



National Centre for Physics

ABSTRACT BOOK

9th International Symposium on Light Matter Interaction (ILMI-2025)

November 20-21, 2025

National Centre for Physics (NCP), Islamabad, Pakistan



Abstract Book

9th International Symposium on Light Matter Interaction (ILMI-2025)

Atomic and Laser Physics, EPD, CoE Physics

National Centre for Physics(NCP), Islamabad.

Organized by



November 20-21, 2025

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Introduction to CoE Physics

The Center of Excellence in Physics is a platform for performing cutting edge research in Theoretical and Experimental Physics, and allied disciplines with emphasis on creating innovative solutions for the socioeconomic development of the country.

The CoE Physics is engaged in following research areas of Physics:

1. **Theoretical Physics:** The Department of Theoretical Physics (TPD) was formally established in 2008. The main aim of creation of this department is to strengthen the activities in theoretical physics and to promote international links. TPD has now the tradition of carrying out research in a broad range of subjects across theoretical physics. This Department is regularly organizing Schools, Workshops and conferences in various areas of theoretical physics. It has also initiated Teachers training program to promote and enhance the skills and capabilities of physics teachers working in Pakistani Universities and colleges.
2. **Experimental High Energy Physics:** The Experimental High Energy Physics (Exp. HEP) department at NCP is playing an active role in the CMS experiment at the LHC since 2000 and collaborating in hardware projects and physics analysis of CMS data. Members of this department have been actively involved in the search for Higgs boson which was discovered by the CMS and ATLAS experiments at CERN in 2012. The large amount of data produced by the LHC has been managed by NCP in real time through Worldwide LHC Computing Grid (WLCG).
3. **Experimental Physics:** Experimental Physics is involved in research areas related to ion-solid interaction focusing on novel materials and ion beam applications in different fields, materials sciences, semiconductors, ion beam applications. The state-of-the-art 5MV Pelletron Tandem Accelerator Facility [Technical specifications: Beam Energy: 0.8MeV to 25 MeV; Charging System: Pelletron Charging; Ion Current: 1 nA -200nA; Ions (available): H, He, C, Si, Cu, Ni and Au; and Two Beam Ports (15° & 30°)] at NCP Complex offers its professional expertise to the researchers and industry in Pakistan. Another focus of the department is on the light-matter interaction, where, thin film growth using Pulsed Laser Deposition (PLD), Laser induced breakdown spectroscopy (LIBS), and the development of Fiber Lasers, and fabrication of photodetectors are the main research areas.

In CoE Physics, we have not only well-equipped Laboratories but also have foreign qualified faculty. At least 30 PhDs are presently working in CoE Physics who have extensive experience in their respective fields.

Atomic and Laser Physics

The Atomic and Laser Physics (ALP) group is mainly working in three different directions

1. Laser Induced Breakdown Spectroscopy (LIBS)
2. Thin film growth by Pulsed Laser Deposition (PLD)

3. Development of Fiber Laser

Laser Induced Breakdown Spectroscopy (LIBS)

The LIBS is a technique for the elemental analysis of any material, including solids, liquid, and gases. It has many applications in different fields, e.g., space exploration, environmental monitoring, mining, agriculture, and the nuclear industry, etc. The ALP group is focusing on the improvement of the Limit of Detection of different elements by LIBS using different emission intensity enhancement methods, including E or B field-assisted LIBS, Dual pulse, and nanoparticle-enhanced LIBS. The control of self-absorption, detection of isotopes by LIBS and its applications in the field of Tokamak is the interest of the ALP group. The use of different machine learning techniques for refining the data analysis is also becoming an important part of research focus. The ALP group is actively collaborating with different research groups of the Chinese Academy of Sciences (CAS), China.

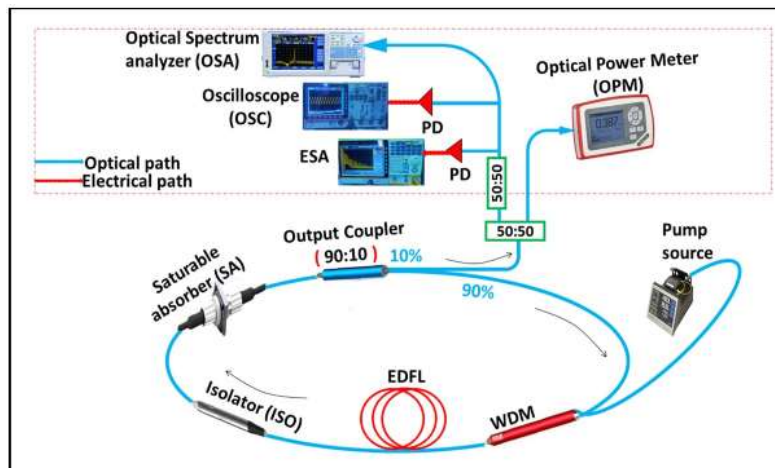
Thin Film Growth by Pulsed Laser Deposition (PLD)

Pulsed Laser Deposition (PLD) is a versatile, high-energy physical vapor deposition (PVD) technique renowned for synthesizing complex thin films with precise stoichiometry, excellent crystallinity, and tailored functional properties. By harnessing the power of pulsed laser ablation, PLD enables the growth of multicomponent materials, including high-temperature superconductors to multiferroic oxides that are challenging to fabricate via conventional methods. The ALP group has already developed the oxides (ZnO , TiO_2 , V_2O_5 , VO_2) thin films by PLD and device fabrication, including diodes, transistors, and photodetectors is the main thrust of this direction. In the device fabrication, the active layer is being prepared by PLD, while the patterned metal contacts are being fabricated using the thermal evaporator system. The ALP group has the facility to characterize the thin films by photoluminescence (PL) and Raman spectroscopy.



Development of Fiber Laser

A fiber laser is a type of laser in which the active gain medium (where light amplification occurs) is an optical fiber doped with rare-earth elements (e.g., Ytterbium (Yb^{3+}), Erbium (Er^{3+}), or Thulium (Tm^{3+})). The laser beam is generated, amplified, and delivered *within the fiber itself*, leveraging the principles of total internal reflection to guide light with exceptional efficiency. It has several advantages as compared to a solid-state laser (e.g., Nd:YAG), including compact design with better beam quality, efficiency, robustness, easy thermal management, and the possibility for scaling its power to kW. ALP group developed a ring cavity Er-doped fiber laser and achieved Q-switching using the saturable absorber fabricated by PLD. The main interest of this direction is to fabricate a mode-locked fiber laser for LIBS and 3D printer applications.



Facilities at Atomic and Laser Physics

The Atomic and Laser Physics Laboratory (ALPL) is equipped with the following experimental facilities.

1. LIBS system including high-power Nd:YAG laser and Avantes spectrometer
2. Pulsed Laser Deposition system (Nd:YAG Laser @266nm + RHEED)
3. Basic infrastructure for the development of Fiber laser, including OSA, ESA, pump diode lasers, doped fibers, and other optical components
4. Photoluminescence setup
5. Photodetector characterization setup
6. Raman spectroscopy
7. Thermal evaporator for metallic thin film coatings

Introduction to ILMI

The International symposium on Light Matter Interaction (ILMI) is being successfully organized from last the NINE consecutive years, establishing itself as a regular scientific event in the national research calendar. The first meeting was held in 2017, attracting more than 70 researchers from various institutions across Pakistan. In 2018, the event grew further, with over 80 participants, including several renowned national scientists. Over time, this activity has gained significant recognition and popularity within the physics community of Pakistan.

During the last five years, more than 90 M.Phil. and Ph.D students, along with university faculty members, have been regularly attending this event. The meeting has become an excellent platform for young researchers to present their work, exchange ideas, and build collaborations. Building upon this success, this year we plan to further strengthen the international dimension of the meeting by inviting five distinguished speakers from outside Pakistan (in person/online). Their participation will enhance the scientific diversity of the event and provide local researchers with valuable exposure to emerging global research trends. The main idea of holding the symposium is to provide a common platform to the national/international researchers working in the field of light matter interaction to discuss and share the recent advancements and challenges. The symposium shall highlight the emerging technologies and prospects in the field of light matter interactions.

Major Topics

- Laser Induced Breakdown Spectroscopy (LIBS)
- Fiber optic sensors
- Fiber Lasers
- Materials spectroscopy
- Pulsed Laser Deposition (PLD)
- Semiconductor thin film preparation and processes
- Semiconductor lasers

This year more than 130 participants are going to attend this activity. There will be 25 oral presentations by the national/international speakers/invited speakers and more that 20 young scholars will present their research work by poster presentation. It is being organized by NCP in collaboration with the Pakistan Academy of Sciences (PAS), Abdus Salam International Centre for Theoretical Physics (ICTP), Italy from November 20-21, 2025 at NCP Islamabad.

9th International Symposium on Light Matter Interaction (ILMI-2025)

Atomic and Laser Physics, CoE Physics, NCP Islamabad

DAY 1 Thursday (Nov. 20, 2025)		
Nov. 20, 2025 Inaugural Session		
09:00 – 09:05	Recitation	
09:05 – 09:20	Introduction of <i>ILMI</i> by <i>M. Aslam Baig (Secretary General PAS)</i>	
09:20 – 09:30	Opening remarks by <i>Qaisar Ahsan (DG NCP)</i>	
09:30 – 09:40	Welcome remarks by <i>M. Aftab Rafiq (DG CoE Physics)</i>	
09:40 – 10:00	Inaugural Address by <i>S.M. Javed Akhtar (Chief Guest)</i>	
10:00 – 10:30	Shaukat Hameed (Keynote Speaker)	A Brief Profile of Lasers in Pakistan
10:30 –11:00	Group Photo & Tea BREAK	
Nov. 20, 2025 ILMI Session - I		
11:00 – 11:30	Qiang Zeng (China)	In-situ analysis of the physical and chemical properties of nuclear materials using laser-induced breakdown spectroscopy
11:30–12:00	M. Saleem (NILOP)	Photomedicine-Contributions of NILOP
12:00 – 12:30	M. Sabbtain Abbas (S. Korea)	Fabrication of freestanding semiconductor thin films using 2D materials coated substrates
12:30 – 13:00	Dr. Izhar Ahmad (NILOP)	Development of an all-diode-pumped picosecond laser system
13:00 – 14:00	LUNCH BREAK	
Nov. 20, 2025 ILMI Session - II		
14:00–14:30	Khurram Siraj (UET LHR)	Measuring elemental compositional effect of diabetes on dental hard tissues: LIBS, a potential tool
14:30–14:50	Mirza Akbar Ali (Germany)	Frequency ratio measurements of a Quantum Logic Al+ Ion Optical Clock and progress towards redefinition of SI unit Second
14:50–15:10	Nasar Ahmad (Univ. AJK)	p-Si/n-WO3 hetero-junctions based high performance UV-photo detection using pulsed laser deposition
15:10–15:30	Muzamil Shah QAU Islamabad	Probing Topological Phase Transitions in Monolayer Jacutingaite through Magneto-Optics
15:30–15:45	Muhammad Mumtaz (NILOP)	Terahertz spectroscopy and its applications
15:45–16:00	Tea/Discussion	

DAY 2 Friday (Nov. 21, 2025)		
Nov. 21, 2025 ILMI Session - III (Online)		
08:45 – 09:00	Saifullah Jamali (China)	Comparison of Dual-Modality Fusion Strategies for Enhanced Rock Identification using Laser Induced Breakdown Spectroscopy (LIBS) and Imaging
09:00 – 09:20	Zhipeng Dong (China)	1.3/1.4 μm fiber laser based on Bismuth-Doped Fiber
09:20–09:40	M. Shafi (Saudi Arabia)	Recyclable photo induced enhanced Raman spectroscopy (piers) substrates using AgNPs-hyperbolic metamaterial for ultrasensitive and reusable detection
09:40– 10:00	Walid Tawfik (Egypt)	Modern advances in laser applications for environmental pollution and biomedical therapies
10:00– 10:15	Muhammad Fakhar-e-Alam (GCU Faisalabad)	Laser-driven photodynamic and chemotherapeutic performance of tempo-capped gadolinium-doped iron oxide nanoparticles for MRI applications
10:15– 10:30	Asadullah Dawood (Univ. of Rasul Mandi Bahuddin)	Optimizing cu-alloy surface characteristics through magnetic field-enhanced fs laser treatment
10:30 – 11:00	Tea BREAK	
Nov. 21, 2025 ILMI Session - IV		
11:00 – 11:20	Yasir Jamil (UAF)	Advancing Elemental Analysis: Machine Learning-Enhanced LIBS for Multidisciplinary Applications
11:20 – 11:40	Hamza Qayyum (COMSATS)	Laser-matter interaction driven formation of anisotropic gold nanoworms with tunable optical and catalytic properties
11:40 – 12:00	Javed Iqbal (AJK Univ.)	Influence of DC Electric Fields on Critical Power for self-focusing and Filamentations dynamics of Laser Pulses in Air
12:00 – 12:20	Sabih-ud-Din Khan (NIOP)	Development of Laser-based Accelerators in Pakistan
12:20 – 12:40	M. Noaman-ul- Haq (Optics Lab.)	Genetic Algorithm Based Optimization in Laser Driven Ions
12:40–13:00	Rizwan Ahmed (NCP Islamabad)	Electric field assisted LIBS for the detection of chlorine and trace elements
13:00–14:00	LUNCH BREAK/Juma Prayer	
Nov. 21, 2025 ILMI Session – V		
14:00–14:15	Madiha Liaquat (IIU Islamabad)	Promising solution for electromagnetic interference shielding using novel Ta2C Mxene-based nanocomposites
14:15–14:30	M. Amin (Univ of LHR)	Transfer matrix method as a tool for probing optical responses of a thin film: a theoretical approach
14:30–14:45	Amina Zafar (PINSTECH)	Synergic effect of a MoS2–V2O5 heterostructure as an advanced catalyst for photocatalytic degradation of methylene blue
14:45–15:30	Concluding Remarks by Dr. M. Usman & Distribution of certificates by Chief Guest.	

Biography of Speakers

Shaukat Hameed Khan

Returning after BSc & D.Phil. (Oxford), Dr. Shaukat Hameed started and headed the laser program in Pakistan for over 3 decades. On retirement from PAEC as Chief Scientist, he joined the Planning Commission looking after national programs in S&T and Higher Education. He has worked as Rector of GIKI, and Coord. General of COMSTECH (OIC S&T programs). Apart from nearly 50 publications in journals and conferences, other major works include the Vision 2030 Foresight Report (2007), National Industrial Policy (2011), and the Ten-Year S&T Program for OIC Countries, (approved at the Kazakhstan OIC Summit in September 2017). As Visiting Scientist at CERN, he helped design the Detector Position Monitoring System for the CMS Tracker, where 40 Pakistani designed laser systems are installed.

Qiang Zeng

Prof. Dr. ZENG is a researcher at the Institute of Modern Physics, and recognized as a scholar of “Hundred Talents Program” in Chinese Academy of Sciences. Also, Dr. ZENG serves as an early committee member of the Spectral Technology and Application Professional Committee of the Chinese Optical Engineering Society, as well as a Young Editorial Board Member of PhotonIX. What’s more, Dr. ZENG has participated in a major scientific instrument and equipment development project under China’s Ministry of Science and Technology, as well as a Singapore-France Joint Circular Economy Project SCARCE, where Dr. ZENG has developed multiple sets of LIBS devices with wide application potential in the industry fields. Currently, Dr. ZENG is employed as a key technical expert in a national-level major project, dedicated to the investigation of online compositional analysis of nuclear materials.

Muhammad Saleem

Dr. Muhammad Saleem is a distinguished scientist with extensive experience in laser spectroscopy, atomic physics, biomedical optics, and the design and development of innovative medical devices. Supervision of MPhil/MS/PhD students and more than 90 research publications at his credit. His work has led to the development of five trademarked medical devices, showcasing his commitment to innovation and translational research. Dr. Saleem has also promoted the use of Photodynamic Therapy (PDT) and Photobiomodulation Therapy (PBMT) for the treatment of various diseases, marking a breakthrough in non-invasive therapeutic technologies.

