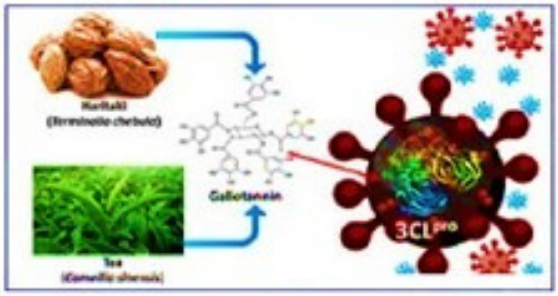

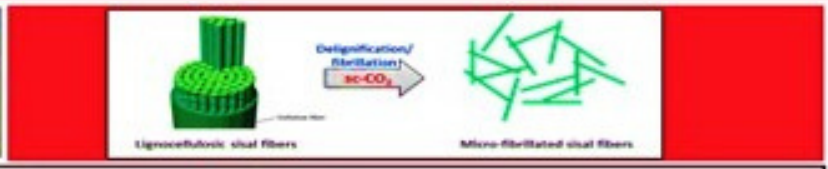

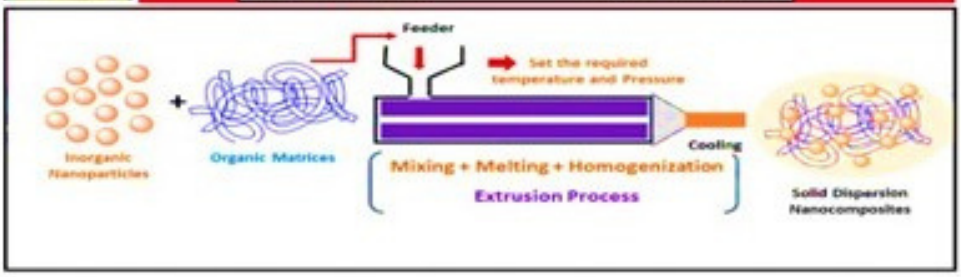

अNUSANDHAN

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About this Endeavour....

The Indian Institute of Technology Delhi strongly emphasizes sponsored research and industrial interaction. The Industrial Research and Development (IRD) Unit at the Institute is committed to providing administrative and managerial support for the operation of sponsored research projects, consultancy work, and other research activities vis-à-vis FIRP, MFIRP, Grand Challenges, and student research. This has led to increased research impetus at the Institute and a significant rise in the quality of research output.

On the occasion of completing 75 years of Indian Independence, when the county is celebrating 'Azadi ka Amrit Mahotsav,' the IRD Unit of IIT Delhi has compiled the recent research achievements of the Institute faculty members in the form of an ebook. We initiated the work last year by inviting information from individual faculty members through the Heads of Departments, Centres, and Schools of the Institute.

The information is presented in the form of an ebook titled 'Anusandhan' as our collective contribution to mark our great nation's 75th Anniversary of Independence. Through this initiative, we seek to showcase the talent and research acumen of our faculty members and students to attract more opportunities and talent to strengthen the Institute's research ecosystem. The ebook highlights the multifariousness of research at the Institute, indicating the diversity of areas undertaken for research. A significant part of research is interdisciplinary, where experts from Engineering, Sciences, and Management have come together to develop solutions to address current global challenges. Even the overwhelming pandemic did little to quell the enthusiasm for research among our faculty members. Many tangible products were launched that proved to be crucial during the pandemic. These products and technologies, which immensely benefitted the end-user, were well-received by the Government of India and the industry.

Collaborations with the industry and academia have empowered and boosted the research framework of the Institute, which is now ranked very high nationally and globally in terms of research. Faculty members have published their research in high-impact journals, generated many international and national patents, and steered many technology transfers and start-ups.

To further strengthen the Institute's research, many new schemes for faculty members and students, viz. the Multi-Institute Faculty Interdisciplinary Projects (MFIRP) scheme with national and international institutions of eminence, have led to significant research output in cutting-edge areas. The IRD has sponsored 140 MFIRP projects since 2018, resulting in 15 sponsored projects, 111 published papers, 14 patents, and two technology transfers so far.

In order to imbue research enthusiasm among undergraduate & graduate students and promote learning through research, the Student Startup Action & Discover & Learn (1-2-3-4) were launched. Since their inception in 2016, twenty-three Student Startup Action projects and thirty-seven Discover & Learn (1-2-3-4) projects have been awarded in various challenging research areas.

The present ebook, 'Anusandhan', is a humble attempt by the IRD Unit to recognize the outstanding research contributions of the faculty members and students. Because of this, IIT Delhi has moved up the NIRF Research Rankings to feature among the top three institutions in 2022, in the Engineering category.

INDUSTRIAL RESEARCH AND DEVELOPMENT (IRD) UNIT

Recent Research Achievements of IIT Delhi

Contents

Research

Innovate

Lead...

Credits

Concept: Prof. Sunil Kumar Khare, Dean (R&D) & Corporate Relations

Data Acquisition & Communication: Ms. Jyoti Grover

Content: Faculty Members, IIT Delhi

Editing & Design: Dr. R. Hemamalini Bibliography: Ms. Rashmi Mishra

CENTRES

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Centre for Automotive Research and Tribology (CART)

Centre for Atmospheric Sciences (CAS)

Centre for Biomedical Engineering (CBME)

Transportation Research and Injury Prevention (TRIPP) Centre

Centre for Rural Development and Technology (CRDT)

Sensors, Instrumentation and Cyber Physical System Engineering (SeNSE)

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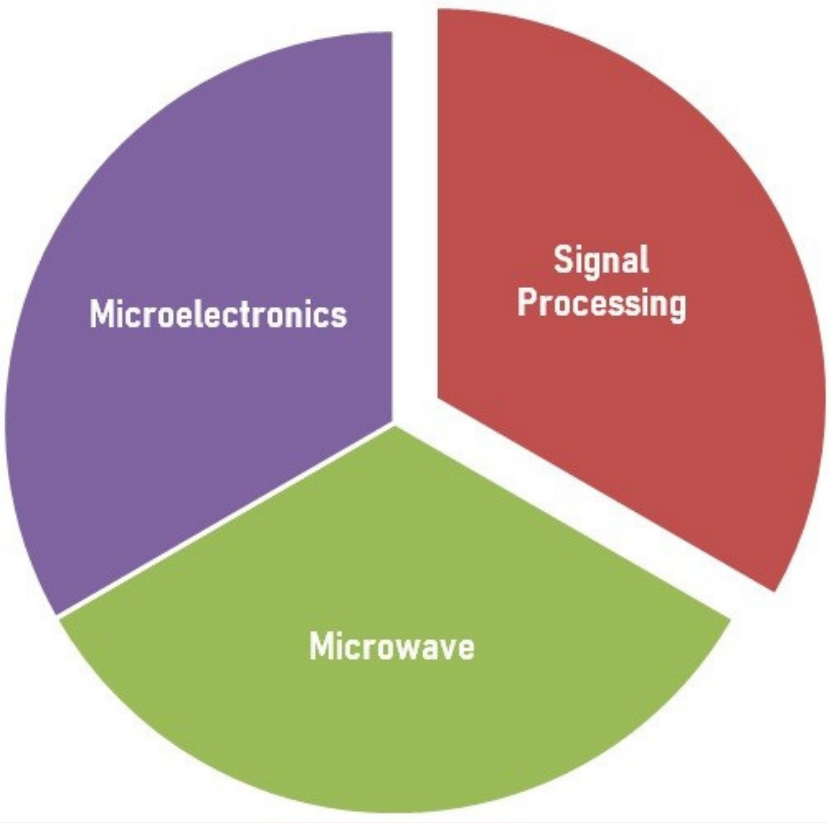
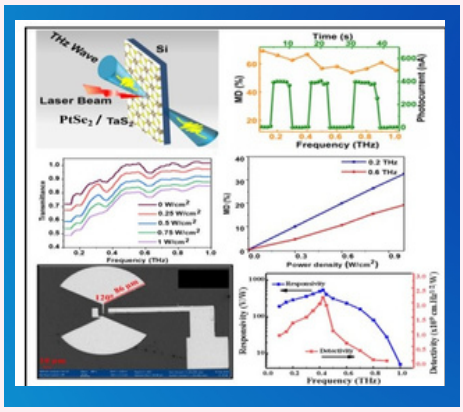
RESEARCH AREAS



The Centre for Applied Research in Electronics (CARE) started as the School for Radar Studies (SRS) in 1971, with an initial grant from the Radar and Communication Project Office, Ministry of Defence. The initially identified areas were Radar Signal Processing and Phased Array Techniques. The scope of R&D was soon broadened to encompass the areas of Signal Processing, Microwaves, and Microelectronics.

Terahertz Modulators and Detectors

Optically pumped terahertz (THz) modulators based on the TMDs material - platinum diselenide ($PtSe_2$), and tantalum sulphide (TaS_2) have been fabricated, with frequency range of 0.1 to 1 THz [Figure 1]. The maximum modulation depth reaches up to 69.3 % and 48.6 % under low power optical excitation of 1 W/cm^2 at 0.1 THz and 0.9 THz frequency, respectively in TaS_2/Si devices. n-type single silicon nanowire (NW) based junctionless field-effect transistor (FET) is demonstrated as efficient terahertz (THz) detector with a maximum responsivity - 468 V/W at 0.425 THz frequency and noise-equivalent-power of ~ 10^{-9} W/Hz$^{1/2}$ which was obtained at room temperature.



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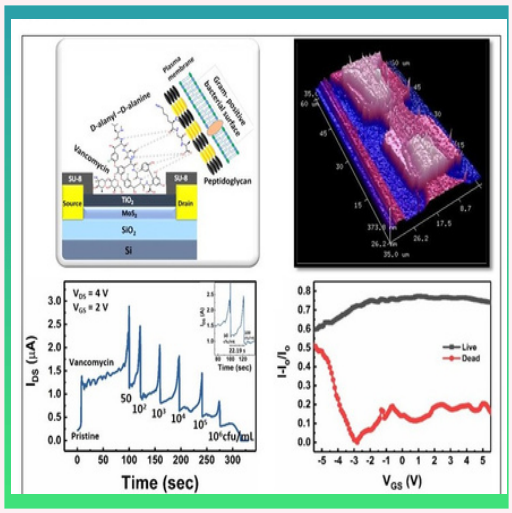


Figure 2

Bio-Sensors

A highly sensitive and selective hybrid TiO /MoS nanostructure-based FET has been developed for the detection of Gram-positive bacteria [Figure 2]. The device, with a wide dynamic range (50-10 cfu.mL^{-1}). allows efficient discrimination between Gram-positive and Gram-negative bacteria with a LOD of 50 cfu.mL^{-1} and high sensitivity of 49.5 ± 1.7 % for *Staphylococcus aureus* among eight different bacteria (at 10^2cfu.mL^{-1}). Real-time detection is possible, with a response time of 22.19 s at 50-100 cfu.mL^{-1} suggesting rapid and low concentration detection of selective bacteria. Quantifying bacteria in the physiological conditions as well as discriminating between live and dead bacteria.

