Two day theme meeting on

Science with Free Electron Lasers and High Power IR-THz Sources

BOOK OF ABSTRACTS

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Science with X-ray Free Electron Lasers

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Advent and development of X-ray free electron lasers (FELs) have led to emergence of new paradigm in probing matter with ultra-short time and length scales. In particular, XFELs can provide X-ray beams with unprecedented of brightness and properties and raise the possibility of studying matter at atomic-level spatial scales and femtosecond timescales for the first time. Here we discuss basic aspects of generation of X-ray FELs using self-amplified spontaneous emission (SASE) method and seeded lasing method and discuss parameters and status of various active XFELs around the world. We discuss various applications of XFELs in exploring new regimes of matter ranging from atomic and chemical sciences to materials and biological systems. We also discuss the new emergent frontier of ultra-fast science achievable with table-top Attosecond pulsed laser sources and discuss some current applications in chemical and materials sciences. Finally, we discuss the new exciting possibilities which emerge with the development of Atto-second pulses in XFELs leading to creation of the most brilliant radiation sources in the laboratory.

Far-Field, Near-Field and High Field Terahertz (THz) Spectroscopy of Materials

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Terahertz (THz) spectroscopy offers large opportunities in the ultrafast study of materials of various kinds. There are no cheap and compact high-power sources or sensitive detectors of THz radiation. They are either expensive or difficult to fabricate. Using Laser driven THz sources and detectors, we can build THz time domain spectroscopy (TDS) setup. We have used several different designs to fabricate laser driven high power THz sources and detectors. The pulsed lasers have given rise to ~4-5 THz bandwidth while Continuous Wave (CW) THz has given rise to ~2-3 THz range with very high (MHz) resolution. While these systems are with powers of the order of few micro watts, there are THz sources which uses Synchrotron or similar resources and generates extremely high-power THz Radiation which gives rise to very high THz fields. These fields are so high that they can alter the properties of solid materials at very short time scales. We have developed several Terahertz (THz) spectroscopic techniques to study different materials from single crystals to metamaterials. We studied THz optical properties of Vanadium doped [100] β-Ga2O3 using THz-TDS.[1] The V-doped β-Ga2O3 crystal shows strong birefringence in the 0.2-2.4 THz range. We measured phase retardation over the whole THz range by developing THz Time-Domain Polarimetry (THz-TDP). It is observed that the V-doped β-Ga2O3 crystal behaves both as a quarter waveplate (QWP) at 0.38, 1.08, 1.71, 2.28 THz, and a half wave-plate (HWP) at 0.74 and 1.94 THz, respectively. [2] We have also studied Metamaterials of different types for various applications. Polarization dependent transmission through an array of subwavelength apertures can have practical applications. Such metasurfaces can be deployed as Intelligent Transmitting Surface (ITS) for 6th Generation (6G) short-range communication. We studied THz transmission through such surfaces. We developed a Near Field Scanning THz Microscope for this purpose. Several interesting Metamaterials were studied using this unique THz Microscope of its kind. Whatever is seen by using Computer simulation, those near field patterns can be observed using this unique microscope. These are however, micro watt THz power applications. There are huge number of high field or high-power THz applications in the study of materials. For example, Graphene shows high harmonic generation under FEL generated THz. The FEL

THz can act as a Pump to create Faraday Rotation in Mn_3Ga material. Several such phenomena can be studied. We will briefly touch many of these issues.

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Probing lattice instabilities, thermal transport, and spin-phonon coupling using X-ray free electron lasers, THz, and IR spectroscopy

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Coupling of charge, orbital, spin, and lattice degrees of freedom (d.o.f.) are essential to realizing various functional properties such as ferroelectricity, thermoelectricity, magnetoelectric effect, metal-insulator transition, superconductivity, and charge-density-wave (CDW). However, the relative contribution of the competing orders to controlling the desired behavior is challenging to decipher. A detailed experimental and theoretical mapping of electrons, electron spins, and lattice vibrations is necessary to decipher the governing mechanism(s). In this talk, I will describe our recent efforts to identify electronically driven lattice instabilities and photoexcited interatomic force constants using X-ray FEL in thermoelectric SnSe [1-5], the role of phasons in controlling thermal transport in the incommensurate CDW state of Zintl-like semiconductor TlInTe2 using Raman, IR, and THz spectroscopy [6], and spin-orbital-phonon coupling in chromium vanadate by experimentally (Raman and IR spectroscopy) and theoretically mapping the phonon, electron, and magnon quasiparticles [7]. Moreover, I will discuss examples from nuclear [8], ferroelectric [9], and magnetoelectric [10] materials where high-power and pulsed IR/THz FEL could provide decisive information on quasi-particle coupling (spin-phonon, electron-phonon, and phonon-phonon) and phase transitions.