Khurram Siraj

Prof. Dr. Khurram Siraj is working as Director in Laser and Optronics Centre, UET, Lahore. He completed PhD from Johannes Kepler University Linz, Austria in 2007. The research interests are Laser matter interaction, Laser Induced breakdown spectroscopy, Pulsed laser deposition, Optical and energy materials.

Muhammad Mumtaz

M. Mumtaz is working as a Principal Scientist at NILOP. I have completed my Ph.D. from NILOP, PIEAS in 2021 in the field of THz photonics. My present research interests are ultrafast spectroscopy and high-power laser development.

Nasar Ahmed

Dr. Nasar Ahmed is an Associate Professor of Physics at the University of Azad Jammu & Kashmir. He completed his PhD in Laser–Matter Interactions from the National Centre for Physics, Quaid-i-Azam University Campus, Islamabad (2019). His research expertise spans Laser-Induced Breakdown Spectroscopy (LIBS), thin film fabrication using Pulsed and Advanced Pulsed Laser Deposition (PLD/APLD), and Light–Matter Interaction for photonic and optoelectronic applications. Dr. Ahmed has published over 60 research papers in reputed international journals. His work has received more than 1,200 citations with an h-index of 21 (Google Scholar, 2025).

Izhar Ahmad

Dr. Izhar Ahmad did his PhD from Max-Planck Institute for Quantum Optics, Garching, Germany. He is currently working at the National Institute of Lasers & Optronics College, Islamabad, Pakistan. He has expertise in the design and development of high-energy short-pulsed laser systems and their applications. He has authored or co-authored > 50 international publications with > 1200 citations.

Saifullah Jamali

Dr. Saifullah Jamali is a researcher at the Hefei Institute of Physical Sciences, Chinese Academy of Sciences. His research focuses on laser-induced breakdown spectroscopy (LIBS), optical spectroscopy, artificial intelligence and data fusion.

Muhammad Shafi

Dr. Muhammad Shafi is a researcher at the Interdisciplinary Research Center for Refining and Advanced Chemicals, King Fahd University of Petroleum and Minerals (KFUPM), Saudi Arabia. His research focuses on plasmonic nanostructures, photoinduced Raman spectroscopy (PIERS), and advanced materials for chemical and biosensing applications. Dr. Shafi has authored and co-authored several papers in high-impact journals in the areas of nanomaterials, spectroscopy, and materials characterization.

Walid Tawfik

Professor Walid Tawfik is the chairman of the Department of Laser Applications in Metrology, photochemistry and Agriculture (LAMPA), leader of the laser Spectroscopy and Ultrafast Lasers group, and head of the Central lab at the National Institute of Laser (NILES), at Cairo University, Egypt. His research focused on the applications of laser-induced plasma spectroscopy and ultrafast lasers in environmental pollution detection and laser cancer treatment; currently, he has two active

international projects in these fields. In Oct 2021, 2022, 2023, 2024 he was officially chosen among the distinguished scientists in the world's top 2% - in the field of photonics, according to a survey given by Stanford University USA. He is a senior member of international professional societies like IEEE, OSA, APS, and SPIE. He has collaborated with different international groups in the applications of laser spectroscopy and ultrafast lasers at Georgia Tech USA, Uni. of Electro-Communications Japan, and POSTECH Uni. South Korea, Quaid-i-Azam Uni. Pakistan, Kind Saud Uni. Saudi Arabia, Max-Planck Inst. Germany and Lodz Uni. of Tech. Poland.

Asadullah Dawood

Asadullah Dawood is a researcher in the field of laser-matter interaction and materials processing. He has worked at the Centre for Advanced Studies in Physics (GCU, Lahore), the National Excellence Institute, and internationally at the University of Waterloo (Canada) and Nazarbayev University (Kazakhstan). His research focuses on ultrafast laser applications, plasma diagnostics, and nanostructured material fabrication for advanced technological applications

Muhammad Noaman ul Haq

Dr. Muhammad Noaman ul Haq specializes in research concerning high-power, ultrashort laser applications, focusing particularly on laser-driven plasmas and particle acceleration. He was awarded an HEC overseas scholarship to pursue his Ph.D. studies in China (2014–2018). Dr. Haq is also an alumnus of the esteemed Lindau Nobel Laureate Meetings in Lindau, Germany and presently working in Optics Labs.

Rizwan Ahmed

Dr. Rizwan Ahmed did his PhD from Austria in 2012 and working as Principal Scientist at National Centre for Physics (NCP), Islamabad, Pakistan. He is a PIFI fellow of Chinese Academy of Sciences (CAS), member board of studies Rawalpindi Women University, member Technical Committee for Competitive Research Programme (CRP), Pakistan Science Foundation (PSF), Symposium Coordinator of ILMI from last 10 years and leading a research group at NCP Islamabad. He has established a well-equipped Laser facility at NCP Islamabad. His research interest includes, LIBS, PLD, Fiber laser and published more than 100 articles in different Journals of good repute and several book chapters.

Madiha Liaquat

Madiha Liaquat is a PhD candidate in Physics at the International Islamic University, Islamabad. Her research focuses on the synthesis and characterization of 2D carbon-based layered nanocomposites for electromagnetic interference shielding.

Muhammad Amin

Dr. Muhammad Amin, Assistant Professor, The University of Lahore, Lahore. I, Dr. Muhammad Amin have first-hand experience to synthesize materials like DMS, Multiferroics, Ferrites, and metal oxides. I also have experience working on High-Temperature Furnaces, Hydraulic Press, coating units, and vacuum systems. I am expert in material synthesizing techniques named sol-gel auto combustion and solid-state reaction (ball milling). I am doing research both in experimental and computational Physics. My area of interest included Nanotechnology, Thin film technology, Magnetism/Magnetic materials, Multiferroics, energy storage, energy harvesting and data storage devices.

Amina Zafar

Dr. Amina Zafar is a Principal Scientist at the Pakistan Institute of Nuclear Science and Technology (PINSTECH). Her research interests include: nanomaterials, 2D semiconductors, energy storage devices and photocatalytic materials. She has authored 45 peer-reviewed publications with more than 970 citations and an h-index of 14. Dr. Zafar also serves as an Editor of *The Nucleus* journal and a reviewer for several international journals in materials science and nanotechnology.

Abstracts of Oral Presentations

IN-SITU ANALYSIS OF THE PHYSICAL AND CHEMICAL PROPERTIES OF NUCLEAR MATERIALS USING LASER-INDUCED BREAKDOWN SPECTROSCOPY

Qiang Zeng^{a,b}, Dongbin Qian^{a,b}

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Introduction:

Nuclear energy is one of the most important energy choices for human beings. According to the development plan of the Chinese government, the total installed capacity will exceed 100 GW in 2030. At this scale, the disposal of the spent nuclear fuel (SNF) will be extremely challenging. Regarding this, the Institute of Modern Physics, Chinese Academy of Sciences proposed the construction of Accelerator Driven Advanced Nuclear Energy System (ADANES), aiming at recycling the SNF. Whereas, the recycling process evolves a lot elementary concentration measurement regarding the SNF and structure parts. Traditional instrumental techniques, such as gamma ray spectrometry and ICP-MS, are complicated and inaccurate under radiation environment. There is an urgent demand of an in-situ analysis method for the concentration analysis without sampling and secondary pollution.

Description of the Work or Project:

With the advantages of flexibility, compactness, remote operability, and enabling real-time, in situ analysis in hazardous or inaccessible environments, Laser-Induced Breakdown Spectroscopy (LIBS) has emerged as a promising analytical tool in nuclear power industry. Our team are developing adaptable LIBS devices for different nuclear scenarios, including stand-off LIBS (ST-LIBS) and fiber-optical LIBS (FO-LIBS). And we are trying to combine the calibrations of physical matrix effects with advanced machine learning algorithms to realize the simultaneous analysis of the physical and chemical properties of nuclear materials. What's more, combining beam shaping of a laser with suitable intensity normalization, we've realized the depth profiling of the structure parts, which enables in-situ characterization of corrosion process.

Conclusions:

LIBS presents significant potential in extensive scenarios due to its intrinsic advantages. And the portability and adaptability of LIBS in complex and harsh environments have been a key factor in their increasing applications in nuclear industrial fields. The integration of advanced data processing algorithms including machine learning could further enhance the accuracy and robustness of LIBS in industrial and nuclear facility monitoring. In the future, more novel optical designs and complementary techniques could be explored to fully leverage the potential of FO-LIBS for real-time, in-situ, and high-precision analysis in ADANES and other nuclear settings.

Keywords: Laser-Induced Breakdown Spectroscopy, FO-LIBS, In-situ analysis, nuclear industry

1.3/1.4 MM FIBER LASER BASED ON BISMUTH-DOPED FIBER

Zhipeng Dong

*Department of Electronic Engineering, Xiamen University, Fujian, 361005, P.R.China***Abstract:**

This report summarizes recent advancements and potential applications of Bismuth-doped fiber lasers (BDFLs) and amplifiers operating in the O-band and E-band (approximately 1260 nm to 1460 nm). Light sources in these bands are critical for various applications, including optical communication (e.g., short-distance communication sources), sensing and metrology (e.g., spectroscopy and gas detection), and biomedical imaging. Significant progress has been made in BDFL development, including power, linewidth, and pulse-width. In recently, we demonstrated a Single-Longitudinal-Mode (SLM) BDFLs, mode-locked fiber laser, and Watt-Level tunable lasers. These results affirm the strong potential of bismuth-doped fibers as a versatile platform for high-performance fiber sources, paving the way for applications in next-generation full-band optical communication, high-resolution spectroscopy, and biophotonics.

A BRIEF PROFILE OF LASERS IN PAKISTAN

Shaukat Hameed Khan

*Presented at the 9th International Symposium on light Matter Interaction (ILMI-2025)***Abstract:**

Laser activity has evolved in Pakistan since 1968 when the first He-Ne laser was built in the Atomic Energy Centre, Lahore. This was the mother institute of the Pakistan Atomic Energy Commission (PAEC) and had introduced a wide range of emerging fields including solar and lasers. After nearly 57 years, there are now more active laser/optronics scientists and engineers in the PAEC compared with nuclear physicists, and the activities include light-matter interaction, spectroscopy, postgraduate teaching, laser manufacture, and exports to S.E Asia and also Europe. A recent acknowledgement was the announcement of Associate Membership with CERN.

The laser activities have now evolved into the National Institute for Lasers and Optics (NILOP). Which has recently been designated as leading National Institute for Quantum Computing. These will be elaborated upon by the Director of NILOP in this conference.

Content:

After a brief introduction of laser profile and facilities in Pakistan, the author will discuss laser produced plasmas and ultra-fast high voltage switches, selective / spectroscopic excitation of atoms and molecules, and use of lasers in agriculture and defence. Exciting new opportunities are emerging in quantum computing, fusion, sensors, semiconductor manufacturing, medical treatment, and defence., and several activities are already underway. Pakistan is quite self-sufficient in manufacture of laser systems and optical components.

- Design and Development of Laser Systems from UV to IR
- Ultrafast High-Voltage Switching
- Laser Spectroscopy of Atoms and Molecules
- Precision Position Monitoring Systems for the massive CMS Detector, CERN, Geneva.

ILMI-4-O

**MODERN ADVANCES IN LASER APPLICATIONS FOR ENVIRONMENTAL
POLLUTION AND BIOMEDICAL THERAPIES**

Walid Tawfik

National Institute of Laser Enhanced Sciences, LAMPA Department, Cairo University, Cairo

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Abstract:

The application of laser technology has rapidly advanced in both environmental monitoring and biomedical therapies, offering revolutionary tools for detecting pollution and treating diseases with unprecedented precision. In the field of environmental pollution, ultrafast picosecond Laser-Induced Breakdown Spectroscopy (Ps-LIBS) has emerged as a powerful technique for the rapid detection of toxic heavy metals in environmental samples, such as soils and plant tissues. Using a 1064 nm Nd:YAG ps-laser, this method can quantify contaminants like Fe, Zn, Cd, and Cu in less than a few seconds, with high spatial resolution. It provides valuable real-time data to manage pollution and safeguard public health, particularly in agricultural environments impacted by untreated industrial discharges.

On the biomedical front, recent innovations in laser-activated nanoplateforms have revolutionized cancer therapy. Gold and graphene nanomaterials, when activated by Near-Infrared (NIR) lasers, exhibit exceptional photothermal properties, enabling precise tumor destruction while minimizing damage to surrounding healthy tissues. These nanoplateforms achieve thermal efficiencies exceeding 85%, significantly outperforming traditional chemotherapy. Notably, these platforms demonstrate the ability to overcome multidrug resistance and induce selective ablation of tumors

in vivo. The combined use of plasmonic resonance and oxidative stress through these laser-activated nanostructures offers promising avenues for personalized and effective cancer treatments.

Both applications represent cutting-edge solutions, emphasizing the potential of laser technologies in solving critical challenges in environmental pollution detection and the treatment of complex diseases. These advancements mark significant strides toward sustainable practices in environmental health and precision medicine.

ILMI-5-O

FREQUENCY RATIO MEASUREMENTS OF A QUANTUM LOGIC AL⁺ ION OPTICAL CLOCK AND PROGRESS TOWARDS REDEFINITION OF SI UNIT SECOND

Mirza Akbar Ali^{a*}, Fabian Dawel^b, Derwell Drapier^b, Lennart Pelzer^b, Kai Dietze^b, Bennet Benny^b, Johannes Kramer^c, and Piet O. Schmidt^{a,b}

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Abstract:

Since 1967, the measurement of time is conducted using atomic clocks. The latest generation of optical atomic clocks shows two orders of magnitude improved statistical uncertainty and estimate an improvement of two orders of magnitude on the systematic frequency uncertainty compared to the microwave Cs-clocks. For the redefinition of the second, confirmation of the estimated error budgets of optical clocks by frequency ratio measurements is required. Here we present realization of aluminum ion clock using quantum logic spectroscopy with co-trapped calcium ion – which is used for cooling and readout. The co-trapped ion allows sympathetic electromagnetically induced transparency (EIT) cooling during the clock interrogation, which reduces the second-order Doppler effect. The introduced electric field of the cooling lasers can be characterized by Ca⁺ allowing to bound the ac-Stark shift on Al⁺ on a low 10^{-18} uncertainty level, which is the largest contribution to the total systematic frequency uncertainty of 1.7×10^{-18} . We show frequency ratio measurements against a Sr lattice clock with a stability of $5.9 \times 10^{-16} \sqrt{1 \text{ s}/\tau}$, limited by the Al⁺ ion clock stability. The resulting frequency ratio of $27\text{Al}^+ / 87\text{Sr}$ shows a significant difference to the published results.

Keywords: Ion Clock, Quantum Logic Spectroscopy, SI Second, Ion Cooling, Atomic Optical Clocks, Precision Measurement

PHOTOMEDICINE-CONTRIBUTIONS OF NILOP

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Abstract

In this presentation, contributions of NILOP in the field of Photomedicine will be presented. NILOP has developed different clinical lasers having applications in various disease conditions and ultraviolet based disinfection units for health care system. Furthermore, portable Fluorosensor has been developed for photodiagnosis, will also be described.