Photodetector

An ultra-high efficiency photodetector was developed and integrated in prototype for real world applications. Its salient features include high performance and packaged UV to Mid-IR detection of light through various photodetection techniques [Figure 3]. Photodetectors based on nanowires, quantum dots and heterojunctions have been fabricated. The detectors have a broad response (400 nm to 4000 nm), high responsivity (~10^4), low dark current (~20 pA), low NEP (~6×10^{-14} W/Hz$^{1/2}$), high detectivity (~9.33×10^{11}) and high gain (~10^4).

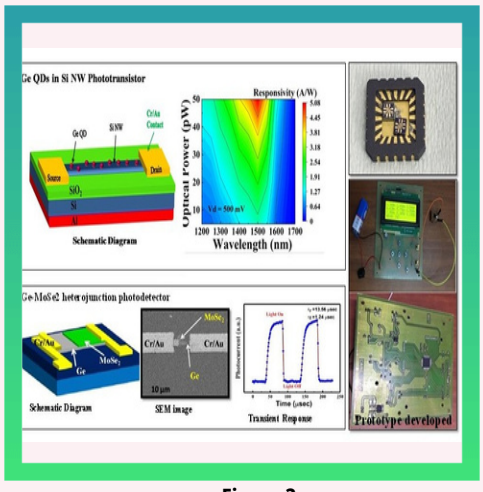


Figure 3

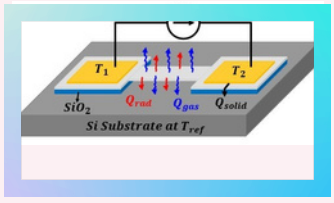


Figure 4

Metal Oxide-Based NEMS Pirani Gauge

An ultrathin metal-oxide (V_2O_5)-based sensing element where suspension is without dielectric membrane support has been developed with increased sensing area to enable in-situ monitoring. Besides, there is the added advantage of reduced footprint due to volumetric reduction. It uses a two-lithography process for ease of integration and compactness. A schematic of the Pirani gauge is shown in Figure 4. Key Performance Indicators (KPIs) inlcude a dynamic Range of 4-2.7×10^3 Pa, power consumption of 0.2 mW (max.), a sensitivity of 5.76 % per decade-Pa, and Thermal Response Time of 500 ms.

Nano Dimensional Piezoresistive Sensing Elements for Multiuse MEMS Sensor

A diameter-dependent gauge factor of silicon nanowire FET [Figure 5], a piezoresistive polycrystalline MoS_2 MEMS Pressure Sensor for gas-flow measurement [Figure 6], a polycrystalline MoS_2-based piezophototronic MEMS Sensor [Figure 7] and a highly sensitive wearable flexible strain sensor based on polycrystalline MoS_2 thin films [Figure 8] have been developed using.

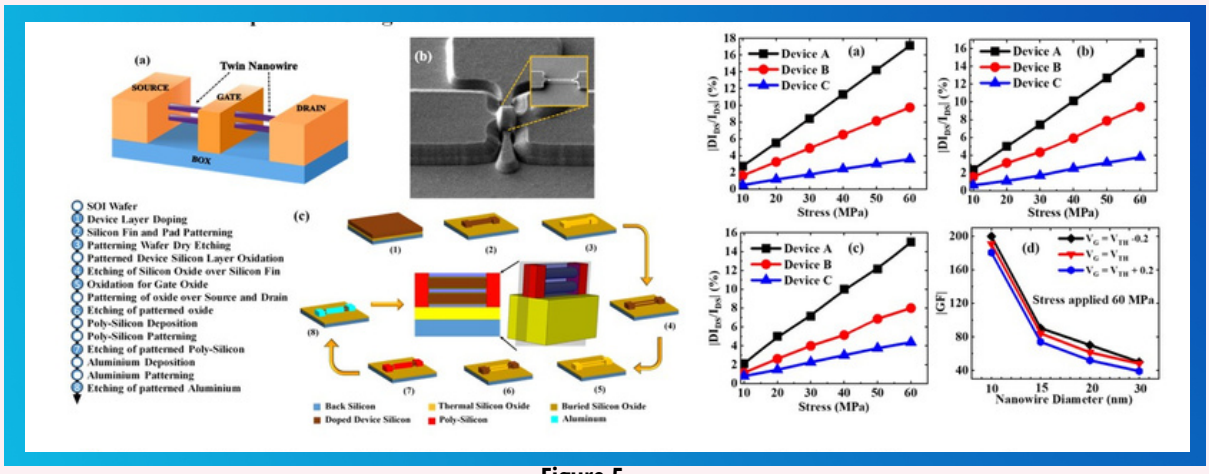


Figure 5

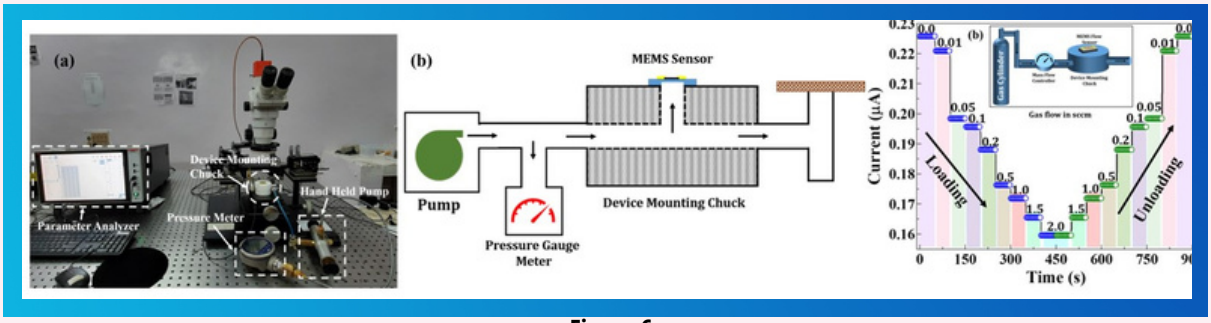


Figure 6

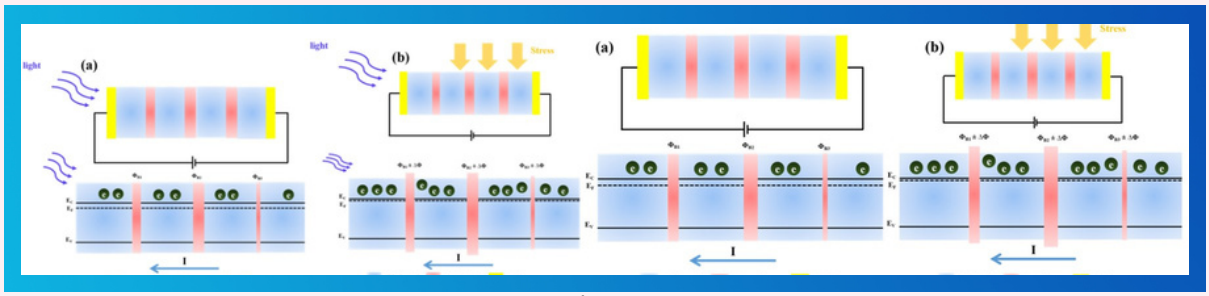


Figure 7

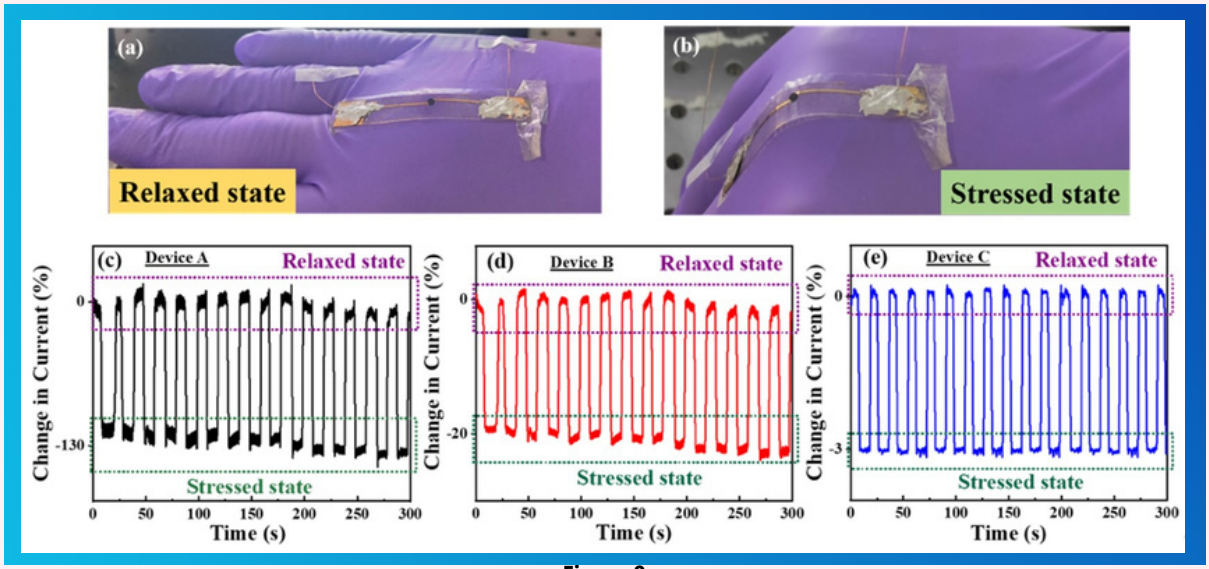


Figure 8

RF Circuit and Devices

A complete RF Power Amplifier (PA) circuit has been fabricated using drain-extended MOS (DeMOS) device with proper biasing and matching network on board a low-loss laminate [Figure 9]. This board was used to perform various small and large signal measurements. New device designs and process technologies are being developed in order to achieve these requirements. An optimization strategy has been developed for DeMOS devices to improve high voltage blocking capability and high frequency switching speed. Such RF amplifying devices are used for GaN based devices. Their structure strongly resembles lateral RF HEMTs and enables high output power densities, higher frequency of operations, higher power-added efficiencies (PAE) and improved reliability GaN-based devices.