FEL Activity at RRCAT

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The first saturated lasing of a Free Electron Laser in the country was achieved on the Infra-red Free Electron Laser (IR-FEL) setup at RRCAT in 2020, which was followed by a period of optimization of its operation parameters to achieve the design goal of wavelength tunability from 12.5 - 50 micrometers with an out-coupled Continuous Wave (CW) average power up to 30 mW. Concurrently with this, a user facility for IR-THz spectroscopy has also been successfully developed and commissioned at RRCAT, which initially used lab sources for spectroscopy experiments. Recently, light from the IR-FEL has been delivered at the user station leading to the successful completion of first experiments using FEL light. This has led to the establishment of a unique facility for FEL as well as lab-source based IR-THz spectroscopy under different environmental conditions of temperature and magnetic field. This talk will cover different aspects of the FEL activity at RRCAT leading to the setting up of this FEL based user facility.

With the successful commissioning of the IR-FEL based user facility, the focus now is on augmentation of the machine for enhanced utilization, and on planning for the short-term, medium-term and long-term future for the activity. Some ideas on these aspects will also be discussed briefly in the talk.

Delhi Light Source – A Compact FEL-THz facility at IUAC, New Delhi

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A compact THz-FEL facility, named as Delhi Light Source (DLS), is being commissioned at Inter University Accelerator Centre (IUAC), New Delhi. The design of the DLS is based on pre-bunched FEL where a train of electron micro-bunches with a maximum energy of 8 MeV will be injected into a compact undulator to produce intense coherent THz radiation in the range of 0.18 - 3.0 THz. The facility consists of RF photocathode electron gun, high power RF system, femto-second (fs) Fibre laser system, the undulator magnet, the Photocathode deposition systems, various electromagnets, the beam transport and the beam diagnostic devices.

An advanced Fibre laser system producing ultra-short pulses with energy of a few μJ has been developed in collaboration with KEK, Japan and is already commissioned at IUAC. A photocathode deposition system also has been developed in collaboration with BNL, USA and being commissioned. At present, the electron beam of ~ 6.2 MeV has been produced from metal (copper) photocathode by using fs fibre laser system. Soon the undulator which was already tested and made operational, will be operated to produce the first THz radiation.

Challenges in building short wavelength FELs

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Short wavelength Free-Electron Lasers (FELs) in the VUV and X-ray region, based on the principle of Self-Amplified Spontaneous Emission (SASE) were conceptualized in 1980s. After detailed theoretical investigations, and successful demonstration of proof of principle experiments at IR/UV wavelength in the next decade, projects towards development of X-ray FELs (XFELs) were undertaken in different laboratories around the word. Era of XFELs started after successful commissioning of Linac Coherent Light Source (LCLS) at Stanford Linear Accelerator Centre (SLAC) in USA in 2009, which was world's first hard X-ray FEL, operating at 1.5 A0. Since then, during the last 15 years, around half a dozen XFELs have been successful built worldwide, which are being used for ground breaking research; and R&D has been continuing to improve the source properties. XFEL is challenging to build, as it requires mastering several new technologies and concepts, such as photocathode e-gun for generation of high brightness electron beam, bunch compressor to generate ultrashort electron bunches, several novel beam manipulation techniques, a highly stable high energy linac that preserves the beam quality, low gap undulators with stringent magnetic tolerances, high precision beam diagnostics, etc. In this talk, we will discuss these challenges, and attempt to evolve a roadmap for short wavelength FEL R&D in India, to meet these challenges.

Development and commissioning of the Fiber laser system for Delhi Light Source

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Delhi Light Source (DLS), at Inter University Accelerator Centre is at its final stage of commissioing which will generate coherent THz radiation using the principle of prebunch FEL. In DLS, a proper laser system was required which could deliver ~300 femtosecond pulses with an energy of a few micro-joules at UV (258nm) to generate pre-bunched electron beam. For this purpose, a Yb-dopped fiber based laser system with enhanced tunability and stability has been developed in collaboration with KEK, Japan. The system can deliver Multi-micro bunch sequence of femtosecond pulses which repeats every machine cycle (10 Hz rate) to RF photocathode gun and can generate electron beam of the similar time structure. Recently the system has been commissioned sucessfully at IUAC and femtosecond electron bunches are being produced from the Cu Photocathode by using the laser system as Master. In this talk, the detail design , challeneges and the present status of the fiber laser system will be presented.