TRANSFER MATRIX METHOD AS A TOOL FOR PROBING OPTICAL RESPONSES OF A THIN FILM: A THEORETICAL APPROACH

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Abstract:

Experimental fabrication of thin films often requires advanced facilities, significant cost, and complex processes. In contrast, the Transfer Matrix Method (TMM) offers a powerful, accurate, and cost-effective theoretical framework for predicting optical behavior prior to fabrication. By systematically analyzing the influence of key parameters such as film thickness, wavelength, and refractive index on transmission, reflection, and absorption phenomena, TMM minimizes experimental effort while providing critical insights that guide experimental studies and the rational design of optoelectronic devices. By utilizing TMM, the transmission, reflection, and absorption properties of Strontium Titanate (STO) thin films are analyzed across a wide range of wavelengths. For 250 nm and 260 nm thick STO thin films, the optical direct band gaps 3.49 eV and 3.59 eV respectively are found to be consistent with the experimental findings. Additionally, the impacts of film thickness and optical band gap on response of STO thin films are explored. It is noticed that with the increase in thickness of thin film, the band gap is redshifted and its value is increased as well. The findings presented in this paper contribute to a comprehensive understanding of the optical behavior of STO thin films, enabling further advancements in the design and fabrication of STO-based optoelectronic devices. We will be able to modify the performance of optoelectronic devices before their physical fabrication by tailoring the properties of the optical materials using TMM that would save both money and time.

Conclusions:

The transfer matrix method (TMM) was used to find the transmission spectra of SrTiO₃ thin films fabricated through pulsed laser deposition and then compared with experimental data. We observed that our theoretical transmission spectrum is similar to the experimental data for shorter wavelengths but for longer wavelengths there is a difference because of reflection domination. Incorporating the Lorentz model with TMM, other optical properties like real refractive index n and absorption coefficient α of the thin film were calculated. The Tauc plot of α^2 versus photon energy helps us to find the optical band gaps of the thin films. It was found that the optical band gap of SrTiO₃ thin films are 3.50 eV and 3.58 eV which is close to the experimental calculations. In future, the researchers will be able to predict the optical properties of thin films of unknown materials successfully with high accuracy by applying TMM.

Keywords: Thin Film; TE-mode of light; TMM; Transmittance; Band Gap

ILMI-8-O

PROMISING SOLUTION FOR ELECTROMAGNETIC INTERFERENCE SHIELDING USING NOVEL TA₂C MXENE-BASED NANOCOMPOSITES

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Introduction:

The rapid expansion of 5G and IoT technologies has intensified electromagnetic interference (EMI) challenges. To overcome these, the development of lightweight, flexible, and high-performance shielding materials has become crucial. However, achieving stable polymer–MXene composites with exceptional shielding efficiency and mechanical flexibility remains a challenge.

Description of the Work or Project:

This study explores the fabrication and EMI shielding performance of PANI/Ta₂C and PANI/Graphene/Ta₂C (PGM) nanocomposites as free-standing, flexible thin films. Chemically synthesized PANI/Ta₂C nanocomposites exhibit a remarkable shielding efficiency of 58 dB across the 7-13 GHz frequency range, corresponding to 99.999% attenuation and a specific shielding performance (SSE) of 580 dB mm⁻¹. The incorporation of graphene nanoplatelets (GNPs) into the PANI/Ta₂C matrix further enhances the shielding to 70 dB (99.99999% attenuation) with an SSE of 700 dB mm⁻¹. This enhancement arises from synergistic effects of interfacial polarization,

Ohmic losses, surface reflection (from Ta₂C MXene and GNPs), and dipole polarization. The excellent shielding, flexibility, and lightweight nature make these nanocomposites ideal for next-generation EMI shielding in wearable electronics, aerospace, and electronic packaging.

Conclusions:

PANI/Ta₂C and PANI/GNPs/Ta₂C composites offer outstanding EMI shielding with mechanical flexibility and low density, showing strong potential for practical applications in modern communication and defense technologies.

Keywords: Electromagnetic interference; MXene; Graphene; Polyaniline; Shielding effectiveness.

ILMI-9-O

INFLUENCE OF DC ELECTRIC FIELDS ON CRITICAL POWER FOR SELF- FOCUSING AND FILAMENTATIONS DYNAMICS OF LASER PULSES IN AIR

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Abstract:

This study investigates the influence of direct current (DC) electric fields on laser filament signal and fluorescence signal, which leads to the precise measurement of the critical power for self-focusing (P_{cr}) of ultrafast laser filamentations in air. Laser filamentations is a complex nonlinear optical phenomenon characterized by the self-focusing of high-intensity laser beams, resulting in the formation of plasma channels and have emerging applications due to its characteristics. We study the application of DC electric fields on filament signal, which significantly increase the intensity of filament signal and enhanced fluorescence in the low ionization region, which effect the dynamics for laser filament. This effect is due the collision driving process of the charge particles with the air molecules. The dominant enhancement of the 337 nm emission (neutral nitrogen) compared with 391 nm emission (Ionized nitrogen) due to DC Electric field in the low ionization region. Due to increase, the collision rates between free electrons and air molecules, increase excitations. We experimentally measured the critical power for self-focusing by Focus Shift method. It is observed that the measurement of critical power for self-focusing is more precise due applied the electric field on the filament signal, which is not possible without field. These results not only advance the understanding of filamentations in the presence of external electric

fields but also have potential implications for the controlling the nonlinear optical processes and applications of laser filamentations

Keywords: femtosecond laser filamentation; precise measurement of critical power for self-focusing; intensity and length of filament, Enhancement in fluorescence signal.

ILMI-10-O

DEVELOPMENT OF AN ALL-DIODE-PUMPED PICOSECOND LASER SYSTEM

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Introduction:

Picosecond (ps) lasers have wide-range of applications in the industry, defense, satellite laser ranging, medical surgery, dermatology, and high-field physics. Conventional high-energy picosecond laser amplifiers are commonly pumped using flash-lamps, which suffer from inherent energy instability, low-rep rate, and higher temporal jitter issues. The diode-pumped solid state (DPSS) laser systems provide a reliable solution of these problems. However, achieving Joule-level energy, in DPSS ps lasers, in non-CPA configuration, is a real challenge. Low optical damage threshold, small scale self-focusing, thermal lensing, and non-uniform diode pumping profiles are the major concerns in this regard.

Description of the Work:

In this work, development of an all-diode pumped Nd:YAG laser amplifier delivering 1064 nm wavelength pulses of 1280 mJ energy with <200-ps pulse duration at a repetition rate of 10 Hz, is presented. The system comprises a low energy seed source followed by a pre-amplifier, a post-amplifier, and a booster amplifier with successively increasing aperture sizes. Relay imaging, spatial filtering, spatial apodization, and polarization rotation techniques have been incorporated in the intermediate amplification stages for spatial pulse cleaning and shaping in order to mitigate the adverse effects of nonlinearities. Extracted energy in each gain amplifier show better than 90% agreement with theoretical calculations. Under normal operation condition with controlled temperature and humidity, the output of the system features ~ 1.1% (RMS) instability in the pulse energy. This is the World-highest reported-energy, to the best of our knowledge, for any ps-class non-CPA Nd: YAG DPSS laser system.

Conclusion:

The developed laser system is a great addition to the non-CPA diode pumped short-pulsed laser technology. This technique offers a simple, compact, and reliable solution to develop a high-energy ps-class DPSS laser system with improved energy stability, and less timing jitter compared with conventional flash lamp based systems. This system is advantageous in short-pulse pumped optical parametric laser amplifiers, medical surgery and remote laser ranging.

Keywords: picosecond laser; diode-pumped laser; short-pulsed Nd:YAG laser.

ILMI-11-O

ADVANCING ELEMENTAL ANALYSIS: MACHINE LEARNING-ENHANCED LIBS FOR MULTIDISCIPLINARY APPLICATIONS

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Abstract:

The work highlights the transformative role of machine learning (ML) in enhancing the analytical capabilities of Laser-Induced Breakdown Spectroscopy (LIBS) across diverse scientific and technological domains. Through a series of case studies, we demonstrate the application of ML-assisted LIBS for in-depth material analysis, such as plasma diagnostics of hafnium and classification of lanthanum-doped bismuth ferrite. In medical science, nanoparticle-enhanced LIBS combined with ML enables early breast cancer detection by identifying elemental biomarkers in blood samples. Agricultural applications include accurate classification of rose species and varieties based on elemental composition, while forensic investigations leverage ML-LIBS to distinguish between burnt and unburnt paper samples, aiding in arson and document authenticity analysis. The integration of supervised and unsupervised machine learning models—such as PCA, LDA, SVM, and neural networks—significantly improves classification accuracy, signal interpretation, and diagnostic precision. These findings underscore the versatility, speed, and robustness of ML-enhanced LIBS as a powerful tool for real-time, non-destructive elemental analysis in research and industrial applications.

Keywords: Machine Learning, Laser-Induced Breakdown Spectroscopy (LIBS), Plasma Diagnostics, Material Classification, Medical Diagnostics, Forensic Analysis, Agricultural Science, Nanoparticle Enhancement, Elemental Analysis, Predictive Modeling.

SYNERGIC EFFECT OF A $\text{MoS}_2\text{-V}_2\text{O}_5$ HETEROSTRUCTURE AS AN ADVANCED CATALYST FOR PHOTOCATALYTIC DEGRADATION OF METHYLENE BLUE

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Introduction:

Rapid industrialization and population growth have led to severe water contamination, primarily from persistent organic dyes discharged by the textile industry. To address this challenge, we explore advanced oxidation processes (AOPs) driven by light-matter interactions as a sustainable route for pollutant degradation. In this work, we present the design of $\text{MoS}_2\text{-V}_2\text{O}_5$ heterostructures that form a type-II band alignment, enabling efficient charge separation and enhanced visible-light absorption. The heterostructures synthesized via an ultrasonic-assisted solvothermal method exhibit remarkable photocatalytic activity toward methylene blue degradation under UV-visible irradiation. Our findings highlight the crucial role of engineered light-matter interactions in heterostructured photocatalysts paving the way for next-generation materials in environmental remediation and solar-driven chemical processes.

Description of the Work or Project:

This project focuses on the design and synthesis of a $\text{MoS}_2\text{-V}_2\text{O}_5$ heterostructured photocatalyst for the efficient degradation of organic pollutants specifically methylene blue (MB) from wastewater. The study aims to address the increasing environmental pollution caused by synthetic dyes through the development of a high-performance, stable and recyclable photocatalyst based on advanced oxidation processes (AOPs).

The $\text{MoS}_2\text{-V}_2\text{O}_5$ heterostructure was synthesized using a hydrothermal-solvothermal combined approach assisted by ultrasonic treatment. Structural and morphological characterizations (XRD, FESEM, TEM, HRTEM, Raman and XPS) confirmed the successful formation of a crystalline, chemically bonded $\text{MoS}_2\text{-V}_2\text{O}_5$ interface, providing enhanced electronic interaction between the two semiconductors.

Optical analysis revealed a reduced bandgap (2.56 eV) and improved visible light absorption due to synergistic coupling between MoS_2 (2.33 eV) and V_2O_5 (2.75 eV). The heterojunction formation facilitates efficient charge carrier separation and minimizes electron-hole recombination which is critical for improving photocatalytic efficiency. Under UV irradiation, the $\text{MoS}_2\text{-V}_2\text{O}_5$ heterostructure achieved 97.35% degradation of methylene blue within 17 minutes outperforming pristine V_2O_5 (85.32%) and MoS_2 (89.06%) respectively. The kinetic rate constant (0.2137 min^{-1}) was approximately 2.7 times higher than MoS_2 and 3.3 times higher than V_2O_5 , confirming strong synergistic behavior. Radical scavenging tests identified hydroxyl radicals ($\cdot\text{OH}$) and holes (h^+) as the primary reactive species in the degradation process. Furthermore, the catalyst exhibited

excellent stability and reusability over six consecutive cycles without significant loss of activity or structural degradation demonstrating its potential for long-term environmental applications.

The overall findings establish that the MoS₂-V₂O₅ heterostructure acts as a type-II photocatalyst, enabling rapid pollutant degradation through effective charge transfer, strong light absorption and enhanced photo-reactivity. This study provides a sustainable and cost-effective solution for wastewater purification and contributes to the broader field of 2D/1D hybrid photocatalyst design for environmental remediation.

Conclusions:

In summary, the MoS₂-V₂O₅ heterostructure was successfully synthesized via a simple ultrasonic-assisted solvothermal method and confirmed through various characterization techniques. The composite exhibited exceptional photocatalytic performance, achieving 97.35% methylene blue degradation within 17 minutes with a rate constant (0.21374 min^{-1}) 2.7 and 3.3 times higher than MoS₂ and V₂O₅, respectively. This enhanced activity is attributed to efficient charge separation, reduced recombination, and strong interfacial synergy between MoS₂ and V₂O₅. Hydroxyl radicals and holes were identified as the main reactive species, demonstrating the catalyst's strong potential for effective pollutant removal and environmental remediation.

Keywords: MoS₂-V₂O₅ heterostructure; Photocatalytic degradation; advanced oxidation processes (AOPs), Charge carrier separation, Methylene blue removal

ILMI-13-O

LASER ENERGY PARTITIONING IN NANO SECOND PULSED LASER INDUCED AIR BREAKDOWN: EFFECT OF LASER INDUCED ENERGY AND WAVELENGTH

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Introduction:

This study presents an experimental comparison of nanosecond pulsed laser-induced air breakdown at 1064 nm and 532 nm wavelengths. For the 1064 nm laser, the deposited energy (E_d) increased from 85% to 92% of incident energy (E_i), while the shock wave velocity followed the laser-supported detonation wave model ($v \propto E_i^{0.3}$). However, the E_i -to-shock wave energy (E_s) conversion efficiency decreased from 83% to 48% at higher E_i , indicating that a greater portion of energy was consumed in plasma heating and radiation. In comparison, the 532 nm wavelength exhibited a threshold for shock wave generation approximately 3.5 times lower due to

the stronger absorption characteristics of air at this wavelength. Despite this, both the shock wave velocity and pressure were consistently higher for the 1064 nm laser — for instance, pressures up to 15.74 MPa were observed at 1 mm — attributed to enhanced cascade ionization rates and stronger inverse bremsstrahlung absorption. The classical Taylor-Sedov blast wave model provided a good fit for the 1064 nm data, whereas a weak shock wave scaling law was required to accurately describe the 532 nm results. These insights into energy partitioning and shock wave dynamics have significant implications for applications such as laser-induced breakdown spectroscopy (LIBS) and laser propulsion systems.

Conclusions:

The characteristics of shock waves produced during air breakdown by 532nm and 1064nm wavelength lasers are experimentally investigated in the laser energy range of 25–140 mJ. Our findings suggest that laser wavelength plays an important role in the formation and propagation of shock waves. For both wavelengths, the shock wave velocity increases as the laser pulse energy increases; however, the velocity of a shock wave generated by a 532 nm laser beam is consistently lower than that produced by a 1064 nm wavelength. Similarly, the shock wave pressure is also consistently lower in the case of a 532 nm laser beam compared to a 1064 nm laser beam. This difference arises from the varying degrees of laser energy coupling with ambient air through different mechanisms at 532 and 1064 nm wavelengths. At higher laser energies, the saturation in the velocity and pressure of the shock wave is probably due to the saturation of the absorption in the blast region. The laser energy threshold for shock wave generation is significantly lower for 532 nm than for 1064 nm laser pulses, as the absorption coefficient of air decreases with increasing wavelength. The shockwave propagation data at a wavelength of 1064 nm aligns well with the predictions of the classical Taylor–Sedov model. In contrast, the recently proposed Wei–Hargather scaling law for weak shock waves provides a better fit to the data at the 532 nm laser wavelength. These findings offer valuable insights into the mechanism of air breakdown and will be beneficial for various applications, including laser propulsion, laser ignition, and laser-induced breakdown spectroscopy.