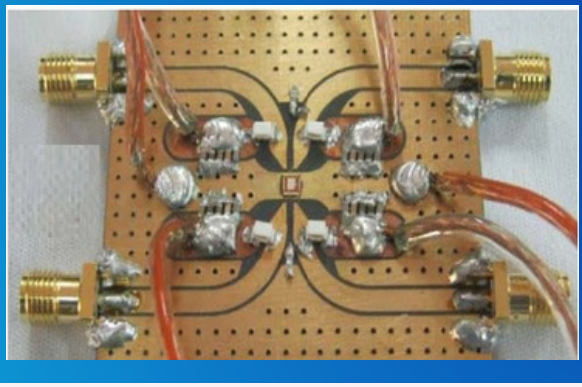


Figure 9

Wi-Fi Signals and Building High-Density Memory Using Spin Torque Technology

National University of Singapore (NUS), IIT Delhi and Tohoku University collaborated to demonstrate that an electronic circuit can be powered directly from the electromagnetic waves generated from a regular 2.4 GHz Wi-Fi signal, using an array of spin-torque oscillators (STO) [Figure 10]. A 1.6V LED was powered from the Wi-Fi signal. Besides, a prototype of high density spin memory has also been demonstrated through a shared channel SOT-MRAM [Figure 11]. A magnetic memory device that can be programmed by the application of a gate voltage was designed, where the gate voltage was used to migrate oxygen ions in the device resulting in the modulation of the spin current polarity therefore making the high density memory feasible.

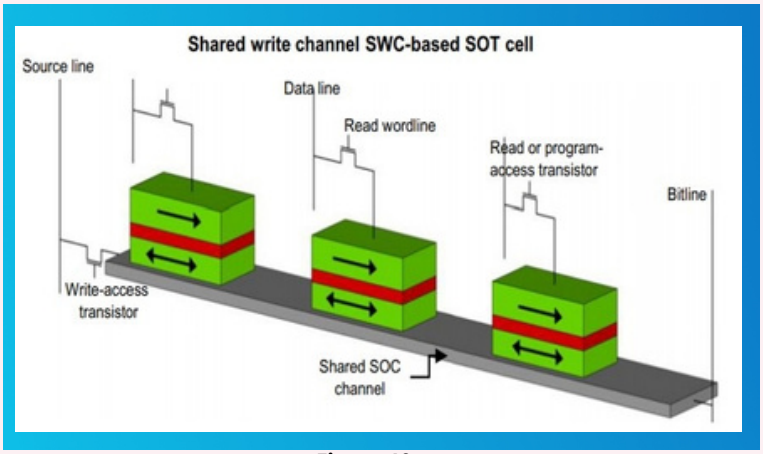
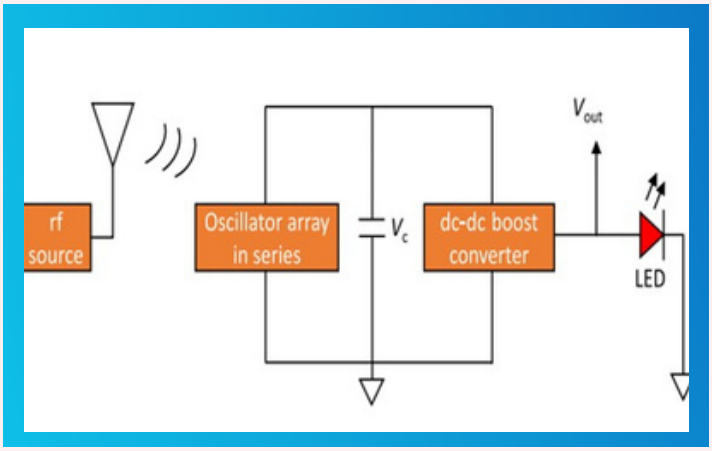


Figure 10



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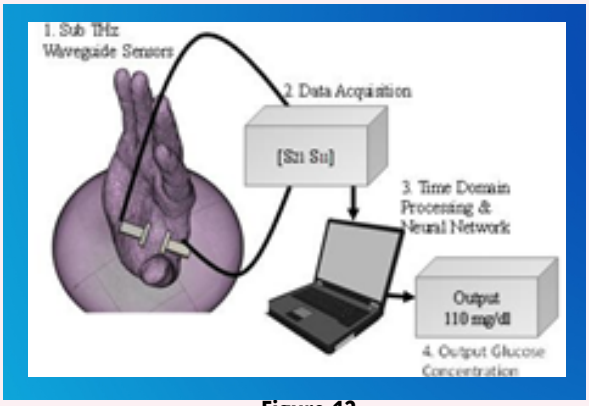

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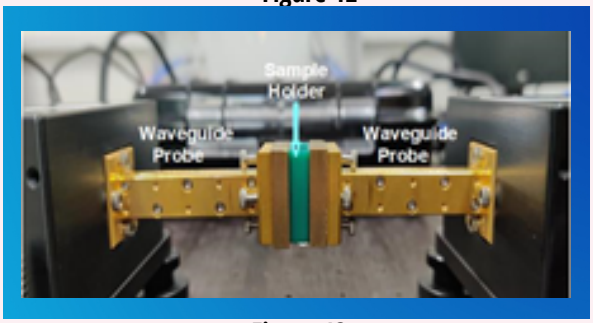


Figure 13

Machine Learning-Based Sub-Terahertz Non-Invasive Blood Glucose Monitoring

The difference in permittivity for different glucose concentrations in a sub-terahertz band (110-170 GHz) has been used to develop a non-invasive blood glucose measurement system [Figure 12]. The proposed device uses transmission and reflection characteristics of the sub-terahertz waves to detect blood glucose concentration change of 15 mg/dl according to ISO:15197 2013 measurement standards (±15 mg/dl error) in a non-invasive manner [Figure 13]. The adoption of a Machine Learning (ML) approach has further made the device more user-friendly. The inclusion of neural network training of the obtained transmission and reflection parameters from the sub-terahertz sensor unit and correlating it with the glucose levels makes the overall glucose measurement system more legible. The output as glucose level value is in units of mg/dl.

Material Characterization in Sub-Terahertz Band

A new robust method for material characterization, which uses RMS delay propagation in Fresnel's region to estimate the permittivity of the unknown dielectric sample, has been developed. A schematic diagram of the setup has been shown in Figure 15. This measurement technique uses Fresnel near field principle with a unique positioning of the sample at the transmitter's end in order to characterize low loss materials' electrical properties [Figure 16]. It uses the principle of change in RMS delay spread with a change in permittivity of the material placed in front of transmitter antenna.

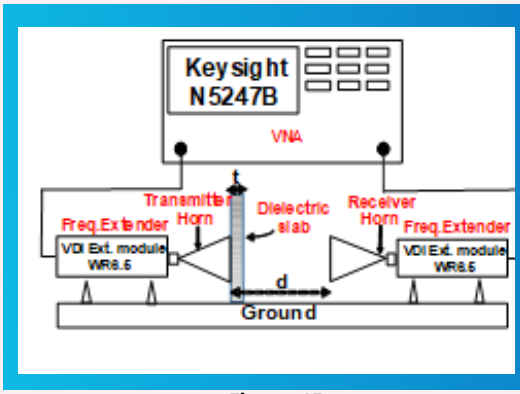


Figure 15

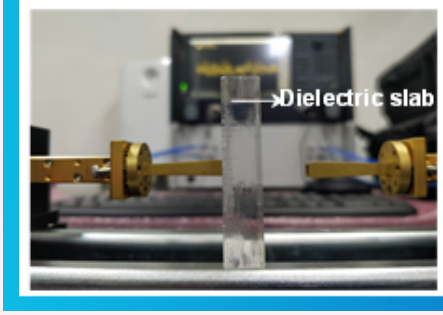


Figure 16

Thin Planar Lens Antenna Array for mm-Wave MIMO Applications

A phase gradient metasurface planar lens having a thickness of 1.3 mm has been developed for mm-Wave massive MIMO applications [Figure 20]. The designed lens when implemented with a circularly polarized antenna array efficiently transforms the radiation from antenna space to beam-space with high directivity for better SNR. Three radiation beams pointing along ($\theta=0^{\circ}\pm15^{\circ}$) with a peak gain of 20.2 dBi is achieved with three antenna elements at the focal plane.

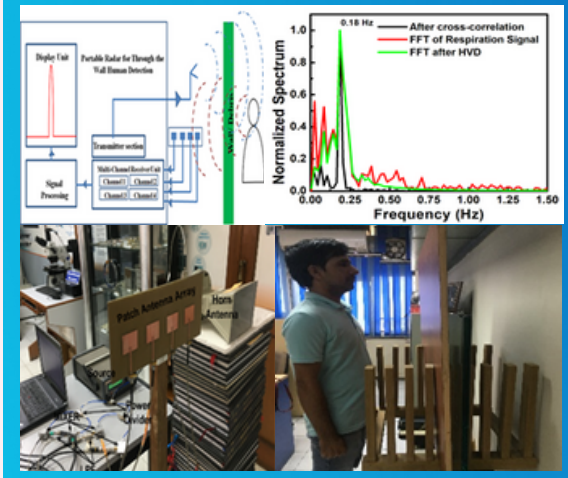


Figure 17

Human Vital Sign Sensing Using Radar

Through-the-wall respiration rate-detection and localization of human subject is now possible. In this, a RF frequency is transmitted towards the human subject, and the reflected signal is analysed to capture information about his/her chest movement [Figure 17]. Due to the periodic motion of chest, the reflected signal is phase modulated and the vital sign information is present in the phase of reflected signal. A multiple antenna system is used to detect the angular position and respiration rate of the human subject. The use of multiple antennas adds several advantages. All four channels contain identical information of respiration signal. The extraction of respiration signal using multiple channels improves the detection accuracy as compared to single channel. This method can be used to detect people trapped during a building collapse, earthquakes, during security operations and even in medical care.

Millimeter Wave Antennas

Millimeter waves experience higher path loss compared to the conventional commercial sub-6GHz or microwave based wireless services. But future wireless systems would be designed in and around 28GHz to support higher data rate systems. Conventional broadside radiators would radiate towards the user and would experience high attenuation. On the other hand, corner bent antennas find utility for 5G. A wideband antenna integrated with an electrically closed reflector would radiate away from the user and will have a high gain [Figure 18]. To combat higher path loss, high gain antennas such as Ultra-compact orthogonal pattern diversity antenna module for 5G need to be designed and integrated with mobile devices [Figure 19].