Superconducting RF Free electron lasers: Present status and future challenges

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Free-Electron Lasers(FEL) are a source of high-power, tuneable, coherent radiation. Compared to a typical storage ring beamlines, the radiation pulses from FEL have much higher peak power, higher brightness and better coherence. The RF linear accelerator (Linac) parameter plays an important role in FEL design. Recent developments in accelerator technology indicate that RF linacs may be a strong contender for driving high average power FEL amplifiers. Now as FEL facilities are being constructed in the far-infrared (IR), vacuum ultraviolet (UV) and X-ray region, there is renewed interest in the special characteristics that superconducting RF linacs offers which include long pulse or CW operation, feedback regulation of accelerating fields, high efficiency, and availability of high gradient, low impedance structures. As progress in RF superconductivity continues to be dramatic, it is expected that SRF linacs not only will play an important role in future FEL development, but they may become the technology of choice for FEL driver accelerators. Because of their capability to provide higher cavity voltage, superconducting radio frequency (SRF) modules can be shorter, more compact and thereby impose less disruption on the beam. RRCAT has made substantial progress in SCRF infrastructure development. A state-of-the-art infrastructure has already been developed at RRCAT for fabrication, processing, dressing and testing of single cell and multicell superconducting RF cavities. SCRF technologist worldwide are working on several recent breakthroughs in superconducting radio-frequency (SRF) technologies to hold the key for enabling the new technologies. These technologies will further improve cavity performance; specially reduce/remove field emission (FE) from cavity surface. Few laboratories are working on cavity development using thin film technology on bulk niobium material to obtain higher quality factors and higher accelerating gradients at a higher operating temperature. In this talk, review on the existing and planned SRF based FEL facilities worldwide will be presented with overview of the superconducting development at RRCAT.

Recent efforts towards implementation of future technologies and SCRF cavities fabrication in industries will also be presented.

RF Systems for the IR-FEL at RRCAT.

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Raja Ramanna Centre for Advanced Technology is playing leading role towards research and development of particle accelerators in India. Synchrotron radiation sources Indus-1 and Indus-2 are national facilities, being operated in round the clock mode for over a decade now. In last few years, Infra-Red Free Electron Laser (IR-FEL) has been commissioned and is being operated regularly.

The RF system is complex sub system of IR-FEL and plays key role in providing high-precision electron acceleration required for lasing.Central to the RF systems is the synchronized RF signal generation unit that provides RF reference signal at 476 MHz for the electron gun and Sub-Harmonic Pre-Buncher (SHPB) along with 2856 MHz reference signal for Linear Accelerator (LINAC). SHPB is a crucial component that utilizes velocity modulation for effective bunching of the electron beam before it enters the LINAC.Adaptive feed-forward based digital Low-Level RF (LLRF) system is implemented for SHPB that ensures amplitude and phase stability within ±0.1% and ±0.1° respectively. Such high precision is critical for maintaining the quality of the bunched electron beam and ensuring reliable lasing.10 kW/476 MHz planar triode-tube based pulsed RF power amplifier provides the necessary power to SHPB cavity. 15 MW/ 2856 MHz RF system is employed to accelerate the bunched electron beam in LINAC to relativistic speed. The high-power S band microwave system, equipped with a 250 kV pulse modulator, delivers the high power required for electron beam acceleration. S-band RF system consist of 300 W SSPA klystron driver for 25 MW klystron based amplifier and 2 kW SSPA for pre-Buncher and giant waveguide based distribution system. The integration and optimization of all the above sub systems enable the IR-FEL to achieve consistent lasing performance. By careful tuning of RF parameters and maintaining stringent stability criteria, the facility successfully produces high-quality infrared radiation on a regular basis. Overall, the sophisticated and high precision development of RF system of IR-

FEL enables the successful operation of the IR-FEL. This paper describes S band LLRF system, digital SHPB LLRF system with synchronization unit, 10kW/ 476 MHz Sub-Harmonic Pre-Buncher and 15 MW/2856 MHz Linear Accelerator Klystron RF system .Operational aspects along with results are also presented.