ILMI-14-O

P-Si/N-WO₃ HETERO-JUNCTIONS BASED HIGH PERFORMANCE UV-PHOTO DETECTION USING PULSED LASER DEPOSITION

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Introduction:

Tungsten oxide (WO₃) is a multifunctional n-type semiconductor widely recognized for its excellent electrical, optical, and structural characteristics. It is used in electrochromic, sensing, and optoelectronic devices. However, its intrinsic limitations in charge carrier mobility and light absorption restrict its full potential in photodetection applications. Doping WO₃ with noble metals such as gold (Au) introduces localized surface plasmon resonance (LSPR) effects, enhancing carrier generation, photon absorption, and overall photoresponsivity. This work explores Au-doped WO₃ thin films fabricated through pulsed laser deposition (PLD) for the realization of high-performance and self-powered ultraviolet (UV) photodetectors.

Description of the Work or Project:

Au-doped WO₃ thin films were deposited on boron-doped p-type silicon (p-Si) substrates using a Q-switched Nd laser (266 nm, ~10 mJ pulse energy) at a substrate temperature of 600 °C and an oxygen pressure of 10 Pa. Structural, morphological, and compositional analyses were carried out using XRD, XPS, FE-SEM, Raman, FTIR, and EDX techniques to confirm crystalline phase formation and successful Au incorporation. The resulting p-Si/n-WO₃ heterojunction exhibited superior UV photoresponse characteristics, achieving a high responsivity of ~80 A/W, specific detectivity of 7.07×10^{11} Jones, and fast response times of 130 ms (rise) and 180 ms (fall). Notably, the device displayed excellent self-powered behavior, generating an open-circuit voltage (V_{oc}) of ~0.48 V and a short-circuit current (I_{sc}) of ~0.06 μA under UV illumination without external bias. The improved performance arises from enhanced charge separation at the p–n junction interface, reduced recombination losses, and plasmon-induced light absorption from Au nanoparticles.

Conclusions:

The Au-doped WO₃ thin films developed via PLD demonstrate a remarkable combination of high responsivity, detectivity, and stability, with efficient self-powered photodetection capability. These findings suggest that Au-doped WO₃ heterojunctions can serve as efficient, cost-effective, and environmentally stable candidates for next-generation UV photodetectors and optoelectronic sensors. The proposed fabrication approach also highlights the versatility of PLD in achieving controlled stoichiometry and doping uniformity, paving the way for future integration into flexible and miniaturized devices.

Keywords: Light–Matter Interaction; Au-doped WO₃; Pulsed Laser Deposition; UV Photodetectors; Self-powered Devices; Heterojunctions.

MEASURING ELEMENTAL COMPOSITIONAL EFFECT OF DIABETES ON DENTAL HARD TISSUES: LIBS, A POTENTIAL TOOL

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Abstract:

Concerning dental treatment failures in diabetic patients, this study evaluates the effect of diabetes mellitus type II (T2DM) on the elemental composition of human dental tissues (enamel, coronal dentine, and cementum). Thirty extracted premolars and molars (healthy group: n=13, diabetic group: n=17) were sectioned into enamel, dentine, and cementum. The one-line calibration-free Laser-induced Breakdown Spectroscopy (OL-CFLIBS) approach was used for compositional analysis of three tissues, which was validated with Energy-dispersive X-ray Spectroscopy (EDS). Laser-induced plasma parameters (plasma temperature and electron number density) were used in OL-CFLIBS. Statistical significance ($P < 0.05$) of the outcomes was assessed using the Student t-test and Mann-Whitney U test. Laser-induced intense plasma on diabetic patient's dental tissues yields higher values of plasma parameters (electron number density and plasma frequency) relative to healthy participants. The diabetic tissues exhibited lower concentrations of Zn, Sr, Si, and K ($P < 0.05$), but higher concentrations of Fe and Sn ($P < 0.05$), which is correlated with diabetes. LIBS quantitative findings agreed with EDS for elements (Ca, P, Na) within a relative error of 5%. Diabetes-induced alterations in the elemental composition of three tissues can be measured by detecting variations in plasma parameters and the concentration of trace elements. Clinically, Laser-induced Breakdown Spectroscopy (LIBS) can serve as a diagnostic and preventive tool in dentistry for monitoring trace element content, allowing early intervention and reducing the risk of dental treatment failures in diabetic patients

Keywords: Laser; LIBS; Diabetes; Dental tissues; Plasma parameters; Trace elements

RECYCLABLE PHOTOINDUCED ENHANCED RAMAN SPECTROSCOPY (PIERS) SUBSTRATES USING AgNPs-HYPERBOLIC METAMATERIAL FOR ULTRASENSITIVE AND REUSABLE DETECTION

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Introduction:

Surface-enhanced Raman spectroscopy (SERS) has emerged as one of the most powerful analytical techniques for ultrasensitive molecular detection due to its ability to amplify Raman signals by several orders of magnitude. However, the limited charge-transfer efficiency between metallic nanoparticles and certain analytes restricts the sensitivity of conventional SERS platforms. To overcome this limitation, photoinduced enhanced Raman spectroscopy (PIERS) has been developed, where UV irradiation stimulates additional charge transfer at the metal-semiconductor interface, further enhancing Raman signals.

Hyperbolic metamaterials (HMMs), characterized by their unique electromagnetic dispersion, offer an excellent platform for integrating plasmonic and photocatalytic functionalities. In this work, Ag-decorated Au/TiO₂ multilayer HMM structures were fabricated as recyclable PIERS substrates. The synergistic interaction between the electromagnetic and chemical enhancement mechanisms enables strong field confinement, increased electron density, and exceptional photocatalytic self-cleaning capability. The developed AgNPs@HMM substrates exhibit a record enhancement factor of $\sim 47\times$ compared with traditional SERS and demonstrate stable reusability for more than sixteen analytical cycles without performance degradation.

Description of the Work or Project:

In this study, recyclable photoinduced enhanced Raman spectroscopy (PIERS) substrates were designed by integrating silver nanoparticles (AgNPs) with a hyperbolic metamaterial (HMM) composed of alternating Au/TiO₂ multilayers. The HMM architecture supports both surface plasmon polaritons and bulk plasmon polaritons, enabling simultaneous electromagnetic (EM) and chemical (CM) enhancement mechanisms. The uniformly distributed AgNPs on the HMM surface generate nanoscale gaps that act as electromagnetic “hot spots,” while UV irradiation induces strong charge transfer at the Ag-TiO₂ interface. This dual mechanism produces a remarkable Raman signal amplification, approximately 47 times higher than that of traditional SERS substrates, representing one of the highest reported PIERS enhancements.

Beyond high sensitivity, the fabricated AgNPs@HMM substrates exhibit excellent photocatalytic self-cleaning capability under UV light, enabling their reuse for at least 16 consecutive analytical cycles without any noticeable decrease in signal intensity. The combination of strong plasmonic coupling, enhanced charge transfer, and photocatalytic activity establishes this platform as a robust and sustainable PIERS system for ultrasensitive molecular detection in biomedical, forensic, and environmental applications.

Conclusions:

This work demonstrates a novel strategy for developing recyclable and high-performance PIERS substrates by integrating Ag nanoparticles with Au/TiO₂ hyperbolic metamaterials (HMMs). The hybrid structure effectively combines electromagnetic and chemical enhancement mechanisms, resulting in a record signal enhancement factor of approximately $47\times$ compared to traditional SERS platforms. Moreover, the AgNPs@HMM substrates exhibit excellent photocatalytic activity, enabling self-cleaning and stable reusability for at least sixteen detection cycles without

any loss of performance. The prolonged relaxation time and efficient charge transfer at the Ag-TiO₂ interface make these structures a promising platform for sensitive, sustainable, and cost-effective Raman sensing. This study provides new insight into the design of multifunctional plasmonic-photocatalytic materials for future applications in biomedical diagnostics, environmental monitoring, and chemical security detection.

Keywords: Photoinduced Enhanced Raman Spectroscopy; Surface-Enhanced Raman Scattering (SERS); Hyperbolic Metamaterials (HMMs); Silver Nanoparticles; Plasmonic Nanostructures; Photocatalytic Activity; Reusability.

ILMI-17-O

OPTIMIZING CU-ALLOY SURFACE CHARACTERISTICS THROUGH MAGNETIC FIELD-ENHANCED FS LASER TREATMENT

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Abstract:

We report on the influence of an externally applied transverse magnetic field (TMF) on the plasma characteristics and surface structuring of Cu-alloys irradiated with femtosecond (fs) Ti: Sapphire laser pulses (800 nm, 35 fs, 1 kHz). A wide range of laser irradiances (0.011–0.117 PW/cm²) were used under argon and neon environments at an optimized pressure of 15 Torr. A TMF of 1.1 T was applied to confine the plasma, and its effects were evaluated by measuring excitation temperature (T_{exc}) and electron density (n_e) through femtosecond laser-induced breakdown spectroscopy (fs-LIBS). The results demonstrate that both T_{exc} and n_e increase significantly in the presence of TMF, confirming the role of magnetic confinement in enhancing collisional processes and plasma stability. Thermal beta (β_t), directional beta (β_d), confinement radius, and diffusion time were analytically evaluated to support these findings. Scanning electron microscopy (SEM) of the irradiated surfaces revealed the formation of low- and high-spatial-frequency laser-induced periodic surface structures (LIPSSs), along with micro-cavities, nano-rims, droplets, and agglomerates. The structures observed under TMF were more distinct, uniform, and spatially organized than those generated in its absence. These findings highlight that the combination of femtosecond laser irradiation and magnetic confinement enables controlled surface nanostructuring of Cu-alloys. The technique shows strong potential for advanced material processing applications, including nano-grating fabrication, surface-enhanced spectroscopies, and field emitters, where spatial uniformity is critically important.

Keywords: Light–Matter Interaction; Femtosecond Lasers; Laser-induced Breakdown Spectroscopy (LIBS); Cu-alloy Surface Structuring; Magnetic Confinement; Laser-induced Periodic Surface Structures (LIPSS).

Introduction:

Laser–matter interaction has become a vital area of research due to its wide applications in materials processing, nanofabrication, and spectroscopy. Among various approaches, femtosecond (fs) lasers are particularly important because of their ultrashort pulse durations and minimal thermal effects, enabling precise micro- and nano-scale structuring of surfaces. Additionally, the application of external magnetic fields to control plasma dynamics has attracted significant attention, as it enhances confinement, excitation temperature, and electron density of laser-produced plasma (LPP). This study investigates the combined effect of fs laser irradiation and magnetic field confinement on Cu-alloy surface structuring, with emphasis on improving uniformity, periodicity, and nanostructure control.

Description of the Work:

In this work, a Ti: Sapphire fs laser (800 nm, 35 fs, 1 kHz) was used to irradiate commercially available Cu-alloy targets under argon and neon environments at 15 Torr. A transverse magnetic field (TMF) of 1.1 T was applied to confine the plasma generated during ablation. Plasma parameters, namely excitation temperature (T_{exc}) and electron density (n_e), were measured using femtosecond laser-induced breakdown spectroscopy (fs-LIBS). Analytical models were employed to calculate thermal beta, directional beta, confinement radius, and diffusion time, confirming magnetic confinement effects.

To correlate plasma parameters with surface morphology, scanning electron microscopy (SEM) was carried out at two irradiance levels (0.025 and 0.082 PW/cm²). The analysis revealed the formation of laser-induced periodic surface structures (LIPSSs), cavities, nano-rims, and droplets. The application of TMF resulted in well-defined, highly uniform structures compared to the field-free case. Both low-spatial-frequency LIPSS (LSFL) and high-spatial-frequency LIPSS (HSFL) were observed, with reduced periodicity under magnetic confinement.

Conclusions:

The study demonstrates that the combination of fs laser ablation and magnetic field confinement enables precise control of Cu-alloy surface structuring. Enhanced plasma parameters (T_{exc} and n_e) in the presence of TMF lead to distinct and uniform nanostructures, confirming the critical role of magnetic confinement in improving laser-material interactions. This approach provides a pathway for advanced applications in nano-grating fabrication, surface-enhanced spectroscopies, and high-performance electronic and optical devices where spatial uniformity is essential.

TERAHERTZ SPECTROSCOPY AND ITS APPLICATIONS

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Introduction:

In the electromagnetic spectrum, terahertz (THz) radiation lies between the microwave and infrared regions, representing a previously unexplored gap. With the invention of the femtosecond laser, broadband terahertz (THz) radiation can be generated, which can be utilized as a spectroscopic tool. Terahertz (THz) spectroscopy has emerged as a powerful, non-destructive tool for probing the structural, electronic, and vibrational properties of diverse materials. Its unique capability to access low-energy excitations enables applications in chemical identification, pharmaceutical quality control, biomedical diagnostics, and security screening. The present work highlights the recent advances in THz spectroscopy, emphasizing its sensitivity, real-time measurement potential, and prospects for implementation in material characterization research.

Description of the Work:

Terahertz time-domain spectroscopy has been utilized for the measurement of optical, dielectric, and conductive properties of different materials such as polymers and transparent conducting oxides. The time-domain THz pulses for the reference and sample were measured, which were converted into frequency-domain spectra with a fast Fourier transform. These spectra contain the information on amplitude and phase which can be utilized to calculate the optical properties, such as refractive indices and absorption coefficient of the sample under observation. We have used this technique to investigate the doping effects in the optical, dielectric, and conductive properties of TiO₂ and temperature effects on the refractive indices of different polymers and their blends. Moreover, we have studied the EMI shielding effectiveness of different polymers/nano-composites.

Conclusions:

In summary, THz spectroscopy is an effective tool for the characterization of materials in a non-contact and non-destructive way.

Keywords: Femtosecond laser; terahertz Spectroscopy; refractive index.

GENETIC ALGORITHM BASED OPTIMIZATION IN LASER DRIVEN IONS

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Introduction:

High peak power laser sources have reached capabilities of hundreds of terawatts (TW) and tens of petawatts (PW), driving various initiatives in both basic and applied research worldwide. The generation of high-power, ultra-short, and intense laser pulses was fundamentally advanced in 1985 with the development of the Chirped Pulse Amplification (CPA) technique. CPA allows an ultra-short pulse to be safely stretched in time, effectively amplified without damaging the laser medium, and then precisely compressed back to its initial duration. When focused onto a solid target, these pulses achieve extremely high peak intensity, often exceeding $\geq 10^{18}$ W/cm², which instantly converts the target matter into the plasma state. These resulting laser-produced plasmas are a promising, compact source for accelerating particles, leading to significant research interest in laser-driven ion acceleration over the past few decades.

Description of the Work or Project:

The acceleration of ion beams using high-power lasers is emerging as a promising alternative to conventional accelerators, attracting considerable interest over the last decade due to its potential applications in science, industry, and healthcare. To make laser-driven protons viable for these applications, it is essential to improve key parameters such as stability, maximum energy, and reduce the broad energy spread. Controlling the laser and target parameters allows for the optimization of the resulting proton beam. This work reports on the use of a deformable mirror (DM) to precisely control the proton beam parameters through a feedback loop and genetic algorithms. By manipulating the laser pulse shape, the DM can effectively manage the crucial laser-plasma interaction to produce optimized proton beams. This proof-of-principle experiment demonstrates the potential of this novel technique for robust and dynamic control of proton beams in future applications.

Conclusions:

In this work, laser-driven protons generated from a tape target were optimized using a genetic algorithm-controlled deformable mirror (DM) integrated into an active feedback loop that utilized the proton spectral information. The optimization successfully maximized the proton energy to approximately 5 MeV with an error of about 10% compared to the reference spectrum obtained from a conventionally optimized focal spot. These results were published in Nuclear Instruments and Methods in Physics Research A (NIMA).

Keywords: Light Matter Interaction; laser driven proton; Deformable Mirror.

COMPARISON OF DUAL-MODALITY FUSION STRATEGIES FOR ENHANCED ROCK IDENTIFICATION USING LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS) AND IMAGING

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Introduction:

Accurate identification of rock types plays a vital role in geological exploration, resource development, and environmental monitoring. However, similar visual and spectral properties among rocks reduce classification accuracy when using only laser-induced breakdown spectroscopy (LIBS). This study proposes a dual-modality fusion approach integrating LIBS with imaging data to enhance rock classification accuracy.