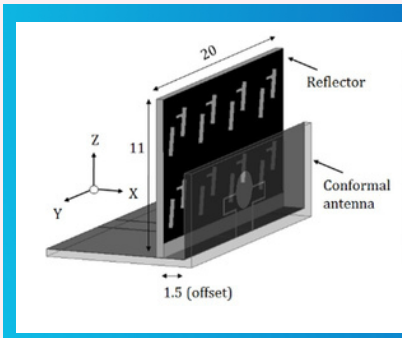


Figure 18

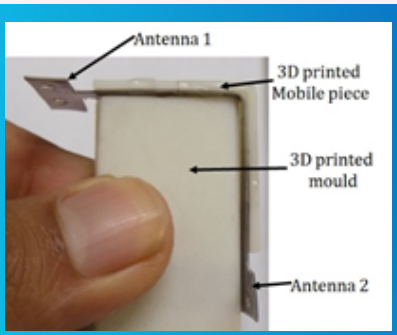


Figure 19

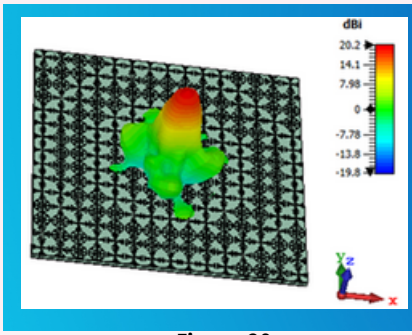


Figure 20

Millimeter Wave Dual-beam Antennas

The design of dual-beam antennas is crucial for mm- Wave communications in enhanced link reliability by combining the power at the receiver side [Figure 21]. A novel technique to generate dual-beam radiation from a single radiating source using the routing phenomena of the high epsilon uniaxial anisotropic media is implemented at millimeter. The anisotropic media is realized using stacked metamaterial ELC slabs with airgaps. A prototype antenna with 7-ELC slabs were tested and measurements agreed with theory and simulated results having dual-beam radiation with main beam peaks directed at ±40^{0} with respect to endfire direction.

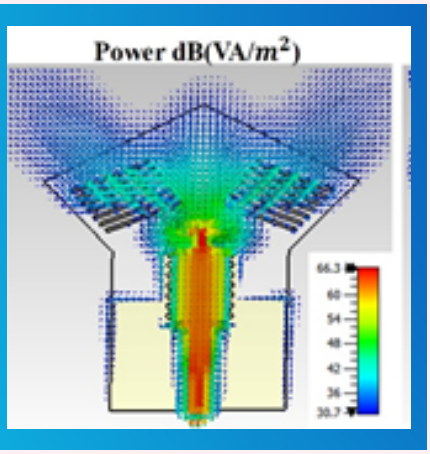


Figure 21

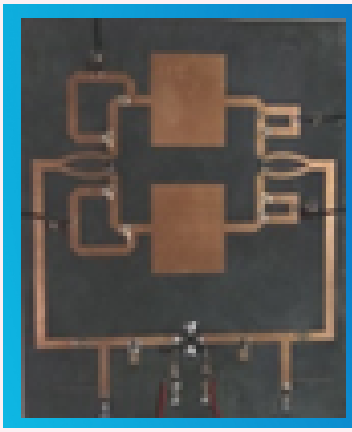


Figure 22

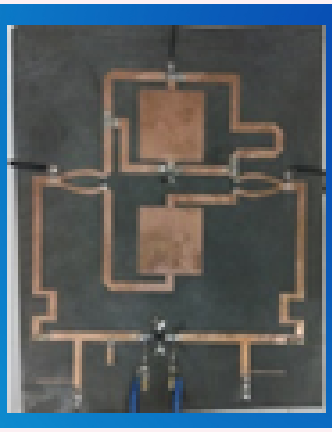


Figure 23

Active Antennae

Pattern Reconfigurable/Switchable Active Integrated Antenna. An oscillating Active Integrated Antenna (AIA) with a switchable pattern among sum or difference has been developed [Figure 22]. This design is suitable to cover the space in a more efficient manner by generating the pattern among broadside or conical. Another AIA with three switchable states (main beam at θ = 0^{0}, +30^{0}, and -30^{0}) of the broadside radiation pattern is developed [Figure 23].

GaN/AlGaN HEMT-Based High Power Sources Using Active Integrated Antenna (AIA)

High power amplifier type AIA is developed with measured EIRP of circuit 49 dBm [Figure 24]. Self-oscillating AIA using series topology with patch antenna is connected in series at output of oscillator. The measured EIRP of circuit is 29 dBm at 2 GHz frequency. Self-oscillating AIA to maximize the radiated power at second harmonic. The measured EIRP of the circuit is 32 dBm at second harmonic (3 GHz) and 16 dBm at fundamental frequency (1.5 GHz). Self-oscillating fixed frequency and frequency reconfigurable AIA based high power source using feedback topology is designed. The fixed frequency circuit implemented radiates 41 dBm power at 2.4 GHz. In frequency reconfigurable AIA, the frequency of oscillation changes from 2.1 GHz to 2.7 GHz, when pin diodes change its state from off state to on state. This circuit has measured EIRP within 1 dB in both states.

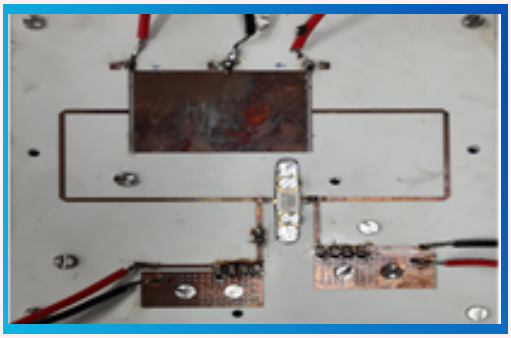


Figure 24

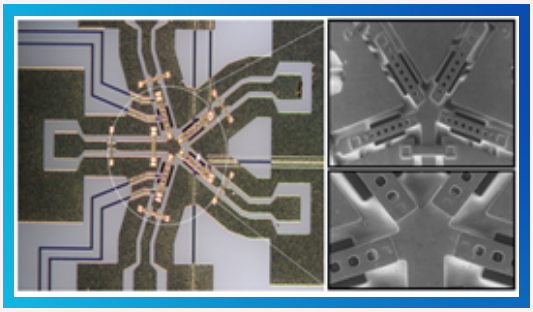


Figure 25

RF-MEMS Switches and Phase Shifters for Microwave Applications

RF MEMS based switches are widely used in modern communication systems for their low loss, excellent linearity, low power consumption and compact size compared to other contemporary solid-state devices. Phase shifters are very critical and essential components in beam steering that are based on phased antenna arrays. The most widely discussed MEMS phase shifters are true-time-delay (TTD) and DMTL phase shifters. Different MEMS SPDT to SP4T switching network followed by different delay line lengths are used to develop a TTD phase shifter. A SP4T network is designed and fabricated at 17GHz. The measurement results confirms its isolation > 30 dB, RL >27 dB , Loss <0.23 dB, Size 0.55 mm^2, Reliability 106 cycles up to 2 W & up to 1 W (in cold & hot switched condition respectively) [Figure 25].

RF-MEMS Switches and Phase Shifters for Microwave Applications (Contd...)

5 Bit Phase shifter (Switched Line Based): Different topologies of a 5-bit phase shifter can be designed and optimized using four SP4T and two SPDT switches with different delay and reference line combinations. Compared with the conventional TTD phase shifter, in which a minimum of 10 switches are actuated at a time, the present design requires only 6 switches to be actuated for 5-bit operation. S11 and S22 is better than 19 dB over 0.1–18 GHz and average loss is 3.89 dB within 13–18 GHz. The maximum phase error is 1.140 at 17 GHz in 258.750 phase state [Figure 26].

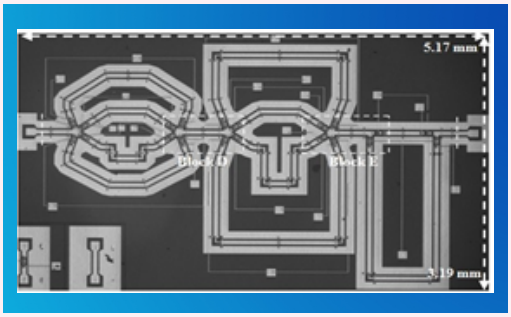


Figure 26

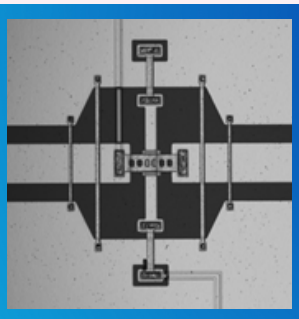


Figure 27

DMTL Phase Shifter Using MEMS Bridges and MAM Capacitors

These capacitors shown in Figure 27 register a measured return loss of better than 41 dB and insertion loss of 0.07 dB are obtained at zero-bias state. The unit cell gives a return loss of 31 dB and worst case insertion loss of 0.09 dB with 55 V bias voltage.

Medical Signal/Image Processing

A system for the diagnosis of various retinal diseases jointly with a team doctors of RP centre, AIIMS New Delhi has been envisaged. Presently work is underway for the glaucoma and diabetic retinopathies. Good results were obtained in terms of segmentation of various features of the retinal images. A complete system will be developed for testing at AIIMS. Auscultated lung signals are also being studied for the diagnosis of lung diseases. Lung sounds are being collected at the OPD of Dr. RML Hospital, New Delhi. A system 'Astute' for the collection and automatic diagnosis is being envisaged [Figure 28].

Figure 28

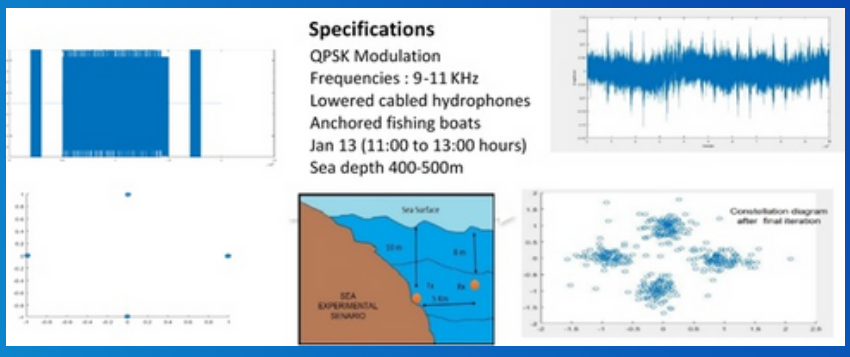


Figure 29

Underwater Communications

Underwater channel is one of the hardest channel to communicate. In 2018 in a major breakthrough error free communication was made in the Bay of Bengal. With several modifications, a complete system is being realized. Negotiations are on with potential user organizations for technology demonstration. Research is in progress to design a system based on light wave [Figure 29].

Underwater Acoustic Vector Sensors (AVS)

Acoustic emissions from underwater radiating sources or targets can be used to detect, localize, and track them passively. The Direction of Arrival (DoA) of an acoustic wave can be estimated by collocated measurement of the particle velocity and the pressure of the signal that gives the acoustic intensity vector. An AVS consists of three orthogonally oriented velocity sensors and a pressure hydrophone, all spatially collocated in a point-like geometry. This measurement can give improved DoA estimation with a single AVS or smaller AVS arrays as compared with only pressure sensor arrays that require comparatively large apertures.