RF System and Control Scheme for the IUAC FEL Facility

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The RF system for the Free Electron Laser facility is designed for production of electron beam having maximum energy up to 8 MeV using a 2.6 cell normal conducting RF photocathode gun operating at 2860 MHz. The RF Gun is operated in pulse mode for 4 μs duration with estimated field gradient of 110 MV/m with maximum 50Hz repetition rate. The high-power RF system for the gun consists of a solid-state pulsed modulator-based Klystron system rated for 25 MW peak RF power for the desired pulse duration and repetition rate. The RF System was installed without any RF circulator and tested up to full rated power with a vacuum based waveguide system connected to water cooled matched load. When the matched load section was replaced with the actual RF gun, the RF power was limited up to 1 MW due to high value of the reflected power during RF conditioning in absence of the high-power Circulator. Although installation of high vacuum-based Circulator was planned initially due to technical reasons it could not be installed and a SF_6 Gas based circulator was installed along with the Vacuum based waveguide system. After installation of the Circulator the RF conditioning of the photocathode gun could be carried out at high RF power level for the entire 4μs pulse duration and RF gun could be conditioned at high field gradient. At higher field gradient, due to excessive electron discharge or arcs at the RF junctions, several anomalies occurred that causes high reflected power, which in turn affected the cavity or waveguide vacuum conditions and caused the system to trip. In order to prevent such incidents and to reduce the frequency of system trips, a model based on machine learning algorithm has been developed that can predict a sustainable and stable vacuum / pressure levels at different RF power levels and if the vacuum level ever tries to go out of control, then it can reduce or control the power level automatically to prevent the system from tripping. The implemented model is based on the use of an unsupervised learning model called K-means Clustering, a supervised linear regressor and a Decision tree classifier. This model is being deployed in the control scheme of RF system for uninterrupted RF conditioning of the photocathode Gun. Now the system is being conditioned up to the desired level of 85 MV/m to produce 6 MeV electron beam using fibre based laser beam. Synchronization of laser reputation rate with RF system is being carried out using laser repletion frequency as master reference. An EPICS GUI is also developed for monitoring and recording of various parameters during RF Cavity conditioning and also during beam operation. A customized control scheme for the FEL operation is getting ready along with GUI and logging facility of the operational parameters. The modules for vacuum system control and read-back are being controlled using VME interface and control modules developed in house. The magnet power supplies are integrated with RS 232 based control scheme in an Orange Pi machine. EPICS based client server architecture is being implemented for LLRF, BPM, and Gigabit Ethernet based camera for beam viewing. The control modules along with distribution racks are finalised and the instrumentation racks are placed at appropriate locations. Development of client GUI interface is being worked out taking care of operational requirements of the facility.

Development of undulators for accelerator based light sources

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A diverse array of undulators is utilized in synchrotron radiation sources (SRS) and free-electron lasers (FELs), each designed to meet specific needs for high-intensity radiation production. Advances in undulator technology have enabled accelerator-based light sources to generate radiation across a wide energy spectrum, supporting various scientific and industrial applications. This presentation will provide an overview of the technological developments in undulators, focusing on four primary types: Permanent Magnet Undulators (PMUs), In-Vacuum Undulators (IVUs), Cryogenically Cooled Permanent Magnet Undulators (CPMUs), and Superconducting Undulators (SCUs). Key features and limitations of each type will be discussed.

The presentation will cover the ongoing development of PMUs at the Raja Ramanna Centre for Advanced Technology (RRCAT), focusing on design strategies, challenges, and solutions. We will discuss the statistical methods used to understand electron trajectories within undulators, including correlated and uncorrelated random walk models. Emphasis will be placed on the importance of precise assembly and fabrication procedures to achieve desired magnetic field characteristics, with a presentation of measured magnetic field data.

Additionally, the basic requirements for undulator properties necessary for effective operation in both SRS and FEL applications will be addressed. Specifications of undulators used in the Infrared Free-Electron Laser (IR-FEL) facility at RRCAT and those proposed for the Terahertz (THz) FEL will be presented. The presentation will also provide a brief overview of current x-ray FEL facilities around the world, highlighting their technological innovations and advancements which may provide insights into the future direction of undulator development.

Undulators at DAVV-Indore

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Over the years, Devi Ahilya Vishwa Vidyalaya (DAVV) has developed undulators and its measurement systems. Today the laboratory is equipped with Hall Probe bench, Pulsed wire bench and Stretched wire bench. Here we present the salient features of our measurement systems and ongoing design, development of a prototype asymmetric magnet pole undulator. The upper and lower magnet arrays of the magnet structure will have 25 mm period length and 50 mm period length with the lower magnet array has a provision of mechanical displacement of 50 mm to introduce phase shifts between the two magnet arrays.