Description of the Work:

LIBS spectra were preprocessed using the Gramian Angular Field (GAF) technique to convert one-dimensional data into two-dimensional images, which were then fused with rock sample images captured by an iPhone. Several data fusion strategies were evaluated, including early-level, feature-level, and advanced-level fusion. The LIBS-only model achieved 92.73% accuracy, early-level fusion 83.63%, feature-level fusion 98.18%, and advanced-level fusion reached 99.09%. The results demonstrate that advanced fusion combining elemental information from LIBS and color–texture data from images significantly enhances rock identification performance.

Conclusions:

Integrating LIBS and imaging data enables more robust and accurate classification of rocks. Among all tested methods, the advanced-level fusion strategy provided the best performance, achieving nearly perfect classification accuracy. This approach offers valuable insights for geological and environmental studies that rely on accurate material discrimination.

Keywords: Light Matter Interaction; Laser-induced breakdown spectroscopy (LIBS); data fusion; Gramian Angular Field (GAF); rock classification.

ILMI-21-O

PROBING TOPOLOGICAL PHASE TRANSITIONS IN MONOLAYER JACUTINGAITE THROUGH MAGNETO-OPTICS

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We present a theoretical framework to investigate quantum magnetotransport in monolayer jacutingaite, focusing on its response to external electric fields and off-resonant circularly polarized laser irradiation. Our analysis reveals a sequence of topological phase transitions triggered by tuning these external parameters. Applying a perpendicular magnetic field, we study Landau Level (LL) formation, spin- and valley-polarized splitting, and magneto-optical response in distinct topological phases. We find that the zeroth LL exhibits spin- and valley-polarized splitting, leading to four distinct peaks in the DOSs. We demonstrate that reversing the electric field or flipping the light helicity changes the Dirac mass sign in specific spin-valley sectors, which in turn reverses both the Berry curvature and the magnetic moment. Our results reveal that external electric, magnetic, and off-resonant optical fields can control these conductivities. These findings highlight monolayer jacutingaite as a highly tunable platform with strong potential for future applications in photonics, optoelectronics, and topological quantum devices.

ILMI-22-O

LAER-DRIVEN PHOTODYNAMIC AND CHEMOTHERAPEUTIC PERFORMANCE OF TEMPO-CAPPED GADOLINIUM-DOPED IRON OXIDE NANOPARTICLES FOR MRI APPLICATIONS

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Introduction:

Photodynamic therapy (PDT) is an emerging treatment modality that employs the photochemical interaction of three components. These are light of suitable wavelength, photosensitizer, and

singlet oxygen. The main objective of this work is the determination of pharmacokinetics of different photosensitizers after laser irradiation in different biological samples like cell lines and tissues to improve the efficacy of PDT. Present study analyzes the dynamic behavior of different photosensitizers under laser irradiation e. g. (a) biodistribution of Photofrin® (b) Laser induced effects (c) Depth of necrosis under exposure of different wavelengths of light sources (d) Synergistic effect of toxicity of ZnO nanostructures bare and conjugated with photosensitizers like Aminolevulinic acid (5-ALA), Photofrin® and protoporphyrin dimethyl ester (PPDME) determined for the treatment of localized cancer cells.

Firstly, biodistribution of Photofrin® into Sprague Dawley rats has been investigated by methodology for radiolabelling of Photofrin® with ^{99m}Tc . In addition, it was explored that labelling efficiency of Photofrin® with ^{99m}Tc is more than 95%. The current technique is more simple and efficient as compared to the earlier published protocol. In the second part of this experimental study, different photosensitizer's uptake was explored in the in vitro model e. g. different cell lines (HepG2, RD, Hep2C, foreskin fibroblast, melanocytes). Study of optimal dose of laser, cell cytotoxicity and photo toxicity were also the part of our experiment. The third aspect of study relates to in vivo study, normal rat liver was treated as biological sample, PDT under illumination of different wavelengths of light (630nm, 660nm, 600nm and its alternate combinations) has been performed and proved that effectiveness of 630nm of wavelength is more efficient for depth of necrosis as compare to other wavelengths of light sources. Finally, the synergistic effect of toxicity of zinc oxide nanorods (ZnO NRs) conjugated with 5-ALA, Photofrin® and PPDME was determined for the treatment of localized cancer cells. Cell toxicity due to microinjection and free standing drug delivery was observed by detection of reactive oxygen species (ROS) liberation, and verified by MTT assay. It is successfully demonstrated that UV-A irradiation increased toxicity and caused significant production of ROS which lead to cell necrosis within few minutes. Zinc oxide nanorods are toxic for both normal as well as malignant cells under exposure of UV containing 240 nm of wavelength.

In current project, TEMPO (Organic materials) capped Gadolinium doped Iron Oxide Nanoparticles has been fabricated and characterized by applying manifold characterization techniques e.g. XRD, TEM, FTIR, EDX and UV Visible spectroscopy for feasibility of Laser guided photodynamic therapy. Finally checked for MRI and PDT, Chemotherapy and shown very satisfactory results towards MRI cancer diagnostics and cancer treatment (photodynamic therapy and chemotherapy applications).

Description of the Work or Project:

This study focuses on making and testing a new material for cancer treatment using light, called photodynamic therapy (PDT) where nanomaterials has been accumulated and under Laser guided applications, significant treatment achievements has been reported. Gadolinium dioxide nanorods (Gd_2O_3 NRs) were first made using the sol-gel method. Then, they were coated with a compound called TEMPO using oxoammonium salts. Several techniques were used to study the material, including X-ray diffraction (XRD), transmission electron microscopy (TEM), FTIR, and Raman

spectroscopy. The material was tested on MCF-7 human breast cancer cells. Results showed that plain Gd_2O_3 nanorods had little effect in the dark. However, when coated with TEMPO and exposed to UV-A light, they killed cancer cells effectively. This shows a strong combined effect (synergy) between TEMPO and Gd_2O_3 under light. The coated nanorods also helped overcome drug resistance in the cancer cells. In conclusion, TEMPO-coated Gd_2O_3 nanorods are a promising material for light-based cancer treatment.

Conclusion:

Very precise and desired based TEMPO (Organic materials) capped Gadolinium doped Iron Oxide Nanoparticles proved itself very marvelous materials towards cancer diagnostics (MRI Techniques) and cancer treatment (via PDT/Chemotherapy via MTT Assay and microscopy confirmed). This new development of leading technique will not only provide the roadmap for fruitful cancer treatment applications, it can be applied towards applied site after essential formalities and optimization.

Keywords: Photodynamic therapy, transmission electron microscopy (TEM), TEMPO-coated Gd_2O_3 nanorods

ILMI-23-O

ELECTRIC FIELD ASSISTED LIBS FOR THE DETECTION OF CHLORINE AND TRACE ELEMENTS

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Abstract:

The effect of external electric field on the laser generated plasma has been studied. It observed that, the laser generated plasma can be used for the ignition of a spark in the presence of a low voltage external electric field. An eight-fold emission intensity enhancement in the spectral lines are measured as compared to the emission intensity in the absence of an external electric field. In the presence of E-field, the plasma parameters remain the same initially up to few micro seconds after the generation of plasma and this feature make it more interesting for the quantitative analysis of any sample using Laser Induced Breakdown Spectroscopy (LIBS). In the presence of external electric field, fluctuations (contraction and expansion) in the laser generated plasma are observed which increase the plasma decay time and consequently result in enhanced emission intensity. The E-field assisted LIBS has been used for the detection of halogens and trace elements in different alloys and Li ore. The detection of halogens by LIBS is also a major challenge, for example the strong emission lines of the chlorine (Cl) are not easy to detect with the conventional LIBS

spectrometers because these spectral lines lie in the VUV region whereas relatively weak spectral lines lie in the NIR region. It will be presented that, an electric field assisted LIBS will be an ideal candidate for the detection of halogens especially Cl. The e-field assisted LIBS can be used for the detection of trace elements in different samples, e.g., Li Ore, alloys and soil samples etc. The limit of detection (LOD) of different elements can be improved using E-field assisted LIBS and few examples will also be presented.

Keywords: E-field assisted LIBS, Emission intensity enhancement, Limit of detection (LOD).

ILMI-24-O

FABRICATION OF FREESTANDING SEMICONDUCTOR THIN FILMS USING 2D MATERIALS COATED SUBSTRATES

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Abstract:

In the traditional epitaxy process, a layer of inorganic semiconducting material is grown on a substrate wafer. Once the material is formed in the desired orientation, the layer remains adhered to the substrate, which is inflexible and mechanically brittle due to strong covalent bond with the substrate. However, In the remote epitaxy process, epitaxial growth of semiconducting material takes place on 2D material coated substrate. This leads to the formation of epitaxial thin films with the same crystal orientation as that of substrate and makes it loosely bound by weak van der Waals (vdW) interaction with 2D material. As a result, there is a pathway to easily isolate semiconducting materials based functional devices by depositing a 2D handling layer and mechanically detaching it. The process is termed remote epitaxy because the 3D single-crystal film does not directly contact the underlying substrate but still follows its crystal orientation through the interlayer.

In this seminar presentation, the fundamentals of remote epitaxy will be thoroughly reviewed and the epitaxial growth of freestanding single-crystal GaN membranes using graphene and amorphous carbon (aC) as 2D inter layer will be demonstrated. The use of direct grown graphene and amorphous carbon acts as buffer layer for the growth of GaN to overcome growth induced thermal expansion coefficient and lattice mismatch between GaN and sapphire. Graphene and aC with tunable thickness and high uniformity are directly grown on c-sapphire using thermal

CVD. Furthermore, process control strategies at each growth step in MOCVD will be explored to ensure the preservation of the underlying graphene and amorphous carbon while maintaining the quality of GaN films. Precise control of process parameters, along with graphene quality control at each growth stage, facilitates the effortless release of GaN films. These epitaxially grown films are further utilized to fabricate transferable GaN LEDs by heteroepitaxial growth of $\text{In}_x\text{Ga}_{1-x}\text{N}/\text{GaN}$ multiple quantum wells and a p-GaN layer on the GaN films. Future perspectives of 2D transfer layer technique will be described for its potential use in next generation flexible electronic devices.

ILMI-25-O

DEVELOPMENT OF LASER-BASED ACCELERATORS IN PAKISTAN

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Abstract:

Since the invention of chirped pulse amplification technique in 1985 by Prof. Gerard Mourou and Prof. Dona Strickland (for which they received 2018 Nobel Prize in Physics) the laser intensities are on the increasing trend. This increasing intensity has surpassed the relativistic barrier of $10^{18}\text{W}/\text{cm}^2$ and enabled scientists to create laser-based accelerators all around the World with Europe's flagship facility ELI-NP and US's Lawrence Livermore National Lab taking the lead. Till date highest reported intensity is $1.1 \times 10^{23}\text{W}/\text{cm}^2$ achieved by our collaborators in CoReIs, Institute of Basic Science, South Korea, while highest accelerated electron energy is $>9\text{GeV}$ is reported by the US group centered around LBNL/LLNL. One of our team members Dr. Ahsan Mehmood conducted experiments of proton acceleration at CoReIs at $1.1 \times 10^{23}\text{W}/\text{cm}^2$ in 2021. In Pakistan, NILOP has already started laser-based acceleration development and its laser part is already under development stage, named "HPLaSE", which will reach $10^{18}\text{W}/\text{cm}^2$ in 2027. In this work, we will overview Laser Wakefield Acceleration for electron acceleration, its experimental design using particle-in-cell simulations at NILOP, various academic applications and our plans to setup acceleration facility at the output of HPLaSE.

ADVANCING ELEMENTAL ANALYSIS: MACHINE LEARNING-ENHANCED LIBS FOR MULTIDISCIPLINARY APPLICATIONS

Yasir Jamil

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Abstract:

The work highlights the transformative role of machine learning (ML) in enhancing the analytical capabilities of Laser-Induced Breakdown Spectroscopy (LIBS) across diverse scientific and technological domains. Through a series of case studies, we demonstrate the application of ML-assisted LIBS for in-depth material analysis, such as plasma diagnostics of hafnium and classification of lanthanum-doped bismuth ferrite. In medical science, nanoparticle-enhanced LIBS combined with ML enables early breast cancer detection by identifying elemental biomarkers in blood samples. Agricultural applications include accurate classification of rose species and varieties based on elemental composition, while forensic investigations leverage ML-LIBS to distinguish between burnt and unburnt paper samples, aiding in arson and document authenticity analysis. The integration of supervised and unsupervised machine learning models—such as PCA, LDA, SVM, and neural networks—significantly improves classification accuracy, signal interpretation, and diagnostic precision. These findings underscore the versatility, speed, and robustness of ML-enhanced LIBS as a powerful tool for real-time, non-destructive elemental analysis in research and industrial applications.

Keywords: Machine Learning, Laser-Induced Breakdown Spectroscopy (LIBS), Plasma Diagnostics, Material Classification, Medical Diagnostics, Forensic Analysis, Agricultural Science, Nanoparticle Enhancement, Elemental Analysis, Predictive Modeling

Abstracts of Poster Presentations

ON EXPLORING THE POTENTIAL OF MACHINE LEARNING ASSISTED NANOPARTICLES ENHANCED LASER INDUCED BREAKDOWN SPECTROSCOPY AS AN INITIAL SCREENING TOOL FOR EARLY BREAST CANCER DETECTION

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Abstract:

Early detection of breast cancer remains a significant challenge in low-income countries due to limited access to advanced diagnostic facilities. This study introduces a novel, rapid, and cost-effective approach that integrates Nanoparticle-Enhanced Laser-Induced Breakdown Spectroscopy (NE-LIBS) with machine learning for the preliminary screening of breast cancer. Silver (Ag) and copper oxide (CuO) nanoparticles were synthesized via pulsed laser ablation and deposited on dried blood samples to enhance plasma emission intensities. The enhanced signals, especially for metallic biomarkers such as calcium (Ca) and sodium (Na), were analyzed using supervised machine learning models including SVM, KNN, Decision Tree, and Neural Networks. Among these, the quadratic SVM and tri-layer neural network achieved the highest classification accuracies of 97–96.7%, effectively distinguishing cancerous from non-cancerous samples. The nanoparticle enhancement produced a 3–4-fold increase in signal intensity and improved signal-to-noise ratio (SNR) values, highlighting NE-LIBS as a sensitive and reproducible tool for biofluid elemental analysis. The combination of nanotechnology, laser-based spectroscopy, and artificial intelligence thus provides a promising non-invasive route for early breast cancer detection, particularly in resource-limited clinical settings.

Keywords: Breast Cancer; NE-LIBS; Laser-Induced Breakdown Spectroscopy; Machine Learning; Nanoparticles; Blood Diagnostics

Conclusion:

The findings of this study demonstrate that the integration of nanoparticle-enhanced LIBS with advanced machine learning algorithms can successfully differentiate between cancerous and non-cancerous blood samples with high accuracy and reproducibility. The inclusion of silver and copper oxide nanoparticles significantly amplified plasma emission intensities and improved SNR, enabling trace-level elemental detection in biofluids. The machine learning-assisted NE-LIBS approach offers a portable, rapid, and low-cost diagnostic alternative to conventional imaging and biopsy-based screening, making it especially beneficial for low-income regions where early

diagnosis remains a challenge. With further clinical validation and optimization, this technique has the potential to evolve into a scalable screening platform for early breast cancer detection and other biomedical applications.

ILMI-2-P

OPTICAL AND SPECTROSCOPIC CHARACTERIZATION OF RARE-EARTH METAL DOPED ZINC OXIDE NANOSTRUCTURES FOR ENHANCED LASER-MATTER INTERACTION

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Introduction:

Electronic and optical doping is an efficient technique for improving the electronic and optical characteristics of wide-bandgap semiconductors by introducing rare-earth elements. By modifying semiconductor materials through controlled doping techniques, their interaction with light and performance in optoelectronic and photonic applications are enhanced. In order to explore the possibility of improving laser-matter interaction and creating optical device technologies, erbium-doped zinc oxide (ZnO) nanostructures are being produced and characterized.

