by the Inter-University Centre for Nanomaterials and Devices (IUCND), Cochin University of Science and Technology, Kerala	7.01.2022	Dr. Praveen C S
18.	Resource Person for the online workshop entitled "D.F.T. investigation of the electronic structure using Quantum Espresso and BURAI software (Atoms, Molecules, Compounds and Crystalline Materials)" organized by the Centre for Research, Innovation and Training (CRIT), IIS (Deemed to be University), Jaipur in collaboration with Gramin Mahila Mahavidyalaya, Sikar	9.02.2022 to 17.02.2022	Dr. Praveen C S
19.	Delivered an invited talk on Laser and Optical Safety at the Workshop on Rendering Your Scientific Output (RYSO-21), held at International School of Photonics, Cochin University of Science and Technology	22.09.2021 to 30.09.2021	Dr. Pramod Gopinath

Memorandum of Understanding

International School of Photonics team up with premier institutes around the globe

Erasmus+ is the European Union's program to support education, training, youth and sport in Europe. ISP has tie-ups with both Gothenburg University, Sweden and Dublin City University, Ireland under this program.

Gothenburg University, Sweden

Dublin City University , Ireland

Indian Institute of Technology , Madras , India

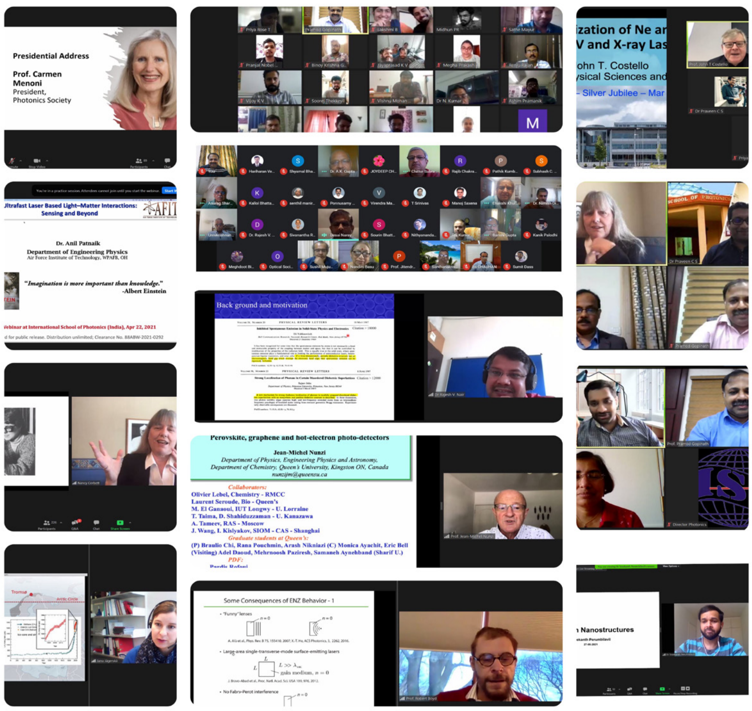
University de Rennes 1, France

NPS 2021

The National Photonics Symposium is an unparalleled event conducted by the International School of Photonics annually during the month-end of February. As a part of the silver Jubilee celebration of the school, NPS-2021 was organized as an international conference focusing on recent trends in photonics science and technology. NPS 2021- International Conference on Recent Trends in Photonics was conducted from 27 February 2021 to 01 March 2021.The conference offered a platform for researchers across the country to present and discuss their research work related to the thrust area. The event included seminars by eminent scholars from the leading institutes from across the globe giving insight to novel arenas of photonics research along with oral and poster presentations of budding researchers. The event was inaugurated by the Hon. Vice Chancellor of Cochin University of Science & Technology, Prof. (Dr.) K. N. Madhusoodhanan. Prof. (Dr.) Pramod Gopinath, Director, ISP welcomed the gathering. Prof. Ebrahim Karimi, from University of Ottawa, Canada gave the keynote address on the structured photons and their applications in quantum optics and also felicitated the event.

"Photonics News", the annual souvenir of the school comprehending the activities of the International School of Photonics for the year 2020, articles briefing the developments in several fields in Photonics by the research scholars and faculty members, and the details of NPS-2021, was released by Hon'ble Vice Chancello by handing it over to the Prof. (Dr). Pramod Gopinath, Director, ISP. Several merit awards were distributed to students and research scholars for their outstanding contribution to research and academic excellence for the year 2020. The inauguration ceremony was concluded by a vote of thanks delivered by Dr. Priya Rose T. The conference had more than two hundred registered participants from various research instututions across the country. All the research scholars, M. Tech. students, project students, and integrated M.Sc.(Photonics) students from ISP also attended and actively participated in discussions of the sessions lead by eminent scientists. The major areas of discussion were Quantum Optics, Terahertz science, Optical fiber technology, Nano photonics, Plasmonics, Metamaterials, Biophotonics, Nonlinear Optics and Laser Technology, Optoelectronic devices, Photonic/Optoelectronic Materials, Laser induced plasma, Ultrafast laser-matter interactions.

Cherishing Moments....



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