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Proposed fields of research at Delhi Light Source, New Delhi

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(on behalf of DLS team and other collaborators who are constantly contributing to develop the experimental facilities for DLS)

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A compact THz-FEL facility, named as Delhi Light Source (DLS), is commissioned at Inter University Accelerator Centre (IUAC), New Delhi. The design of the DLS is based on pre-bunched FEL where a train of electron micro-bunches with a maximum energy of 8 MeV will be injected into a compact Undulator to produce the THz radiation in the range of 0.18 - 3.0 THz. The electron energy about 6 MeV has been produced so far and the beam is being delivered to perform scheduled experiments at a few locations of the beam line. The beam is being injected in to the undulator to check the first lasing of THz radiation and the first signature is expected very soon. The experiments with electron beam have already been started and lot of initiative are taken to develop the experimental facility by using the THz radiation. To plan for the experiments with THz and electron beam, a series of workshops by inviting the national and international experts were conducted in the past and another one will be conducted in Oct. 2024. Terahertz radiation has got immense potential to perform cutting edge research in various fields of Biological Sciences like Plant biology & Agriculture, Clinical applications like Cancer treatment, Dentistry, Protein detection, Anti-microbial study, Food quality, etc. THz radiation has also gained tremendous popularity in various fields of Physical Sciences like THz time domain spectroscopy, THz tomography, imaging, Materials Physics, Device Physics, High altitude communication, Security, Electro-optics, Coherent Quantum control, and in so many other fields. The electron beam can be used for many fundamental and applied researches like Atomic Physics, Material modification, material/food sterilization, life time measurement of solar cells and other electronic devices being used in space, Cancer therapy, Water and biosolids treatments, cargo scanning, etc. By using the synchronized laser beam along with the THz radiation or the electron beam, many interesting pump-probe experiments can be performed at DLS.

Development of IR-FEL based experimental facilities

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An infrared free electron laser (IR-FEL) is now in operation at RRCAT, Indore. Presently, it is operating in the wavelength range 12 to 54 microns, and is delivering highly intense, monochromatic but continuously tunable pulsed radiation to the user laboratory in the adjacent building. In the user laboratory, facilities have been established (along with ample scope for future expansion) for the utilization of this FEL light for doing materials research and trial experiments have started for studying selected functional materials as functions of temperature and IR-FEL wavelength. The initial results shall be presented and scope for the utilization of this IR-FEL light for experimental research in different branches of science shall be discussed to motivate user-requirement driven development of future experimental facilities around the IR-FEL. Experimental facilities complementary to such studies, already established in the user laboratory, shall be discussed, and the the future developmental ideas for the next 3-4 years on the building of additional experimental facilities shall also be shared.

Terahertz magnon spintronics with non-collinear antiferromagnets: Exploring nonlinear interactions with intense radiation

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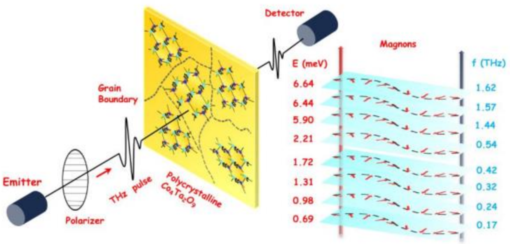
The terahertz (THz) spectrum (0.1-10 THz) offers promising opportunities in the evelopment of next-generation data processing and quantum memory technologies. These aspirations are driven by simultaneous developments in the THz spectrum and, the area of spintronics, magnonics, caloritronic, and many more [1]. In magnetic systems, magnons-the quanta of spin waves-in a spin ordered state envisage the prospects of non-Boolean-based spin wave computation, magnon logic gates, and so on [1]. However, magnonics has been widely explored in ferromagnets resulting in gigahertz magnons. However, the area of magnonics can be extended to ultra-low dissipation and ultrafast THz region as the antiferromagnets have magnons in this region. This offers THz radiation-based tools play a prominent role in exploring the technological utility of antiferromagnets which, so far, have played only a passive role in the emergence of magnetic devices.