Description of the Work:

Sol-gel synthesis was used to create erbium-doped ZnO nanostructures, which were then deposited onto silica substrates by pulsed laser deposition (PLD). The successful integration of erbium ions into the ZnO lattice was validated by structural analysis, which also showed structural stability and uniform doping. Photoluminescence (PL) and laser-induced breakdown spectroscopy (LIBS) methods were used to examine the material's optical behavior.

The material's suitability for photonic and optoelectronic applications was confirmed by the intense photoluminescence produced around 1.55 μm by strong erbium-related emission transitions. Fluorescence lifetime values in the 8–12 ms range confirmed effective radiative recombination processes, while LIBS measurements showed a breakdown threshold of roughly 2.5 J/cm². According to the findings, erbium incorporation and improved optical stability and nonlinear response in ZnO nanostructures are strongly correlated.

Conclusions:

According to the study, erbium doping significantly enhances the optical and electrical properties of ZnO nanostructures, improving photonic performance and light-matter interaction. The material exhibits excellent emission stability, strong nonlinear optical properties, and efficient energy

transfer. These findings show that erbium-doped ZnO nanostructures have potential applications in solid-state lasers, optical limiters, and sophisticated spectroscopic sensing systems.

Keywords: Light–Matter Interaction; Materials Spectroscopy; Semiconductor Lasers; Nanomaterials; Energy Materials; Optical Properties; Photonic Devices

ILMI-3-P

LASER-MATTER INTERACTION DRIVEN FORMATION OF ANISOTROPIC GOLD NANOWORMS WITH TUNABLE OPTICAL AND CATALYTIC PROPERTIES

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Introduction:

Gold nanoparticles (Au NPs) have attracted significant interest due to their exceptional optical, thermal, and chemical properties, especially their tunable surface plasmon resonance (SPR), which can be adjusted by altering particle size and shape. This tunability makes them ideal for various applications, including photothermal therapy, catalysis, energy storage, and environmental remediation. Over the years, researchers have synthesized diverse gold nanostructures—such as nanorods, nanostars, nanoworms, and nanoflowers—using different biological, chemical, and physical methods. These anisotropic structures exhibit enhanced surface areas and broadband light absorption, making them particularly valuable for light-to-heat conversion in solar cells and cancer treatment, as well as in surface-enhanced Raman scattering (SERS) and photocatalysis.

Despite the success of chemical synthesis methods in producing shape-controlled Au NPs, they often involve toxic chemicals and surfactants that limit biocompatibility and catalytic efficiency. To overcome these drawbacks, laser-based physical synthesis methods have emerged as cleaner alternatives. Laser irradiation techniques, such as pulsed laser ablation in liquid (PLAL), allow the fabrication of surfactant-free Au nanoworms (NWs) with strong broadband absorption across the visible and near-infrared spectra. Previous studies demonstrated the formation of anisotropic or branched Au nanostructures using variations in laser fluence, wavelength, and pulse number. However, challenges remain in achieving precise control over the size and morphology of these laser-synthesized nanostructures while fully exploring their potential applications.

Description of the Work or Project:

We report the laser-induced fabrication of anisotropic gold nanoworms (Au NWs) through the morphological transformation of gold nanospheres (Au NSs) dispersed in ethanol. This surfactant-free, template-free approach enables the scalable synthesis of biocompatible Au NWs with broadband plasmonic absorption extending from the visible to the near-infrared (NIR) region. The formation process is strongly dependent on laser parameters, with optimal Au NW generation achieved at 120 mJ pulse energy and 4 minutes of irradiation. Control over nanoworm length was realized by varying ethanol concentration, enabling the synthesis of Au NWs with distinct aspect ratios. Structural and optical characterization by transmission electron microscopy (TEM) and UV–NIR spectroscopy confirmed their anisotropic morphology and broadband optical response, which was further supported by finite element method (FEM) simulations. Catalytic studies revealed that Au NWs possess significantly higher activity than their spherical counterparts, with long Au NWs showing up to 5.5-fold enhancement in azodye reduction. Furthermore, Au NWs were evaluated as surface-enhanced Raman spectroscopy (SERS) substrates for detecting crystal violet and the antibiotic vancomycin under 532 nm and 638 nm excitations. Longer Au NWs exhibited superior SERS enhancement due to a higher density of electromagnetic hotspots, with markedly stronger performance at 638 nm excitation as revealed by FEM simulations. These results demonstrate that laser-fabricated Au NWs combine tunable morphology, catalytic functionality, and broadband plasmonic properties, positioning them as promising nanostructures for photonic, catalytic, and sensing applications.

Conclusions:

In summary, gold nanoworms (Au NWs) were successfully synthesized using a laser-assisted, surfactant-free method that ensures high biocompatibility and broadband plasmon absorption from visible to near-infrared regions. The formation of Au NWs occurs through the coalescence of fragmented nanoparticles in ethanol, with their length tunable by adjusting ethanol concentration, laser energy, and exposure time. The resulting Au NWs exhibited superior catalytic performance over spherical nanoparticles, with higher aspect ratios further enhancing catalytic efficiency due to increased surface area.

Keywords: Laser-Assisted Synthesis; Broadband Plasmon Absorption; Catalytic Activity; SERS

SPECTROSCOPIC PROPERTIES AND TUNABLE COLOR EMISSION VIA $\text{Ce}^{3+}/\text{Dy}^{3+}$ ENERGY TRANSFER IN $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{P}_2\text{O}_5$ GLASSES FOR SOLID-STATE LIGHTING AND SCINTILLATION APPLICATIONS

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Introduction:

The continuous demand for advanced luminescent materials suitable for display technologies and solid-state lighting remains a central focus in materials research applications. Non-crystalline luminous glasses have been extensively developed either by controlled doping or by forming a coalescence of host lattices. Incorporation of transition metal ions or rare-earth (RE) elements into glass hosts has yielded a wide range of luminescent materials with tunable optical properties. Furthermore, co-doping with multiple activator ions has emerged as an effective approach to enhance emission efficiency and broaden emission spectra. RE-doped luminescent glasses have broad applications because of their extensive emission colors spanning broad wavelength regions

specifically for w-LEDs. Phosphate glasses have attracted considerable attention for their versatile applications in waveguides, solid-state lasers, sensing, detection, optical data transfer, and fiber-optical amplifiers. In their trivalent valence state $3+$, cerium (Ce^{3+}), and dysprosium (Dy^{3+}) ions serve as promising luminous centers for the development of w-LEDs. Thus, co-doping the phosphate glasses with Ce^{3+} and Dy^{3+} may significantly enhance their luminous properties.

Abstract:

The investigation of luminescent glasses has long aimed to improve emission intensity. Phosphate glasses doped with rare-earth (RE) ions are regarded as a promising high-gain laser material due to their favorable spectroscopic properties. In this study, a new series of glasses with the composition $15\text{K}_2\text{O}-20\text{Al}_2\text{O}_3-(64.5-X)\text{P}_2\text{O}_5-0.5\text{CeF}_3-X\text{Dy}_2\text{O}_3$, where $X = 0.0, 0.1, 0.3, 0.5, 1.0$, and 2.0 mol%, were synthesized using the solid-state reaction method. The physicochemical and optical properties were characterized by using X-ray diffraction (XRD), optical absorption spectroscopy, photoluminescence (PL) analysis, Judd–Ofelt (J-O) parameterization, decay time measurements, and photoluminescence quantum yield (PLQY) determinations. XRD confirmed the amorphous nature of all samples. The absorption spectra revealed ten distinct bands, including a hypersensitive transition at ${}^6\text{H}_{9/2} + {}^6\text{F}_{11/2}$, centered at 1278 nm. The glasses exhibited characteristic PL emissions in the blue (~ 484 nm) and yellow (~ 575 nm) regions. The J-O intensity parameters followed the order $\Omega_2 > \Omega_6 > \Omega_4$, indicating strong transitions. The ${}^4\text{F}_{9/2} \rightarrow {}^6\text{H}_{13/2}$ transition of Dy^{3+} ions displayed a high stimulated emission cross-section ($15.733 \times 10^{-22} \text{ cm}^2$), branching ratio (β_r ; Exp. = 0.637, Cal. = 0.593), and radiative transition probability (583.1 s^{-1}). The measured decay time of Dy^{3+} emission at 574 nm ($\lambda_{\text{ex}} = 350$ nm) decreased with increasing Dy^{3+} concentration, reaching a minimum of 0.52 ns at 2.0 mol%. Photoluminescence and X-ray luminescence spectra showed close agreement, both dominated by similar emission bands, confirming consistent radiative channels. Under UV excitation, $\text{Ce}^{3+}/\text{Dy}^{3+}$ co-doped glasses exhibited radiative energy transfer from Ce^{3+} to Dy^{3+} , with emission intensity increasing as Dy^{3+} ion concentration increased. The highest PLQY value of 37.62% was recorded for the 0.5Ce:0.1Dy glass sample. Additionally, the CIE coordinates (0.3895, 0.4332) and correlated color temperature (CCT) of 4100 K demonstrate that $\text{Ce}^{3+}/\text{Dy}^{3+}$ co-doped $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{P}_2\text{O}_5$ glasses are promising fluorescent materials for solid-state lighting devices.

Conclusion:

In this study, $\text{Ce}^{3+}/\text{Dy}^{3+}$ co-doped phosphate glasses were successfully synthesized and comprehensively characterized, revealing efficient energy transfer mechanisms and tunable photoluminescence. XRD confirmed the amorphous nature of all samples, while density increased from 2.561 to 2.689 g/cm³ and molar volume decreased from 49.59 to 48.95 cm³/mol with Dy^{3+} incorporation, indicating structural compaction of the glass network. The incorporation of Dy^{3+} ions led to strong yellow emission, while co-doping with Ce^{3+} ions effectively sensitized the Dy^{3+} emission through radiative energy transfer. Judd–Ofelt analysis confirmed a high degree of asymmetry around Dy^{3+} ions, with the ${}^4\text{F}_{9/2} \rightarrow {}^6\text{H}_{13/2}$ transition emerging as a dominant radiative

pathway well-suited for laser applications. Decay time measurements and photoluminescence quantum yield (PLQY) analysis revealed a concentration-dependent quenching behavior, offering valuable insights into optimal dopant levels for maximizing luminescence efficiency. The agreement between photoluminescence and radioluminescence decay profiles further confirmed the robustness of the $Ce^{3+} \rightarrow Dy^{3+}$ energy transfer process under varying excitation conditions. For the glass sample 0.5Ce:0.1Dy, the maximum PLQY value recorded was 37.62%. CIE chromaticity analysis revealed a shift from bluish-violet emission (0.1679, 0.0086) for Ce^{3+} to near-white emission (0.3895, 0.4332) for co-doped glasses, close to the ideal white point (0.3333, 0.3333). The correlated color temperature (3500–6500 K range) further supports their suitability for commercial solid-state lighting. Overall, the combined spectroscopic, quantum efficiency, and radiative property analysis demonstrates that Ce^{3+}/Dy^{3+} co-doped phosphate glasses are promising candidates for UV-pumped white LEDs, scintillation devices, and mid-range solid-state lasers. Future work will focus on evaluating their thermal stability, fabricating bulk and fiber glass forms, and advancing device-level integration to fully exploit their technological potential.

Keywords: Phosphate glasses, PL, Ce^{3+} & Dy^{3+} ions, Energy transfer, J-O Analysis

ILMI-5-P

LIGHT-MATER AND ELECTRON-MATER READOUTS CONVERGE: COMPARATIVE LIBS-EDS ELEMENTAL MAPPING WITH PCA BASED CLASS SEPARATION OF BOTANICALS.

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Introduction:

The universe exhibits remarkable diversity in the infinite wisdom of Allah, since every substance is made up of a distinct combination of elements. These elemental compositions determine the physical and chemical characteristics of substances and influence their effects on human health. The therapeutic value of medicinal plants is strongly associated with their elemental composition.

Description of the Work or Project:

In this study, Laser Induced Breakdown Spectroscopy (LIBS) was applied for rapid comparative elemental quantification of six commonly used botanicals: *Momordica charantia* (Bitter melon), *Terminalia chebula* (hareer), *Allium sativum* (garlic), *Cinnamomum verum* (cinnamon), *Commiphora Mukul* (Guggul), and *Azadirachta indica* (neem). Quantitative analysis was performed via CF-LIBS through the One-Line method, Number Density method and Intercept method, with careful self-absorption correction to boost precision. To further strengthen reliability,

results were cross-validated with SEM-EDS, confirming consistency in both major and trace elemental distributions. Importantly these plants are commonly consumed as food and herbal remedies in local diets. Their elemental evaluation not only scientifically relevant but also critical from a public health and nutritional perspective.

Conclusions:

This work demonstrates that LIBS, supported by PCA, provides a fast, non-destructive, and environmentally friendly analytical approach for quality assurance of medicinal quantification. It also bridges traditional ethnobotanical wisdom with modern spectroscopic sciences. Principle Component Analysis (PCA) of the all spectra revealed clear clustering patterns, showing distinct elemental fingerprints and inter-linkage of all plant. By linking their elemental enrichment profile with conventional pharmacological assertions reveals distinctive bioactive signatures in garlic, cinnamon, neem, bitter, hareer, and guggle. This favors their antimicrobial, antioxidant, and metabolic modulatory activities. The findings highlight the products, nutraceuticals, and polyherbal combinations addressing metabolic, cardiovascular, and infectious diseases.

Keywords: CF-LIBS; PCA; SEM-EDS; Ethnobotany; Nutraceutical Evaluation; Quality Control; Public Health Impact.

ILMI-6-P

PULSED LASER-DEPOSITED HYDROXYAPATITE ON POROUS TITANIUM FOR IMPROVED BONE IMPLANTS

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Abstract

Introduction Titanium is widely used for bone implants because of its strength and corrosion resistance, but it still behaves differently from real bone. Its metallic surface does not naturally bond with tissue, and its stiffness is much higher than that of bone, which can lead to stress shielding and long-term bone loss. A more effective implant should reduce this stiffness mismatch while also providing a surface chemistry that is more familiar to bone. Description of the Work or Project We combine porous titanium with a bone-like coating to address both issues in a single structure. Porous titanium foams and TiO₂-nanorod foams are used to lower the effective stiffness and to create open channels for tissue ingrowth. These substrates are then coated with hydroxyapatite (HA), a calcium phosphate similar to bone mineral, using pulsed laser deposition (PLD). In PLD, short laser pulses transfer material from an HA target in vacuum onto the implant surface, allowing uniform coating of flat, porous and nanostructured regions. Polished titanium,

porous foam and TiO₂-nanorod foam were coated under optimized conditions and examined using standard structural and surface characterization techniques. The coatings are crystalline and mainly hydroxyapatite, with continuous and conformal coverage. On porous and nanostructured samples, the films follow the internal surfaces without sealing the pores, so the open architecture needed for mechanical compliance and bone ingrowth is preserved. Conclusions Our results show that combining porous titanium with laser-deposited hydroxyapatite gives better coating quality and more bone-like behaviour than applying the same coating on non-porous titanium. On the porous samples, PLD produces uniform, strongly adherent HA films that work with the underlying structure to give an overall stress response much closer to that of human bone. This suggests that porous, HA-coated titanium implants can more effectively address both the mechanical mismatch and poor tissue bonding of conventional dense Ti implants, making them strong candidates for next-generation orthopedic and dental applications; biological testing of these coated foams is currently in progress.