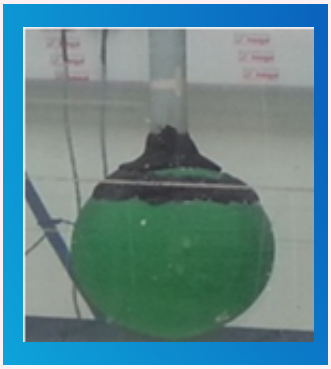


Figure 30

Figure 31

Figure 32

Underwater Acoustic Vector Sensors (AVS) (Contd...)

The AVSs designed, fabricated in the lab, and field tested underwater provide close to ideal directivity pattern. Novel algorithms were developed for estimating DoA using AVS [Figure 30]. IITD AVS characterization tests were carried out at NIOT Chennai [Figure 31] while field tests were carried out in Ganga river [Figure 32].

Figure 33

Figure 34

3-D Forward-Looking Imaging Sonar for AUVs

A 3D imaging sonar mountable on the nose of an autonomous underwater vehicle (AUV) has been developed. A table-top test setup with the electronics modules (without Tx, Rx arrays) is shown in Figure 33. The sonar can provide underwater images in three dimensions up to a range of 50 m. It uses two uniform linear arrays in the 270-330 KHz band. The key novelty of our technology development is the use of much lower number of sensors i.e. 256 compared to 10,000 sensors used in available product. This is made possible with the use of advanced signal processing algorithms. This first of its kind and will allow mission-specific customization at much lower costs. Its potential uses include underwater inspection and maintenance of ship's hull, imaging and obstacle avoidance with AUVs, port and harbour monitoring and reconnaissance, offshore site surveys and inspection etc. The integrated testing of the imaging sonar in underwater tank facility is underway [Figure 34].

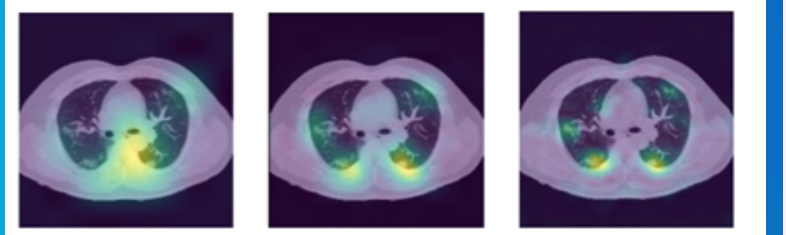


Figure 35

Covid-19 Research Contribution - Ambu Bag-Based Ventilator

The design and successful testing of Ambu Bag ventilator has been done at AIIMS. Work is underway for converting this design to a compressor-based ventilator. A few units of battery-operated positive air pressure unit for healthcare workers have been made and sent to doctors for feedback. Covid-19 detection based on CXR and CT-scan images: Using available data of chest X-rays a system was trained to diagnose the Covid-19. We obtained almost 99% accuracy and sensitivity [Figure 35].

Context Awareness of a Mobile Device User

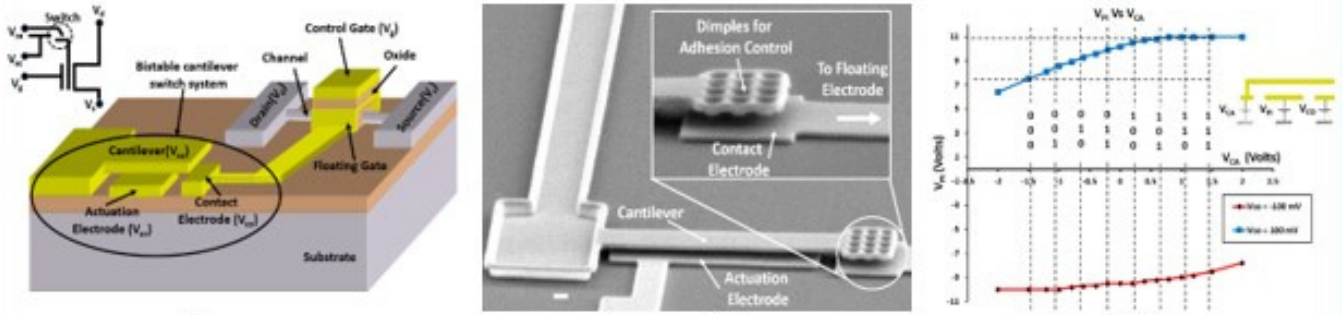
The inclusion of MEMS sensors in mobile and wearable devices has made it feasible to make the device context aware. Architectures and algorithms have been developed by a research group in the department for determining the "base-level" context awareness of a mobile device user that determines the continuous and transient motion activities, spatial environment of the user, and voice activity in the vicinity. The context information are a function of time and are combined to determine the "meta-level" context awareness of the device user. The detection of a meta-level context of the user can be used to initiate follow-up activities automatically. The technology development work was carried out in collaboration with ST Microelectronics Inc., USA, and was tested for various scenarios and applications.

Array Signal Processing

Novel maximum-likelihood, high-resolution algorithms have been developed for direction-of-arrival estimation and beam-forming mainly for wideband sources, spread sources and wideband spread sources. Array design problems and inherent array ambiguities due to the array geometry were studied. A system of single acoustic vector sensor to estimate the direction of arrival and beamforming is being developed. Arrays to handle the underdetermined systems such as non-circular signals along with second and higher order statistics-based optimum nested array for non-circular signals, have been developed.

Bistable MEMS Switches: Non-Volatile Memory

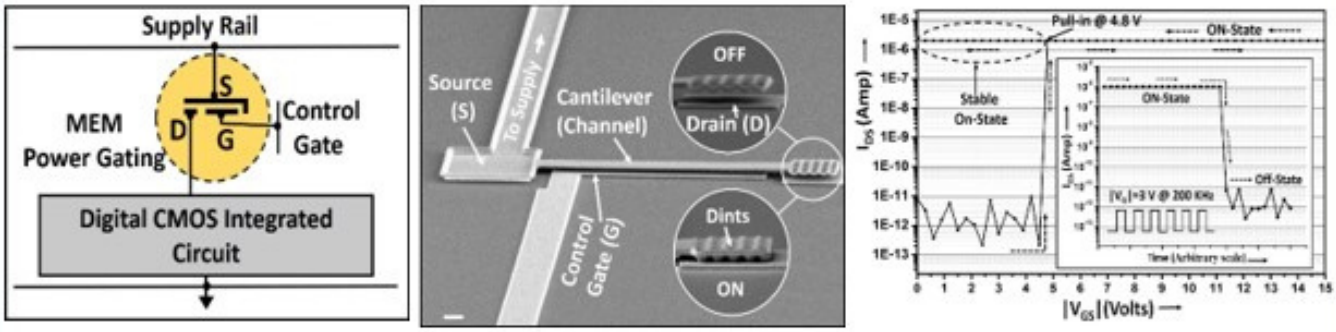
MEM-FLASH non-volatile memory device for high-temperature multibit data storage



(i) (ii) (iii)

(i) Non-volatile MEMS-Flash memory cell: Symbol and layout. (ii) SEM of the dynamic part of NEMS FLASH (scale bar 1µm). (iii) Pull-in variation for positive and negative V_{PI} based on charge loading.

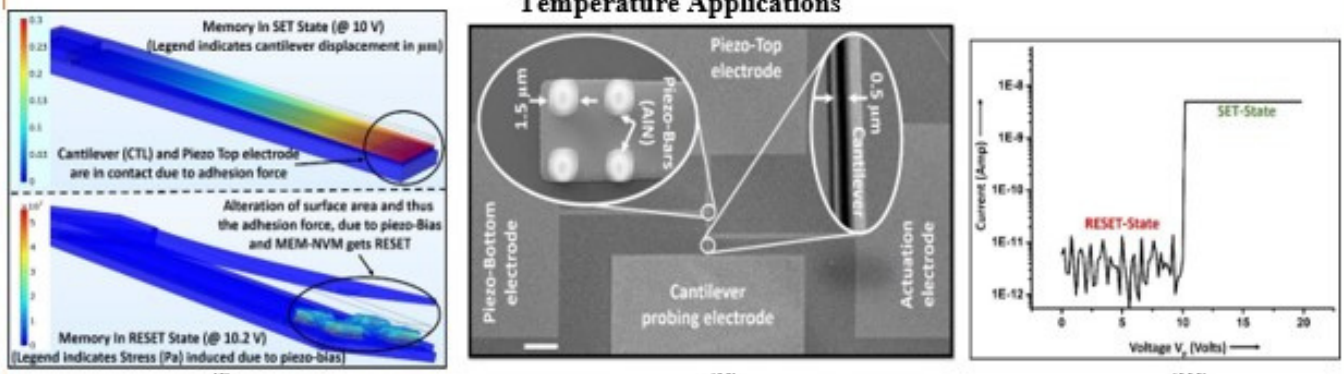
Reducing Dynamism in DRAM with Bistable MEMS Switch as Sleep Transistor



(i) (ii) (iii)