The THz radiation mainlycouples with the magnetic-dipole moment of the spins unveiling not only the low-energy antiferromagnetic magnons but also its interplay with distinct quasiparticles such as phonons, photons, polaritons, and many more. Recently, for the first time, magnons sum and difference generation was demonstrated in YFeO3, thus, raising the importance of algebraic operations of different THz frequency magnons [2, 3]. This study necessitates the exploration of antiferromagnets possessing closely spaced magnons in terahertz region (0.1-2 THz) for their potential in THz magnon algebraic logic operations [3]. Such control over spin-waves/magnon can be contemplated in magnetoelectric/multiferroic systems, in which the spin and electric orders are entangled, resulting in electric as well as magnetic control of magnons. In this work, I'll present our recent work in exploration of a variety of non-collinear magnets for magnon and magnon-phonon excitation modes in the THz spectral region, considering two examples. First, I'll show that A4B2O9 (A=Co and B=Nb, Ta) family of non-collinear magnetoelectric antiferromagnetic [4, 5] exhibit *i)* a multitude of lowenergy antiferromagnetic resonances comprised of magnons, phonons, and hybridized spin-phonon coupled modes and *ii)* the notion of beyond conventional magnon, that is, electromagnon. The second example is based on RCrO3 (R=rare-earth) orthochromates in which weak magnetic moment is accompanied by sub-THz magnon modes along with complex crystal-field excitations. Finally, I'll present the need for intense THz radiation to drive non-linear interactions between magnon-magnon, magnon-phonon and other quasiparticles in this spectral region.

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Magnetic Ordering in Antiferromagnetic topological insulator, $MnBi_2Te_4$ investigated using time domain THz spectroscopy and Pump-Probe Spectroscopy

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$MnBi_2Te_4$, an intrinsic antiferromagnetic topological insulator, has garnered significant attention due to its involvement with exotic quantum phenomena such as anomalous quantum hall effect and axion insulator state. The Fermi level of $MnBi_2Te_4$ can be tuned across the bulk band gap via Sb-substitution, yielding phases with enhanced topological functionality and facilitating its implementation in device fabrication. In this study, THz time-domain spectroscopy was employed to investigate $MnBi_2Te_4$ and Sb-substituted $MnBi_2Te_4$ thin films, which were grown using the pulsed laser deposition technique. THz conductivity spectra (in the 0.4-2 THz range) at various temperatures (from 7K to room temperature) were obtained from our measurements. The THz studies [1] indicate metallic behaviour for both samples, while the transport studies reveal a metallic nature for $MnBi_2Te_4$ and a semiconducting nature for $Mn_{1.7}Sb_{0.7}Te_4$. The THz conductivity spectrum, fitted with a Drude-Fano-Lorentz model, reveals a strong IR active Eu phonon absorption peak and its significant changes around the Néel temperature of ~25K, indicating a coupling between magnetic ordering and electronic band structure. The frequency of the Eu phonon shows an anomalous blue-shift with increasing temperatures for both materials, more pronounced in the Sb-doped MnBi2Te4. This suggests that both anharmonicity and electron-phonon coupling contribute to the higher anomalous blue shift of phonons in Sb-doped MnBi2Te4. Additionally, pump-probe reflectivity measurements [2] reveal the presence of a Raman active A1g coherent phonon mode with normal temperature dependence.

Application of FEL for investigating carrier dynamics in semiconductors

Prof. Jayeeta Bhattacharya

Department of Physics
Indian Institute of Technology Madras, Chennai

We used free-electron laser (FEL) emitting in the mid to FIR range to probe intersubband transitions We used free-electron laser (FEL) emitting in the mid to FIR range to probe intersubband transitions in III-V semiconductor heterostructures. In this talk I will discuss the method of transient photoluminescence (PL) quenching in semiconductor quantum wells and quantum dots. I will emphasize on the techniques of performing transient PL measurements in presence of a delayed FEL pulse tuned to the intersubband transition energies. The dynamics of the carriers, excited to higher excited states by the FEL pulse as they drop back to the lowest conduction band state, contributing to the recovery of the PL was studied. This gave insight on the lifetimes associated to intersubband transitions and the possibility of coulomb mediated interactions in the system.

Ultrafast Phenomena: Conventional Femtosecond Lasers and Future Prospects with IR-FEL

Praveen Kumar Velpula

UGC-DAE Consortium for Scientific Research, Indore

In this talk, I will present a comprehensive overview of our research on ultrafast phenomena, focusing on ultrafast imaging in bulk dielectrics and the dynamic processes in semiconductor materials using conventional table-top femtosecond laser systems. These systems have enabled us to probe and understand intricate ultrafast dynamics at the microscopic level. In the latter part of the talk, I will explore the future prospects of Infrared Free-Electron Lasers (IR-FELs) in advancing ultrafast phenomena and vibrational/Raman spectroscopy.