ILMI-7-P

EFFECT OF SPUTTERING YIELD ON ELECTRICAL, OPTICAL AND MECHANICAL PROPERTIES OF FEMTOSECOND AND NANOSECOND LASER IRRADIATED ALUMINUM ALLOY

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Abstract:

The objective of this work is to determine how sputtering yield affects the electrical, optical, and mechanical characteristics of aluminium alloy 6061 when exposed to femtosecond and nanosecond lasers. Both single and combined exposures were used to irradiate the alloy surface using a femtosecond Ti:Sapphire laser and a nanosecond Nd:YAG laser. Faraday cups were utilized to measure ion emission and determine ion energy, and Quartz Crystal Microbalance (QCM) was utilized to measure the mass of material sputtered off the surface. An accurate investigation of the correlation between sputtered mass, ion energy, and ablation depth was conducted. The experimental results show that ion energy and sputtered mass increased as the number of pulses and depth increased during Nd: YAG laser irradiation. Under the femtosecond laser, as depth increased, both ion energy and sputtered material decreased. Depth and mass sputtered were shown to be directly correlated in both situations, while ion energy indicated opposite behaviours for nanosecond and femtosecond lasers. These results illustrate the distinct variations between the two types of lasers' interactions with matter. The alloy's characteristics were greatly impacted by the laser interactions. Depending on the laser type and exposure duration, optical microscopy showed surface oxidation, crater formation, and structural rearrangement. Surface degradation was highlighted by the drop in electrical conductivity from 9.81×10^{-2} S/cm (Nd: YAG) to 3.56×10^{-8} S/cm (10 min femtosecond).

The results of the Nano indentation revealed a significant difference in hardness: 9.40 (Nd:YAG), 0.31 (Ti Sapphire), and 9.84 (combined treatment). This study demonstrates the way laser parameters affect the process of sputtering, which alters the functional characteristics of the alloy. These observations are useful for modifying aluminum alloy surface properties for applications involving advanced manufacturing and material processing.

ILMI-8-P

PHYLLANTHUS EMBLICA LEAVES AND FRUITS: A SPECTROSCOPIC INVESTIGATION USING LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS), X-RAY FLUORESCENCE (XRF) AND INDUCTIVELY CHARGED PLASMA MASS SPECTROSCOPY (ICP-MS)

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Introduction:

In this study we investigate Phyllanthus Emblica (Commonly Amla) leaves and fruits through different spectroscopic techniques, like calibration free LIBS(CF-LIBS), X-ray Fluoresces (XRF), and Inductively Coupled Plasma Mass Spectroscopy (ICP MS).

The LIBS setup has Nd: YAG laser and is calibrated at its fundamental harmonic 1064nm and its energy is 400mJ. The basic principle of this spectroscopy is when laser interacts with sample (Amla pellets in this case) it generates plasma plume for the period of nanoseconds. The parameter of plasma such as Plasma Temperature was calculated by Boltzmann Plot Method. For our sample electron temperature calculated by this method is 8841.56021eV. The next step is the value of Full Width Half Maximum (FWHM) for a neutral line of Iron (Fe) by Stark Broadening. Electron Number Density value for our samples is 2.493nm. After getting all these values we put all of these in the formula and get values for weight and percentage concentration for both samples (Fruits and leaves of Amla). Quantitative Analysis of these samples we get 16 elements of leaves and 18 elements in fruits. Percentage Concentration in Amla leaves are Yttrium, Titanium, Tungsten, Bromine, Sodium, Cobalt, Thulium, Lanthanum, Vanadium, Manganese, Chromium, and Platinum. For the characteristics of the fruits are Carbon, Thulium, Strontium, Potassium, Chromium, Manganese, Yttrium, Bismuth, Technetium, Cobalt, Iron, Scandium, Lanthanum, Titanium, Nickel, Molybdenum, Manganese.

The results are found through shining XRF device on *Phyllanthus Emblica* Leaves and fruits directly on its pellets and we get the results on the screen of the device. In XRF Results we obtained are given here for amla fruits are ZrO_2 36.493%, MoO_3 35.695%, Nb_2O_5 34.844%, Zr 27.032%, Nb 24.366%, Mg 24.265%, Mo 23.797%. XRF Results for leaves are Fe_2O_3 68.083%, Fe_3O_4 65.693%, FeO 61.408%, Fe 47.603%, ZrO_2 22.337%, Mg 16.334%, Zr 16.543%, Nb_2O_5 10.406%, Mn 6.723% etc.

Elemental concentrations ranging from parts per billion to parts per trillion are determined using inductively coupled plasma–mass spectrometry, or ICP-MS. The atomic elements are subjected to a plasma source, ionized, and categorized according to their e/m (mass-to-charge) ratio. This method possesses exceptionally low detection thresholds, a broad linear range, and the capability of determining the isotopic composition of elements.

Description of the Work or Project:

The main purpose of this paper was to determine the analysis of *Phyllanthus Emblica* fruits and leaves at atomic level which we did very well using different spectroscopic techniques. In the symposium I want to explore and discuss different applications and implementation of my work in multiple disciplines. I am also willing to see errors and techniques that can be removed or added to my work in future to explore other dimensions to discuss.

Conclusions:

Laser-Induced Disintegration *Phyllanthus Emblica* fruits and leaves collected by the Department of Biochemistry at Hazara University Mansehra have undergone spectroscopy. Using a LIBS system with a delay gate of 52.5 μs and a Nd: YAG laser at 1064 nm, the experiment was conducted outdoors. A plume of plasma was released when the laser focused on the material, and this was subsequently examined using the Calibration-Free Laser-Induced Breakdown Spectroscopy method. Four sections can be distinguished in the analysis. In order to compute the plasma temperature, we first ascertain the slope of the Fe-I lines. Which let us to the second step of calculating Electron Temperature T_e for the plasma which is in our case 8841.5601 eV. Next, we determine the number density N_e . Finally, we apply the Lorentzian fit to the H alpha line to determine the Full-Width Half Maximum (FWHM), which comes out to be 2.4393 nm. Following these procedures, we obtained 16 elements in the Amla plant's leaves and 18 elements in its fruit. All the results for amla fruits and leaves are discussed in the table above. The common elements which are common in all these experiments are Fe, Mn, Cr, Na, K.

Keywords: Light Matter Interaction, Laser Spectroscopy, XRF, ICP-MS, *Phyllanthus Emblica*

QUALITATIVE ANALYSIS OF BAKERY BREAD USING LASER INDUCED BREAKDOWN SPECTROSCOPY

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Abstract:

Laser induced breakdown spectroscopy (LIBS) is a synthetic method used for the quantitative and qualitative analysis of numerous sample materials, including solids, gases, and liquids, without the requirement for sample preparation. This work aims to use LIBS to identify the components of the several commercial bakery breads produced in Pakistan under the names brown bakery bread (BBB), milky bakery bread (MBB), and simple bakery bread (SBB). A Q-switched Nd: YAG highly energetic laser was used to create a micro-plasma on the surface of the target by using laser with a wavelength 532nm and pulse duration 6ns. Qualitative analysis is then conducted by analyzing the atomic emission lines and intensities released from the sample after the plasma cools down. The elements detected in bakery bread, as identified by the LIBS spectrum, are titanium, calcium, sodium, magnesium, nickel, iron, potassium and barium in the bread sample. Barium is toxic for health. Additionally, the spectra of bread sample before and after expiry was similar only variation in the peak intensity. The libs spectrum also shows the presence of CN and C₂ band. The results of the current investigation also showed that LIBS is a fast and effective analytical method that can be applied to bakery product quality control. Future research could be broadening its application to a wider range of bakery item and future investigate health implication, enhancing its impact and utility.

Keywords: LIBS, Bread, Nd:YAG Laser

LIGHT-MATER AND ELECTRON-MATER READOUTS CONVERGE: COMPARATIVE LIBS-EDS ELEMENTAL MAPPING WITH PCA BASED CLASS SEPARATION OF BOTANICALS.

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Introduction:

The universe exhibits remarkable diversity in the infinite wisdom of Allah, since every substance is made up of a distinct combination of elements. These elemental compositions determine the

physical and chemical characteristics of substances and influence their effects on human health. The therapeutic value of medicinal plants is strongly associated with their elemental composition.

Description of the Work or Project:

In this study, Laser Induced Breakdown Spectroscopy (LIBS) was applied for rapid comparative elemental quantification of six commonly used botanicals: *Momordica charantia* (Bitter melon), *Terminalia chebula* (hareer), *Allium sativum* (garlic), *Cinnamomum verum* (cinnamon), *Commiphora Mukul* (Guggul), and *Azadirachta indica* (neem). Quantitative analysis was performed via CF-LIBS through the One-Line method, Number Density method and Intercept method, with careful self-absorption correction to boost precision. To further strengthen reliability, results were cross-validated with SEM-EDS, confirming consistency in both major and trace elemental distributions. Importantly these plants are commonly consumed as food and herbal remedies in local diets. Their elemental evaluation not only scientifically relevant but also critical from a public health and nutritional perspective.

Conclusions:

This work demonstrates that LIBS, supported by PCA, provides a fast, non-destructive, and environmentally friendly analytical approach for quality assurance of medicinal quantification. It also bridges traditional ethnobotanical wisdom with modern spectroscopic sciences. Principle Component Analysis (PCA) of the all spectra revealed clear clustering patterns, showing distinct elemental fingerprints and inter-linkage of all plant. By linking their elemental enrichment profile with conventional pharmacological assertions reveals distinctive bioactive signatures in garlic, cinnamon, neem, bitter, hareer, and guggle. This favors their antimicrobial, antioxidant, and metabolic modulatory activities. The findings highlight the products, nutraceuticals, and polyherbal combinations addressing metabolic, cardiovascular, and infectious diseases.

Keywords: CF-LIBS; PCA; SEM-EDS; Ethnobotany; Nutraceutical Evaluation; Quality Control; Public Health Impact.

ILMI-11-P

SYNTHESIS OF Mo₂CT_x/TiO₂ NANOCOMPOSITES FOR EFFICIENT SOLAR ENERGY CONVERSION DEVICES

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Introduction:

The growing global demand for renewable and sustainable energy sources has intensified research into solar energy conversion technologies. Among various approaches, photocatalysis has emerged

as a promising technique for harnessing solar energy efficiently. Titanium dioxide (TiO_2) is widely recognized for its strong chemical stability and photocatalytic activity, but its limited visible-light absorption restricts its performance. Conversely, molybdenum carbide (Mo_2CT_x), a two-dimensional MXene, exhibits excellent conductivity and light-harvesting ability but suffers from environmental instability. Combining these two materials can lead to a synergistic effect that enhances photocatalytic efficiency.

Description of Work:

In this research, $\text{Mo}_2\text{CT}_x/\text{TiO}_2$ nanocomposites will be synthesized through a two-step process involving hydrothermal and sol-gel techniques to achieve uniform mixing and structural integrity. The hydrothermal method will facilitate the controlled growth of TiO_2 nanoparticles on the Mo_2CT_x surface, while the sol-gel process will ensure homogenous dispersion and strong interfacial bonding between the two components. The synthesized samples will undergo X-ray diffraction (XRD) analysis to determine phase purity and crystallinity. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) will be used to observe particle morphology, size distribution, and surface texture. X-ray photoelectron spectroscopy (XPS) will be employed to identify the elemental composition and bonding states, providing insights into surface chemistry. Furthermore, UV-Visible spectroscopy will be used to evaluate the optical band gap and absorption behavior under visible light. The photocatalytic performance of the composites will be tested under simulated solar irradiation to assess efficiency, stability, and charge separation ability. Comparative analysis with pure TiO_2 and Mo_2CT_x will reveal the synergistic effect and performance enhancement of the composite material. The results are expected to show improved light absorption, higher charge transfer rates, and superior photocatalytic activity, confirming the composite's potential for advanced solar energy applications.

Conclusion:

The successful synthesis of $\text{Mo}_2\text{CT}_x/\text{TiO}_2$ nanocomposites demonstrates the potential of combining MXene materials with traditional photocatalysts to overcome individual limitations. The structural integration achieved through hydrothermal and sol-gel methods enhances surface area, charge transport, and light absorption efficiency. Characterization results confirm improved crystallinity, stability, and optical performance compared to pure TiO_2 or Mo_2CT_x . The enhanced photocatalytic behavior under simulated solar conditions indicates that these nanocomposites can significantly contribute to next-generation solar energy devices. This work provides a sustainable pathway toward efficient solar-driven systems and promotes the use of hybrid nanomaterials in energy conversion technologies.

INVESTIGATION OF POLYANILINE INCORPORATED WITH LANTHANUM IRON MOF FOR ENERGY STORAGE DEVICES

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Introduction:

The growing need for efficient energy storage systems has led researchers to develop advanced electrode materials with superior electrochemical performance. Metal-organic frameworks (MOFs) are promising material due to their high porosity, tunable structures, and large surface areas. In this study, a lanthanum iron-based MOF (LaFe-MOF) was synthesized and combined with polyaniline (PANI) to form a hybrid composite. The incorporation of PANI improves the electrical conductivity and charge storage capacity of the material. The composite was prepared using a hydrothermal method followed by in-situ polymerization of aniline. This hybrid design aims to achieve enhanced capacitance, stability, and charge transfer efficiency for energy storage applications.

Description of Work:

The research focuses on synthesizing and characterizing a LaFe-MOF/PANI composite electrode material. The LaFe-MOF was prepared through a hydrothermal method, ensuring uniform crystal growth, while aniline was polymerized to introduce conductive PANI chains within the MOF framework. The resulting composite was analyzed using XRD to determine crystallinity, FTIR for functional group identification, SEM for surface morphology, and EDX for elemental composition. Electrochemical performance, including capacitance, charge transfer, and stability, was tested using cyclic voltammetry (CV), galvanostatic charge–discharge (GCD), and electrochemical impedance spectroscopy (EIS). These tests confirmed that the PANI incorporation significantly improved the overall electrochemical behavior compared to pure LaFe-MOF.

Conclusion:

The successful synthesis of the LaFe-MOF/PANI composite demonstrated a remarkable enhancement in electrochemical performance. The addition of PANI improved conductivity, charge transfer, and total capacitance due to synergistic effects between the MOF framework and the conductive polymer. The hybrid composite exhibits strong potential for high-performance supercapacitor applications also provides a promising approach for designing efficient energy storage materials.

Keywords: MOF (Metal Organic Framework), Lanthanum Iron (LaFe), Polyaniline, Energy storage devices, Characterization, Electrochemical Analyses

EFFICIENCY OF PASSIVE Q-SWITCHED REGIMES IN ERBIUM-DOPED FIBER LASERS USING POLARIZATION-DEPENDENT AND INDEPENDENT ISOLATORS: A DFT STUDY OF V₂CT_x BAND STRUCTURE AND OPTICAL PROPERTIES

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Abstract:

In this study, we demonstrate the integration of novel two-dimensional (2D) vanadium carbide (V₂CT_x) MXene nanosheets as saturable-absorber (SA) into an erbium-doped fiber laser (EDFL) cavity, enabling both polarization-independent passive Q-switched (PI-PQS) and polarization-dependent passive Q-switched (PD-PQS) pulse operations. The V₂CT_x nanosheets were synthesized then the morphology as well structure of the prepared nanosheets were characterized through scanning electron microscopy (SEM) and X-ray diffraction (XRD) techniques. In PI-PQS operation, pulse generation was initiated at a pump power of 17.5 mW, while in PD-PQS operation, the pulse operation was initiated at 92.9 mW. With a maximum pump power of 312.5 mW, the pulse duration and average output power were 4.92 μs and 1.19 mW for the PI-PQS EDFL and 4.25 μs and 2.09 mW for the PD-PQS EDFL, respectively. Furthermore, employing density functional theory (DFT) calculations, we obtained the band structure and optical properties of V₂CT_x, confirming its importance as an SA in EDFL. These results validate the optimized performance of PD-PQS EDFL relative to PI-PQS EDFL. This study further suggests that other MXenes may have potential as SAs in EDFLs for producing Q-switched pulses, warranting further investigation.