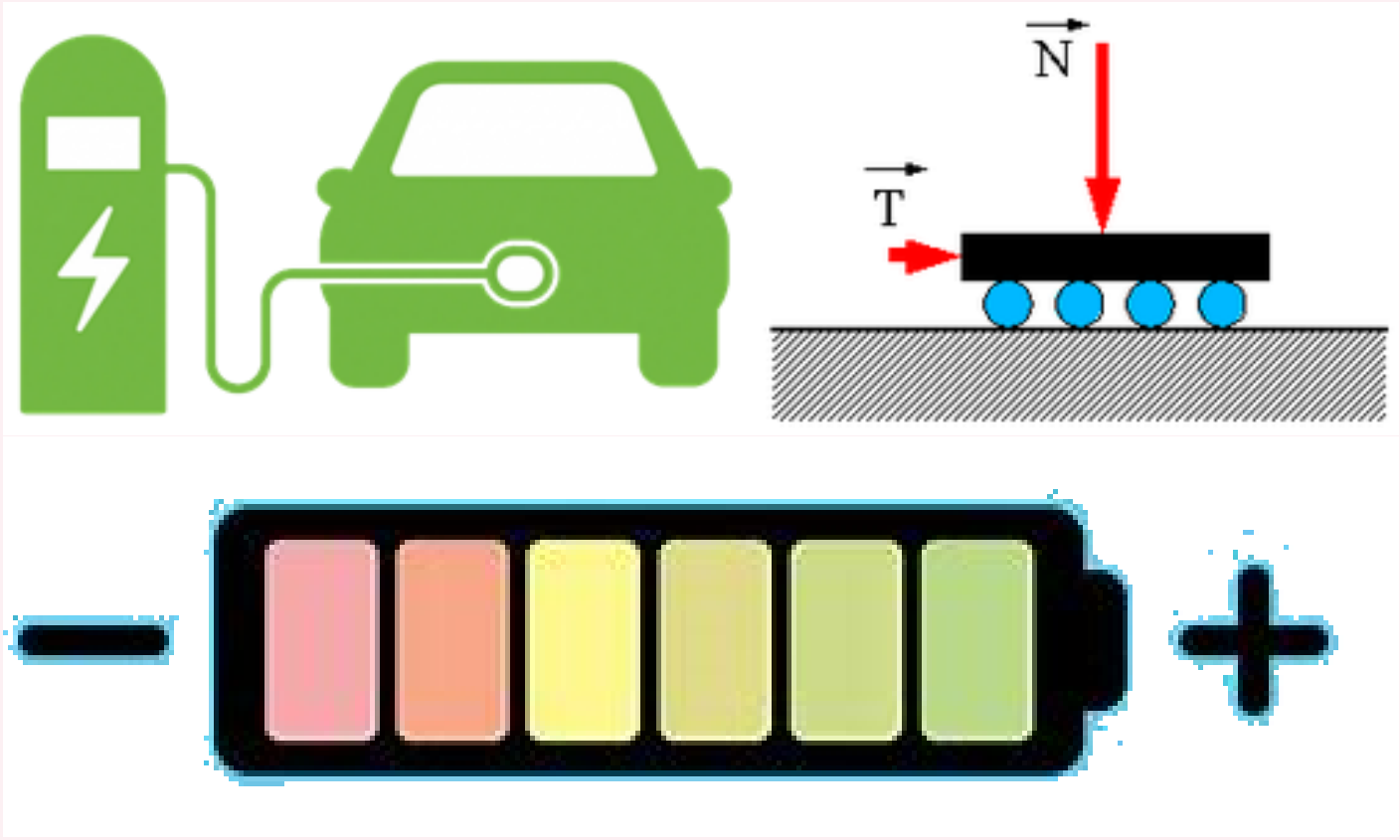
(i) Doubly stable MEM power gate as sleep transistor in CMOS ICs. (ii) Bistable MEMS sleep transistor in both the stable modes (active/sleep). The notches on the cantilever end are designed to precisely (scale 2µm). (iii) Cyclic test for MEMS sleep transistor.

A Cantilever Type Bistable MEM Non-volatile Memory with Piezoelectric Deactuation for High-Temperature Applications



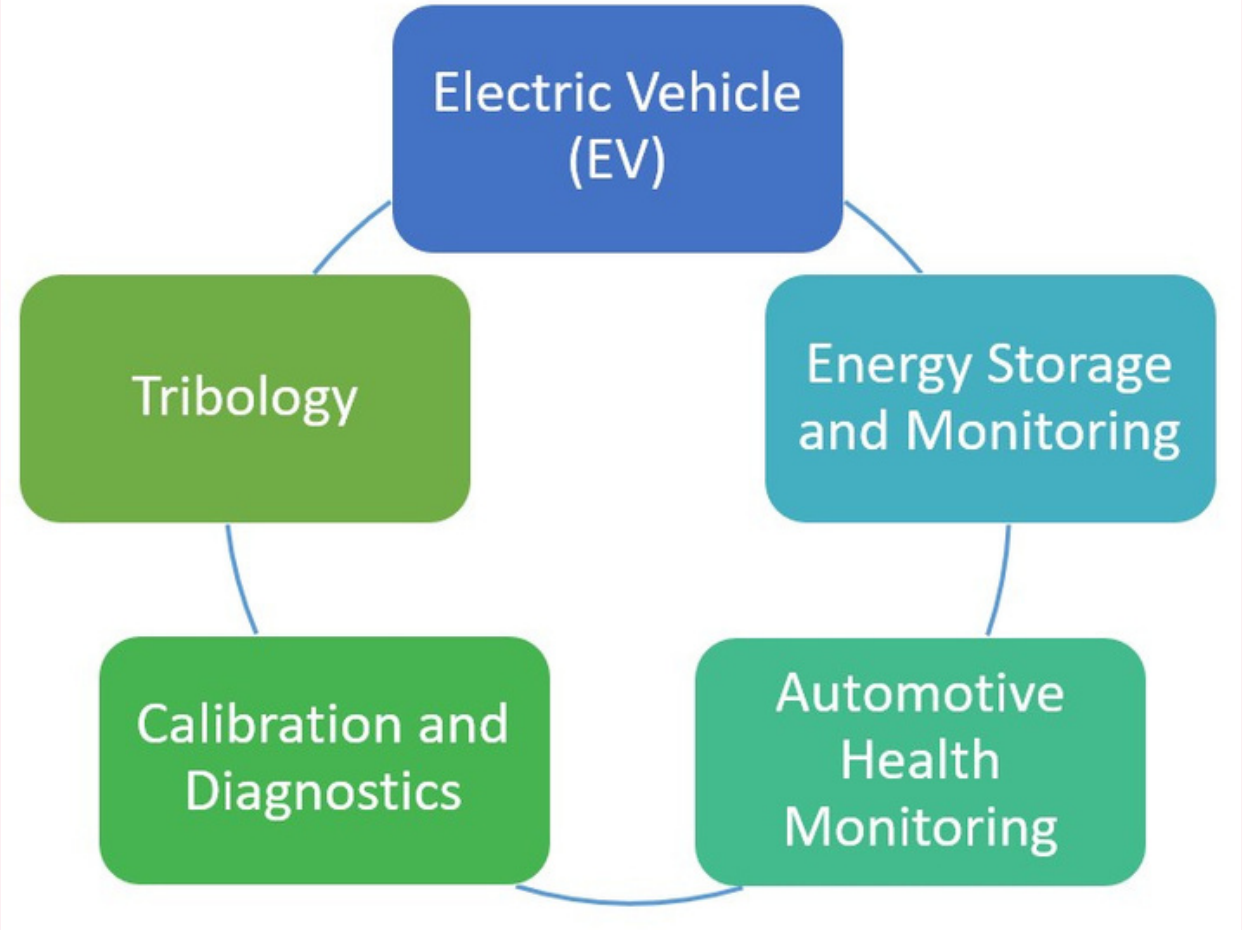
(i) (ii) (iii)

(i) FEM analysis for piezo-based MEM-NVM showing memory in two different states. (ii) SEM image of MEM-NVM showing key parts (scale bar 25 µm). (iii) E-Test for Piezo MEM-NVM SET State at 250 °C in vacuum indicating SET voltage of 10 volts.



CENTRE FOR AUTOMOTIVE RESEARCH AND TRIBOLOGY (CART)

RESEARCH AREAS



The Centre for Automotive Research and Tribology (CART) was established in May 2019 with a vision to promote interdisciplinary research in the area of Electric Vehicle (EV), energy storage and other relevant areas. The centre envisages strong networking and collaboration among various academia, industries, research labs in India and abroad to carry out cutting edge research.

Charging Infrastructure

A great emphasis is given for the design and development of Level 1, Level 2 chargers, Fast DC chargers, battery swapping stations etc. Researchers are also involved in the development of various intelligent algorithms for the placement of fast charging stations and battery swapping stations in a distribution network. They are also looking into the Grid issues pertaining to the higher penetration of EVs.

Battery and Battery Management System

In context of batteries, the key areas of research at CART are (a) battery materials; (b) novel thermal management system for maintaining temperature uniformity among the cells and restrict the rise of maximum temperature above normal conditions; (c) digital twin based on IoT; sensors; cloud computing; multi-physics modelling and machine learning for real-time monitoring of SoC and SoH of batteries under dynamic discharge conditions;(d) aging controlled fast charging of batteries by evaluation of optimal charging current, and simultaneously optimizing charging time and capacity.

Autonomous Vehicles

Modern vehicles come with a myriad sensors and hence it makes good design sense to integrate additional sensors to enable autonomy, starting from systems for lane departure to parking assists to complete driverless platoons. The research focus is mainly to enable sensor fusion to enable perception, developing embedded system with safety properties running millions of codes in an autonomous EV system. Close collaboration with faculty in CSE, ME and EE working in the area of Robotics, embedded systems and AI/ML will lay the foundation for a strong research programme in autonomous vehicles.

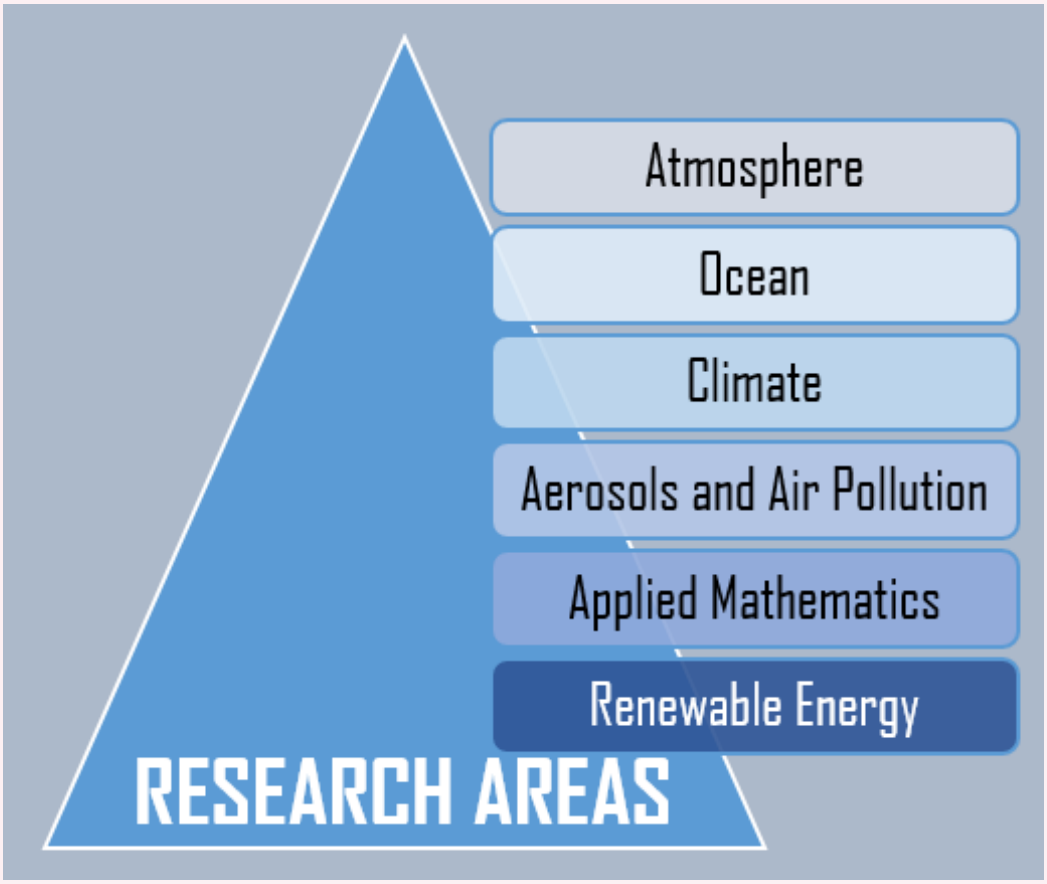
Power Electronics and Drives for Electric Mobility

The focus is on the design and development of high-power density electronic converters, onboard chargers, machines for electric vehicles, power train technology and various controllers for drives and converters. Development of various novel control algorithms for converters and motor drives is one of the key focus at present. The future plan is for the development of fuel cell-based electric buses in association with various industry partners.