Why & how to use IR-THz radiation sources in R&D

Abhishek Singh[1, 2]

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[2.] *THz-Innovations Private Limited, Lucknow, India*
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Investigating the light-matter interaction at the THz frequency has been at the forefront of the research from decades. THz radiation has been relatively less explored radiation than other side bands in the radiation spectrum. At the same time there are several interesting physical phenomena taking place in the scientifically attractive materials like graphene, topological insulators, 2D materials, semiconductors, superconductors, etc. at the THz photon energy level of the order of 10 meV. Therefore, use of THz (also known as FIR) radiation has been increasing in R&D activities.

To extract the useful information out of the THz/FIR light-matter interaction several experimental methods and tools have been developed. Among the THz sources, the free electron laser-based THz source has been highly desirable due to its high THz power and large wavelength tunability range. In recent years several new and highly important studies have been done including observation of transient magnetic fields in graphene induced by THz pulses, giant THz nonlinearity in HgTe-based heterostructures, transient trion-exciton conversion in monolayer $MoSe_2$ induced by THz pulses from FEL THz sources, etc. [1-3] At the same time, developing and operating a FEL based THz source is extremely challenging due to its size, cost and radiation safety concerns. Therefore, only a few number of FELs are operational/under-development world-wide, and two of them are in India at RRCAT Indore and IUAC Delhi.

Apart from the FEL THz source, several other supporting instruments and experimental setups are required to perform the useful measurements. Some of the most common techniques are pump-probe (optical pump-THz-probe, THz pump-optical probe, single colour and two-colour THz pump-probe), THz time-domain spectroscopy, transient photoluminescence, etc. Since the photon energy of THz radiation is of the order of meV that is much smaller than the thermal energy at room-temperature, many times these measurements are performed in a cryostat at low temperature.

Scope of IR-FEL for Biomedical applications: An Overview.

Dr. S. K. Majumder

Director, Material Science & Advanced Technology Group
Raja Ramanna Centre for Advanced Technology
(Email: shkm@rrcat.gov.in)

The Infrared Free Electron Laser (IRFEL) facility at RRCAT has opened up a plethora of opportunities at our disposal to explore the relatively unchartered territory in the Mid-Infrared Radiation (MIR) domain. The continuous tunability of IRFEL within its working range along with high photon flux offers an unprecedented advantage not only in basic spectroscopy, but also it offers an opportunity towards targeted radiation therapy. This talk will present an overview of the recent works in the fields of biomedical applications where IRFEL has played crucial role. Considering the present working range of IRFEL at RRCAT, this talk will also propose schemes of operation which can make it readily applicable in the field of biology with a few examples.

IR/THz Spectroscopy under Extreme Pressure and Temperature

Himal Bhatt

High Pressure & Synchrotron Radiation Physics Division, Bhabha Atomic Research Centre, Trombay, Mumbai INDIA 400085; Homi Bhabha National Institute, Anushaktinagar, Mumbai INDIA 400094

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Infrared spectroscopy is among the techniques that have shown tremendous growth during the last century in terms of sources, instrumentation and hence the applications. The transition from black body sources, giving excellent flux in mid – infrared regions (600 – 6000 cm^{-1}) to synchrotron radiation sources from electron storage rings witnessed a manifold increase in the brilliance, thus opening an opportunity to address many challenging questions utilizing IR micro-spectroscopy and more recently SNOM techniques. The brilliance as well as flux in the far- infrared regions have further seen a multifold increase with the development of Free Electron Laser (FEL) based source. In addition, the FELs provide a unique time structure from microseconds to sub-picoseconds regime. These newer opportunities are poised to unfold many new discoveries using the grand old infrared spectroscopy technique. In particular, the dynamical motions that take place in these timescales can now be studied using a high fluence source. Hydrogen bond dynamics in a strongly hydrogen bonded material is one such example, having a very wide range of applications domain. Our recent studies on simple molecular systems such as formic acid, oxalic acid, glycine systems in conjunction with the simplest system, i.e. ice, have provided the glimplse of a highly delocalized nature of proton through the study of hydrogen bond dynamics under extreme pressure, temperature conditions, thereby tuning a double well potential. Current studies being carried out at other FEL facilities to understand the proton dynamics in such hydrogen bonds will also be discussed. Another important problem which can be solved using IR/ THz frequencies is the understanding of carrier dynamics in low dimensional quantum materials. Our recent studies on a charge density wave molybdate system and few layer graphene using synchrotron infrared and THz will be presented. This will be followed by the THz studies carried out in similar 2D system black phosphorous by the Italian FEL group where the carrier dynamics could be tuned by changing the applied electric field of THz photons by tuning the fluence of FEL source.