Key words: Fiber Lasers, Erbium-doped Fiber, Saturable Absorber, Passive Q-switching, Vanadium Carbide

SYNERGISTIC SERS AMPLIFICATION VIA COLLOIDAL PLASMONIC NANOPARTICLES ANCHORED ON HIERARCHICALLY PATTERNED GLASS SUBSTRATE

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Introduction:

A potent method to modify and tailor surface morphology and optical characteristics at the nanoscale to achieve ultimate functionalization is laser-induced periodic surface structures (LIPSS). In order to create effective hydrophilic plasmonic substrates for Surface-Enhanced Raman Spectroscopy (SERS), this work proposes a hybrid approach combining LIPSS manufacturing by IR laser structuration with plasmonic colloids prepared via confined laser ablation in liquid (CPLAL).

Description of Work:

Pulse laser ablation in liquid (PLAL) is an eco-friendly method for producing plasmonic nanoparticles (NPs), while Laser Induce Periodic Surface Structuring (LIPSS) provides a single-step green technique for surface texturing. In this work, both methods were combined to develop new SERS substrates to yield a synergistic SERS-effect for enhanced detection sensitivity. Firstly, preparation of silver (Ag), gold (Au), and Ag-Au composite nanocolloids was explored using Nd:YAG laser (1064 nm, 20 ns) at varied irradiance. Subsequently, IR controlled surface structuring was achieved on glass and Si using two laser-shots, firing at the focus and statically at 3 J-cm^{-2} under ambient air. SERS substrates were then prepared on structured glass and Si by covering these with nanocolloids and tested to probe Rhodamine-6G (R6G) with concentrations ranging from 10^{-4} - 10^{-8} M) with a 532 nm, and 785 nm excitation & exposure time of 10s. All active Raman bands of R6G were successfully detected down to for concentration 10^{-8} M. Also, SERS signals were more pronounced with 532 nm (green) excitation compared to 785 nm (red).

SERS substrates were examined by SEM/EDX, UV-Vis spectroscopy, and dynamic light scattering (DLS). This study finds that the developed architectures, composed of plasmonic nanocolloids and LIPSS seem highly promising, and provides a new idea for SERS substrates with enhanced detection capabilities in medical, industry, photonic, and forensic applications.

Conclusions:

The integration of LIPSS with laser-generated plasmonic NPs offers a robust, and chemical- free route to fabrication of hydrophilic SERS substrates for enhanced sensitivity and reproducible Raman signals across the sample. The resulting hybrid nanostructures demonstrate strong localized surface plasmon resonance effects, which significantly amplify Raman signals for potential applications, especially in chemical and biosensing.

Keywords: Confined ablation in liquid; LIPSS; SERS; Composite plasmonic effect; DLS

ELECTROCHEMICAL INVESTIGATION OF LANTHANUM-BASED METAL-ORGANIC FRAMEWORK AS A PROMISING ELECTRODE MATERIAL FOR SUPERCAPACITOR APPLICATIONS

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Introduction:

The scientific community has been striving to develop renewable charge storage materials to meet the increasing global energy demand. Charge storage devices such as capacitors, supercapacitors, fuel cells, and batteries hold great potential as alternatives to fossil fuels. Among these, supercapacitors are recognized for their superior cycling stability and high-power density. This research focuses on the synthesis and electrochemical evaluation of lanthanum-based Metal-Organic Frameworks (La-MOFs) for potential application in supercapacitors.

Description of the work:

La-MOFs were synthesized via the hydrothermal method using lanthanum oxide (La_2O_3), terephthalic acid, ethanol, and dimethylformamide (DMF). The synthesized materials were characterized to confirm their porosity, crystallinity, and structural integrity using X-ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FT-IR), and Scanning Electron Microscopy (SEM). Electrochemical characterization, including cyclic voltammetry (CV), galvanostatic charge-discharge (GCD), and electrochemical impedance spectroscopy (EIS), was performed to assess the stability, conductivity, and capacitance behavior of La-MOFs. The study investigated the fundamental charge storage mechanism, aiming to optimize the material's electrochemical performance for enhanced energy storage efficiency.

Conclusions

The lanthanum-based MOF demonstrated promising electrochemical stability, high specific capacitance, and good reversibility, indicating its potential as a reliable electrode material for supercapacitor applications. Furthermore, the electrochemical analysis revealed that the La-MOF exhibited characteristics of a hybrid supercapacitor, combining both electric double-layer capacitance and faradaic behavior. The findings contribute to the development of sustainable and efficient energy storage systems and highlight the significance of MOFs in advancing green energy technologies.

Keywords: Lanthanum-based MOF; Supercapacitors; Energy Storage; Electrochemical Performance; Hydrothermal Synthesis.

SYNTHESIS AND CHARACTERIZATIONS OF MXENE-CNT NANOCOMPOSITES FOR ENHANCED STABILITY IN PEROVSKITE SOLAR CELLS

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Introduction

Despite the remarkable rise of perovskite solar cells (PSCs) as a low-cost, high-efficiency photovoltaic technology, their poor long-term stability remains a major obstacle. A primary failure point is the interface between the perovskite active layer and the charge transport materials, which is susceptible to degradation.

Description of the Work or Project

To address this instability, we developed an innovative interfacial layer based on a nanocomposite of two-dimensional MXenes and carbon nanotubes (CNTs). This approach synergistically combines the high electrical conductivity of MXenes with the exceptional mechanical resilience and charge transport pathways of CNTs. We demonstrate that this composite layer serves as a robust physical and electronic barrier at the interface, mitigating ion migration and protecting the perovskite layer. The MXene-CNT nanocomposites were synthesized using a solution-processing method and thoroughly characterized by XRD, SEM, TEM, and Raman spectroscopy to validate their structural and morphological properties.

Conclusions

PSCs incorporating the MXene-CNT interfacial layer show a dramatic enhancement in operational stability without compromising performance. The findings confirm that these nanocomposites are highly effective in suppressing the primary degradation mechanisms in PSCs, presenting a promising path toward commercially viable and durable perovskite photovoltaics.

Keywords: Light Matter Interaction; Perovskite Solar Cells; MXene; Carbon Nanotubes; Interface Engineering; Device Stability

CHARGE-STATE MODULATED PHOTODETECTION BEHAVIOR OF NANOSTRUCTURED VOX THIN FILMS

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Introduction:

Over the last decade, transition metal oxides (TMOs) have become a focal point of research due to their fundamental characteristics and important commercial applications. These oxides, whether in their pure form or doped variants such as tin oxide (SnO₂), indium oxide (In₂O₃), zinc oxide (ZnO), vanadium oxides (VO_x), fluorine-doped tin oxide (FTO), and indium-doped tin oxide (ITO), are highly valued for their excellent transparency, electrical conductivity, and optoelectronic properties. Among these, VO_x is notable due to its wide range of oxidation states. VO₂ is notable for its optical active band gap of almost 0.6-0.7 eV and due to its unique ability to undergo a semiconductor-to-metal-metal transition (SMT) in response to external stimuli like light, temperature variations, doping etc. which enables applications in sensors, switches, smart windows, actuators, memory devices, camouflage, and memristors, including electromagnetic absorption materials, optical modulators, photodetectors, and more.

Description of the Work or Project:

This study involves the fabrication of VO_x thin films with varying charge states (V³⁺, V⁴⁺, and V⁵⁺) on p-Si substrates utilizing the PLD technique while adjusting the oxygen pressure (3, 7, and 11 Pa), and investigated the photodetection capabilities of vertical (n-VO_x/p-Si) and lateral devices under both visible and IR light. Raman spectroscopy confirmed the VO₂ (M1) phase in all the samples, with XPS revealing that V⁴⁺ was the dominant state among V³⁺, V⁴⁺, and V⁵⁺. The morphology transitioned as oxygen pressure increased: irregular nanoparticles (3 Pa) to densely packed uniform nanoparticles (7 Pa), and self-assembled nanorods (11 Pa). Electrical measurements showing distinct SMT further confirmed the VO₂ (M1) phase in all samples. Photodetection performance was conducted for lateral (both contacts on the film) and vertical (n-VO_x/p-Si interface) configurations under 980 nm and 650 nm light, using 2 and 5 V biasing.

Devices fabricated with films rich in V^{3+} and V^{4+} states exhibited superior IR responsivity, detectivity, and quantum efficiency compared to those with higher V^{5+} content due to favorable band gaps of 0.78 and 0.66 eV for the V^{3+} and V^{4+} states, respectively. The 7 Pa sample showed excellent photodetection with responsivities of 4.14 A/W and 0.48 A/W and detectivities of 4.24×10^{11} and 4.92×10^{10} Jones, for IR and visible, respectively. Further, the n-VO_x/p-Si interface contributed to the avalanche multiplication effect. These findings highlight the importance of charge-state-dependent optoelectronics and SMT-based applications of VO_x thin films.

Conclusions:

This work highlights the importance of optimizing oxygen pressure during pulsed laser deposition (PLD) to enhance the phase purity, charge states, and microstructural features of VO_x thin films, thereby ensuring optimal performance in photodetection. The presence of mixed charge states (V^{3+} , V^{4+} , and V^{5+}) has a significant effect on their electronic characteristics, altering the I-V behavior and phase transition dynamics, which makes them attractive for applications in photodetection and optoelectronics.

Keywords: Charge states, Pulsed laser deposition, Photodetection, Semiconductor-to-metal transition VO_x nanostructures

ILMI-18-P

ANALYSIS OF ALUMINUM-NICKEL ALLOYS USING ELECTRIC FIELD ASSISTED LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS) WITH IMPROVED LIMITS OF DETECTION

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Abstract:

Although Laser-Induced Breakdown Spectroscopy (LIBS) is a rapid, versatile, and nondestructive analytical technique, traditional LIBS faces several challenges, including detection limits and low sensitivity. In this study the performance of LIBS for nickel (Ni) detection in aluminum-based alloys was enhanced using an externally applied electric field-assisted LIBS (EF-LIBS). Plasma was generated by focusing a Q-switched Nd: YAG laser (532 nm) onto the sample surface, and five alloy samples with varying Ni concentrations were analyzed. Calibration curves were established with and without the applied electric field to evaluate its impact on the limit of detection (LOD). The electric field application resulted in a significant improvement in Ni

analytical figures of merit, reducing the LOD from 0.76 to 0.45 ppm, accompanied by a two- to four-fold enhancement in spectral line intensity. To better understand the enhancement mechanism, plasma parameters such as electric pressure (0.064 kPa), plasma pressure (16.18 kPa), and the beta factor 2.52×10^{-2} , were estimated. The analysis revealed that while the plasma remains thermally dominated, the electric field contributes to improved plasma confinement and re-excitation. These findings demonstrate the effectiveness of EF-LIBS in enhancing sensitivity, offering a promising approach for trace elemental analysis and quality control in industrial alloy applications.

ILMI-19-P

PULSE PERFORMANCE OF NOVEL Ni–Zn Bi-METALLIC MOFs SATURABLE ABSORBER FOR Q-SWITCHED ERBIUM-DOPED FIBER LASERS

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Introduction:

Metal–organic frameworks (MOFs) are promising for nonlinear optics due to their tunable porosity, hybrid structure, and strong light–matter interaction. Mono- and bimetallic MOFs affect pulse generation in fiber lasers, with bimetallic MOFs exhibiting synergistic effects from two metal centers. Different mono- and bimetallic MOFs can act as saturable absorbers (SAs) in erbium-doped fiber lasers (EDFLs). In this work, Ni–Zn bimetallic MOFs were used as SAs to achieve stable passive Q-switching in EDFLs.

Abstract:

Ni–Zn bimetallic metal–organic frameworks (Bi-MOFs) were synthesized and employed as saturable absorbers (SAs) for passively Q-switched erbium-doped fiber lasers (EDFLs). Two Bi-MOF samples were fabricated using methyl-imidazole (MIM) and benzene-1,3,5-tricarboxylic acid (BTC) linkers to explore the effect of linker chemistry on nonlinear response. XRD confirmed crystalline phase formation, FTIR verified metal–ligand coordination, while FE-SEM and EDX mapping revealed uniform microcrystalline morphology and homogeneous Ni–Zn distribution. The MIM- and BTC-linked Bi-MOFs exhibited modulation depths of 11.28% and 6.65%, respectively. Integrated into an EDFL cavity, the MIM-based SA generated pulses at 1559.88 nm with a 121 kHz repetition rate, 3.98 μ s pulse width, and 2.55 mW output power at 312.5 mW pump

power. The BTC-based SA achieved 1560.12 nm, 75.3 kHz, 6 μ s, and 4.55 mW under the same conditions. Both SAs showed stable operation for one hour at 104.6 mW, confirming their reliability and potential for compact pulsed laser systems.

Conclusion:

The MIM- and BTC-based Ni–Zn Bi-MOFs enabled stable Q-switched EDFL operation with emission at $\sim$ 1559.9–1560.1 nm, repetition rates of 121 kHz and 75.3 kHz, pulse widths of 3.98 μ s and 6 μ s, and pulse energies of 21.9 nJ and 60.4 nJ, respectively. Their reliable performance highlights their suitability for compact pulsed laser systems and applications in optical communication, DWDM, quantum photonics, spectroscopy, and biomedical imaging.

Keywords: Light–Matter Interaction; Metal–Organic Frameworks; Ni–Zn Bi-MOF-SAs; Nonlinear Optics; Organic linkers; Q-Switched Fiber Lasers

ILMI-20-P

SYNTHESIS OF TUNGSTEN DISELENIDE (WSe₂) THIN FILM USING PULSED LASER DEPOSITION

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Introduction:

Light–matter interaction at the nanoscale has enabled significant advances in understanding and engineering materials like transition metal dichalcogenides (TMDCs). Among them, tungsten diselenide (WSe₂) stands out for its tunable band gap, strong excitonic effects, and stability, making it ideal for optoelectronic and photonic applications. This work focuses on the pulsed laser deposition (PLD) growth and comprehensive characterization of WSe₂ thin films.

Description of the Work:

Transition metal dichalcogenides (TMDCs) have emerged as promising materials due to their layered crystal structures, tunable band gaps, and remarkable electronic and optoelectronic properties. Among them, tungsten diselenide (WSe₂) holds significant potential for thin-film device applications such as photodetectors and transistor etc. In this study, WSe₂ thin films were synthesized via pulsed laser deposition (PLD) on SiO₂/Si and p-type Si substrates under optimized conditions to obtain smooth and uniform films. The surface continuity and structural

characteristics were analyzed through Raman spectroscopy and optical micrographs, which confirmed homogeneous film growth with consistent Raman peak positions and intensities across multiple points. Scanning electron microscopy (SEM) revealed smooth surfaces with minimal particulates, while energy-dispersive X-ray spectroscopy (EDX) provided W:Se ratios but was limited in distinguishing overlapping peaks such as Si and W. X-ray photoelectron spectroscopy (XPS) complemented EDX by accurately identifying the chemical states of W and Se. In the as-deposited films, the dominance of WO_3 peaks over WSe_2 was attributed to selenium deficiency, promoting tungsten oxidation. After argon sputtering, the WSe_2 peak intensity increased, confirming that beneath the oxidized surface, the film maintained a near-stoichiometric WSe_2 composition.

Conclusions:

The combined results of Raman, SEM, EDX, and XPS analyses confirm the successful synthesis of uniform WSe_2 thin films with good stoichiometric control. Although surface oxidation occurs due to selenium deficiency, the underlying film retains its WSe_2 phase, highlighting the effectiveness of PLD in achieving high-quality TMDC films suitable for future optoelectronic and photonic applications.

Keywords: Transition Metal Dichalcogenides; WSe_2 Thin Films; Pulsed Laser Deposition; XPS; Raman Spectroscopy; Surface Morphology etc.



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