Automotive Health Monitoring and NVH

The thrust of research is on the development of an intelligent fault diagnosis and prognosis system for electric vehicles and remaining useful life estimation of components of electric vehicles. Research is also focused on the improvement of NVH (Noise, Vibration, and Harshness) characteristics of the electric vehicle by developing strategies for noise characterization, control, and detection of electric vehicles.

CENTRE FOR ATMOSPHERIC SCIENCES



The Centre for Atmospheric Sciences (CAS) was set up in 1979 by the India Meteorological Department (IMD) to undertake modelling studies to improve monsoon prediction. In the year 1981, the Planning Commission upgraded CAS to a premier centre for education and interdisciplinary research in atmospheric and oceanic sciences in India. Research activities at CAS are oriented towards advancing our understanding of the fundamentals of atmospheric and oceanic processes occurring in the tropics with particular emphasis on real-world issues such as weather forecasting, the Indian summer monsoon, tropical cyclones and associated storm surges, air quality modelling and impacts, renewable energy, climate model development, and climate change [Figure 1,2].

Figure 1

Figure 2

DST CoE in Climate Modeling

A 'DST Centre of Excellence (CoE) in Climate Modeling' was established at CAS with funding support from the Department of Science and Technology (DST), Government of India. The main objective of this CoE is to develop an India-centric climate model to address the pressing issues of climate change in India.

Air Quality Monitoring Station (AQMS)

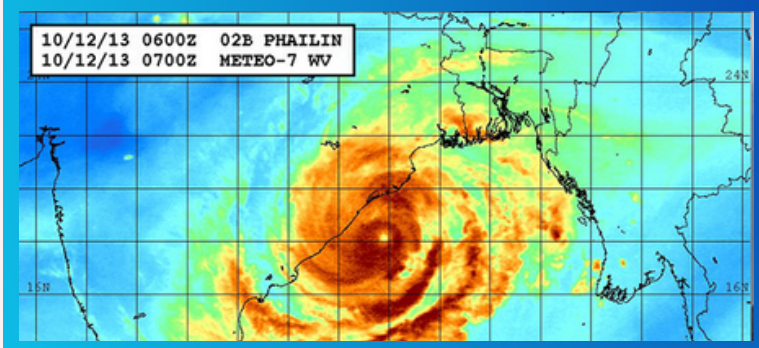
The CAS strengthened its observational capabilities for atmospheric and air-quality measurements through its partnership with the IMD to establish an Air Quality Monitoring Station (AQMS) at the Gramodaya Parisar on the IIT Delhi campus.

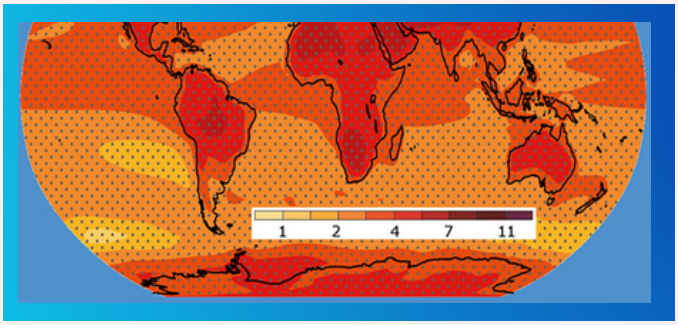
CERCA

A 'Centre of Excellence for Research on Clean Air (CERCA) was established at IIT Delhi with initial funding from IIT Delhi alumnus, Mr Arun Duggal.

Weather Forecast

A coupled system of hydrodynamic and hydraulic models is developed to predict storm tides and associated inundation, validated using recent cyclones 'Tauktae' and 'Yaas' formed in the Arabian Sea and Bay Bengal, respectively. The CAS provides a forecast of storm surges from time to time based on the cyclone information provided by the IMD, which uses the model-forecast storm surges for its operational purpose.



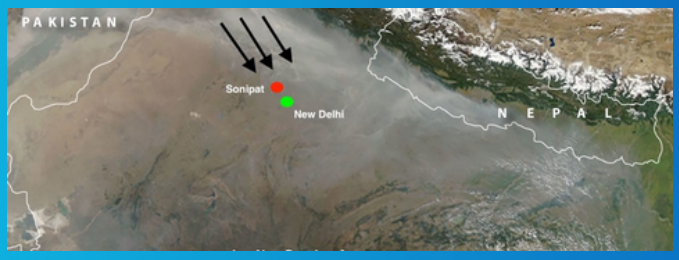


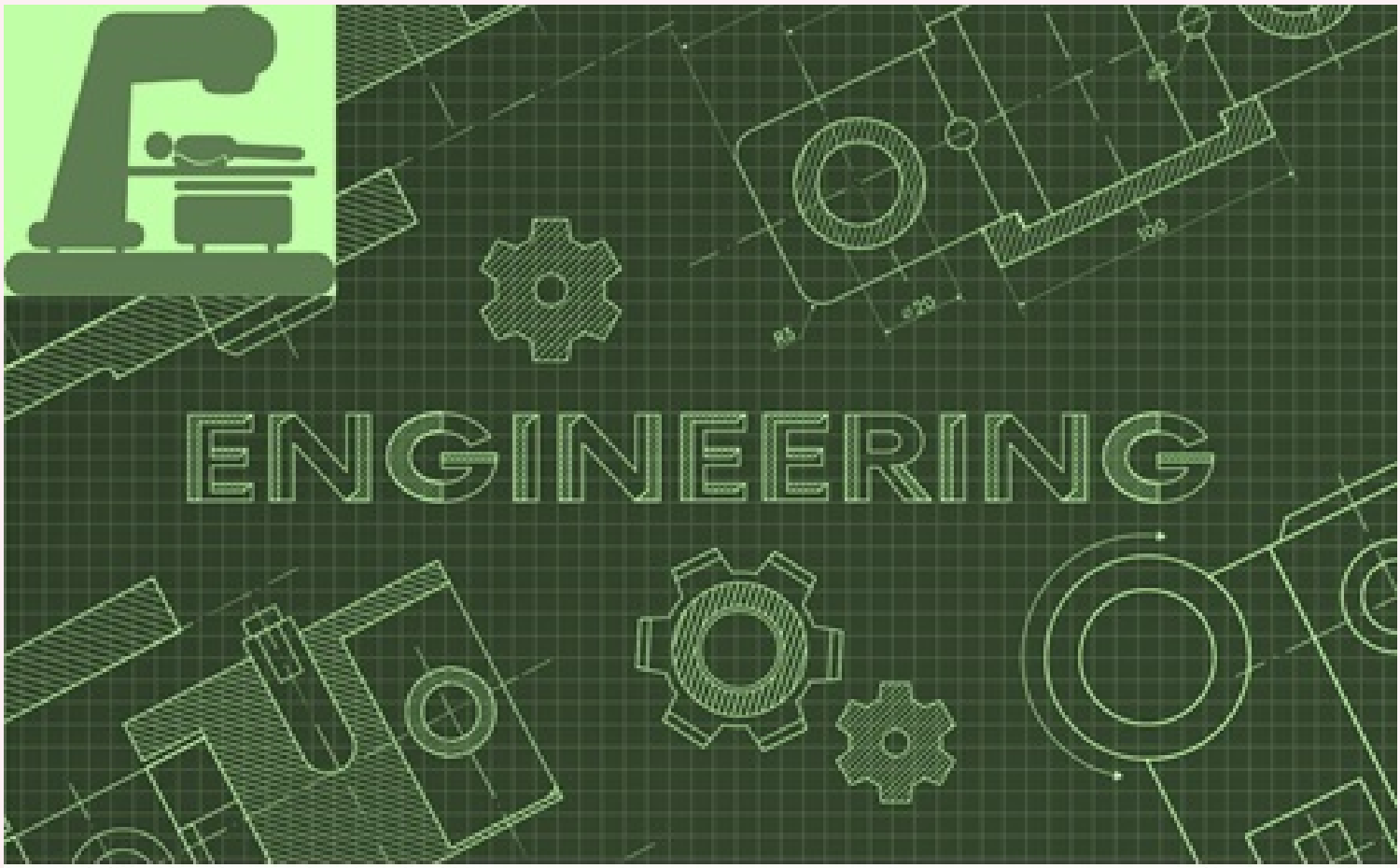
Modelling & Simulation

An integrated modelling approach is developed for simulating the diurnal variability of the ocean environment, which can become handy for Navy operations. The model has been transferred to NPOL/NODPAC (Ministry of Defense) for their operational use.