Ultrafast Dynamics of Hydrogen Bond Reorganization: Femtosecond Infrared Spectroscopy

Rajib Ghosh

Radiation & Photochemistry Division, Bhabha Atomic Research Centre, Mumbai 400085

Homi Bhabha National Institute, Anushaktinagar, Mumbai 400094

Solute-solvent hydrogen bonding plays important role in chemical reactivity of many condensed phase reaction. Thus elucidation of molecular level picture of site specific hydrogen bonding and their dynamics is of relevance to chemical and biochemical reactions. Perturbation of hydrogen bonding network by electronic excitation of the solute gives the opportunity to monitor the site-specific hydrogen bond reorganization event in real time scale with femtosecond visible infrared probe pulse. In this talk, I shall discuss hydrogen bond breaking and reorganization dynamics in the excited state of a few organic chromophores in protic solvents. The photoinduced cleavage and reorganization of hydrogen bonding between the fluorophore and solvent molecule is captured in real time by probing the time dependent evolution of carbonyl stretch frequency. [1] Comparison of spectral dynamics in nonprotic and protic solvents can disentangle timescale of vibrational cooling process, solvation and hydrogen bond reorganization.[2,3] Dependence of hydrogen bond structure and dynamics on the nature of electronic state of the solute in excited state will be discussed.

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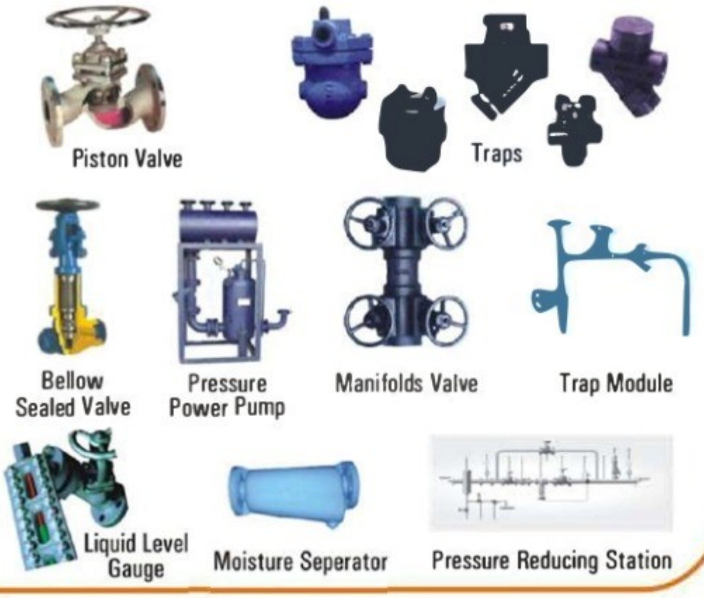

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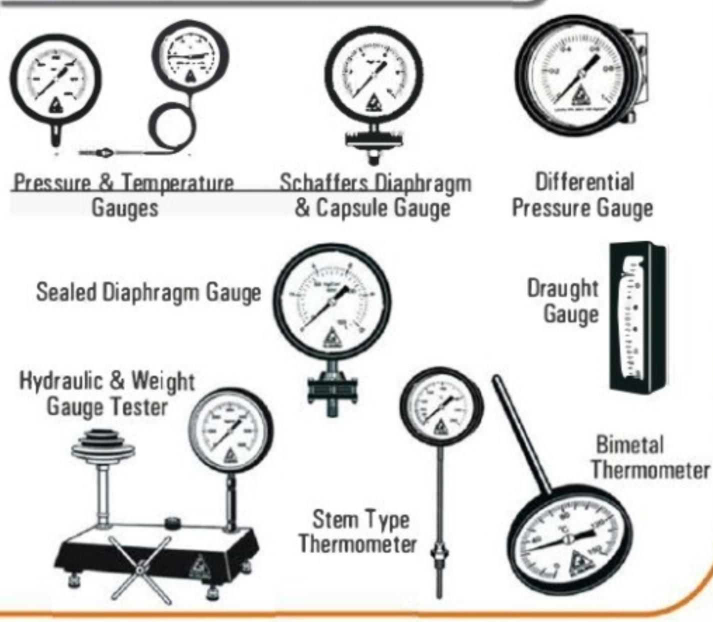

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