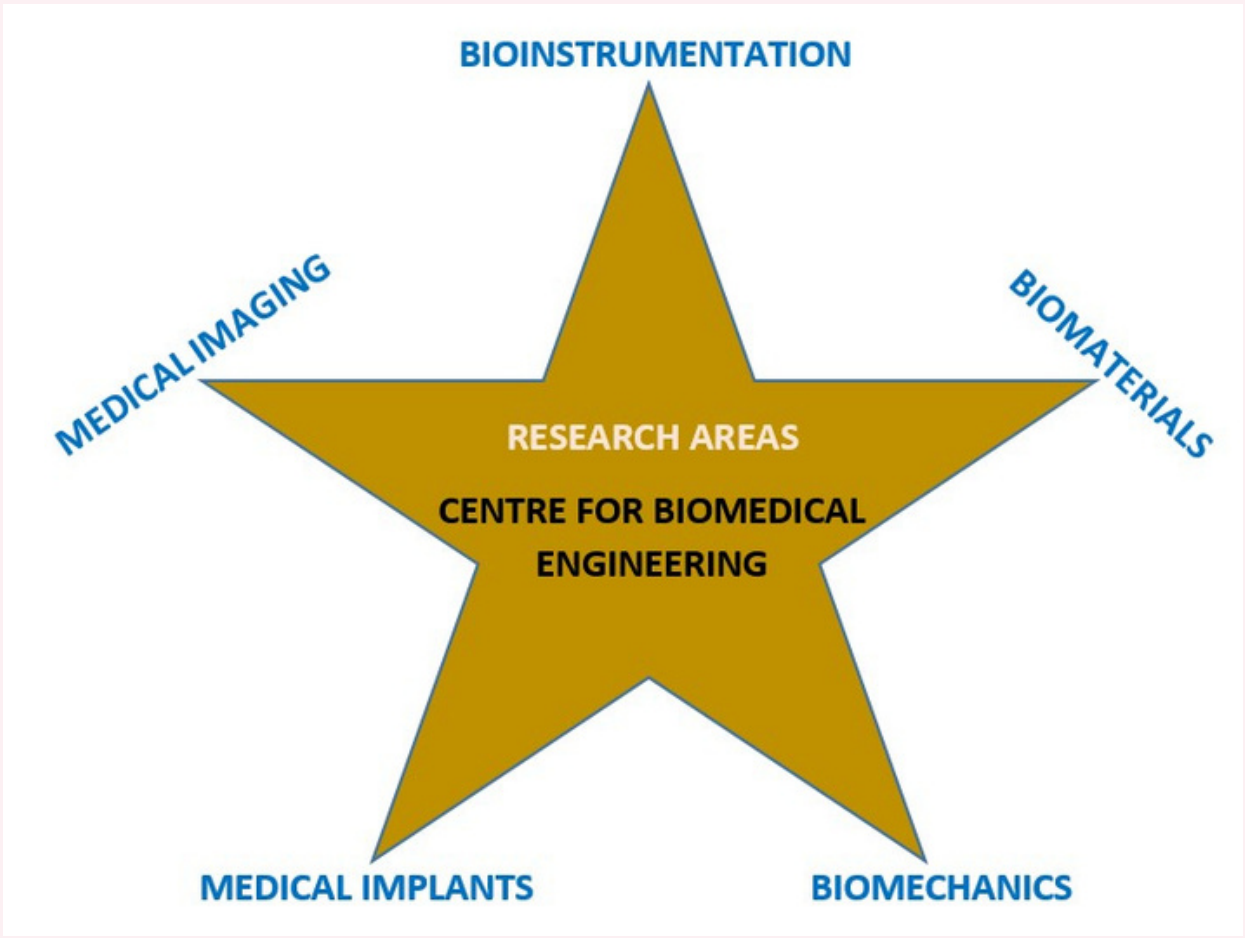
Atmospheric Observatory

An 'Atmospheric Observatory' is being established at the Sonipat campus of IIT Delhi under the Institution of Eminence programme. A groundbreaking ceremony was held on March 25, 2021. A first-of-its-kind observatory in the heart of the Indo-Gangetic belt, this laboratory will enable researchers to make discoveries and help find sustainable solutions to some of the country's pressing problems such as severe air pollution, erratic monsoons, and extreme weather events associated with climate change.





CENTRE FOR BIOMEDICAL ENGINEERING



The Centre for Biomedical Engineering (CBME) was established in 1971 as a joint venture between IIT Delhi and the All India Institute of Medical Sciences (AIIMS), New Delhi. The Centre has applied engineering principles to address medical and biological problems. CBME has provided interdisciplinary insights to biological research for the development of health care technologies. Over the last two decades, the focus has shifted to include biological medicine, the behavior of molecular health systems for better and innovative drug delivery, development of biomaterials, rehabilitation engineering, development of medical devices and implants.

Bioinstrumentation

The Bioinstrumentation group's mission is to promote cutting-edge biomedical engineering research and development. At present, the group carries out research in neuromechanics, lab-on-a-chip, biosensors group, biomechatronics and imaging. Neuromechanics integrates computational biomechanics approaches with neural data to discover the underlying neural mechanism of gait equilibrium in healthy and clinical populations, investigates the recovery and advancement of assistive devices for clinical populations such as an amputee [Figure 1], cerebral palsy, epilepsy, stroke and spinal cord injured patients. Furthermore, studies on the neural characterization of balance and gait in various neurodegenerative diseases are also being carried out. Lab-on-a-chip and biosensors research looks at non-invasive clinical biosensors, capillary electrophoresis microchip devices for clinical, environmental, and biopharmaceutical applications, microfluidic Lab-on-a-chip for PCR, and on-chip cytometry, on-chip COD analysis, pathogen detection biosensors, and an on-chip neurochemical analyzer. Research in biomechatronics and imaging focuses on the development of complex biomechatronic and biomedical systems that incorporate diverse sensing paradigms, electronics, ultrasound imaging, signal processing, embedded hardware, and software to better understand human movement, neuromuscular disorders, and chronic disability in general.

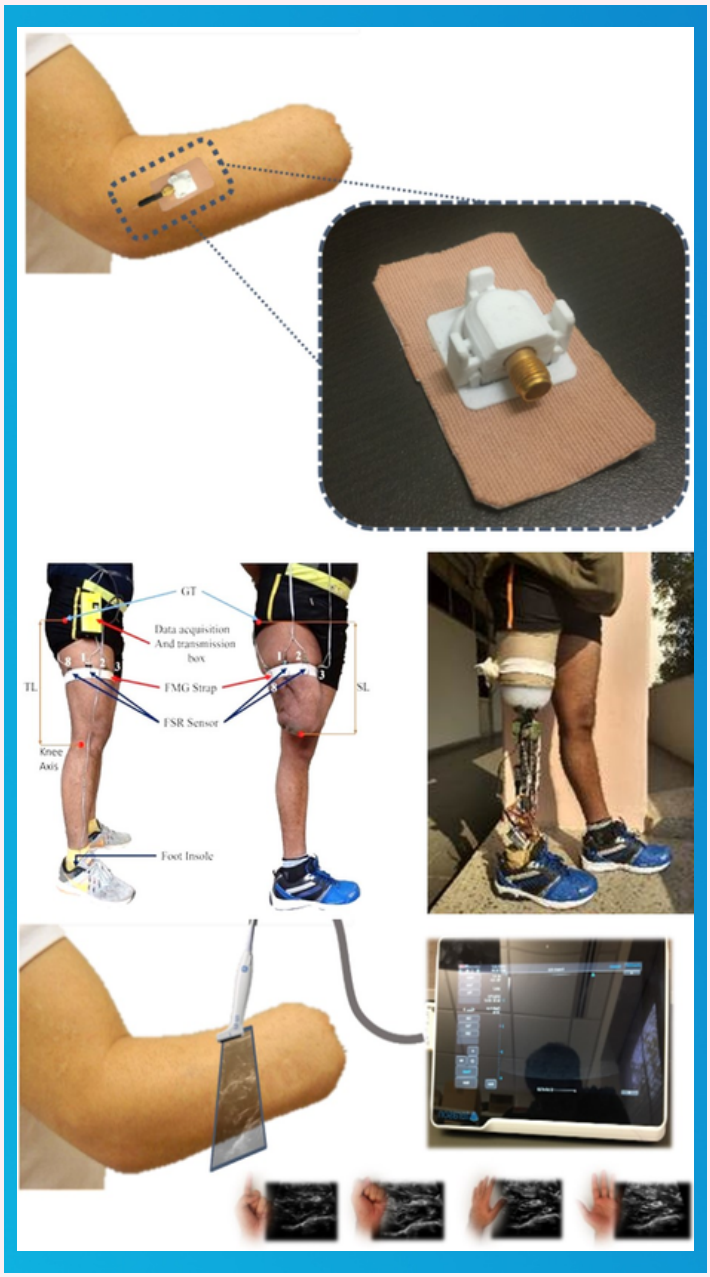


Figure 1

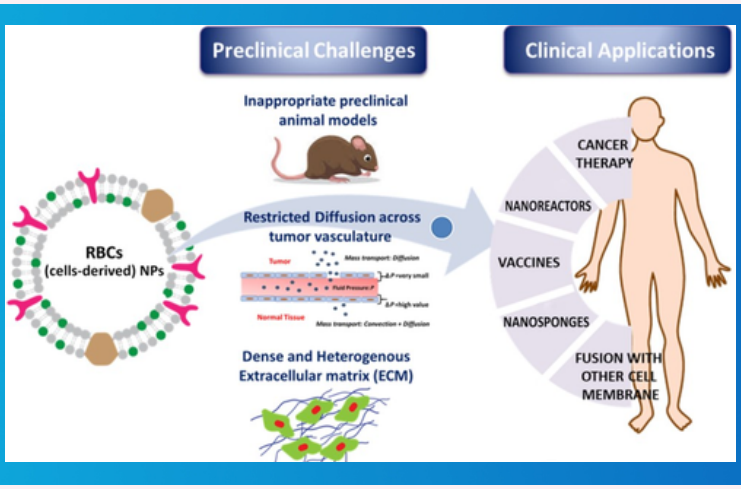


Figure 2

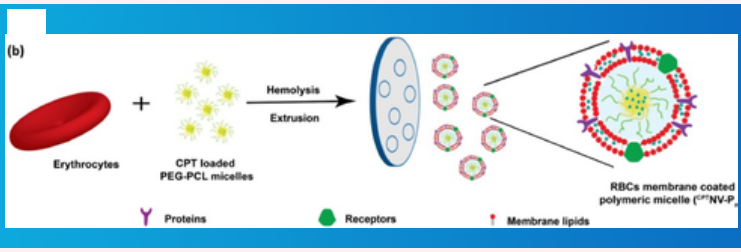


Figure 3

Biomaterials

Biomaterials group integrates the concepts and skills from chemistry, materials science, and biology to design, synthesize, characterize, evaluate, and validate next-generation biomaterials to make a translational impact on improving human health [Figure 2]. Research is in the domain of nano-structured materials to improve their functionality for applications in biomedical implants, cancer diagnostics, and drug delivery. Main research interest of the group is the development of bio-inspired and bio-derived materials to meet unmet needs in treating and diagnosing disease.

Biomaterials

Some areas of research are cancer immunotherapy, smart functional nanomaterials (drug delivery, biosensors and biomedical implant coatings), tissue engineering, biomaterials and bioengineering: new functionalized and bioactive polymeric materials, non-invasive clinical biosensors and biosensors for pathogen detection [Figure 4].

Figure 5

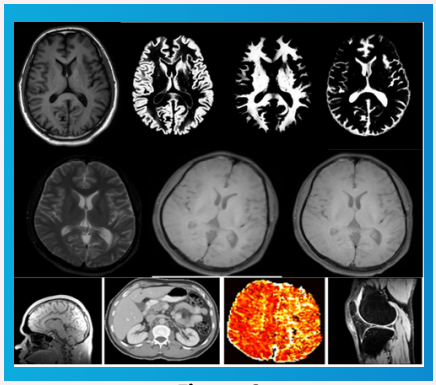


Figure 6

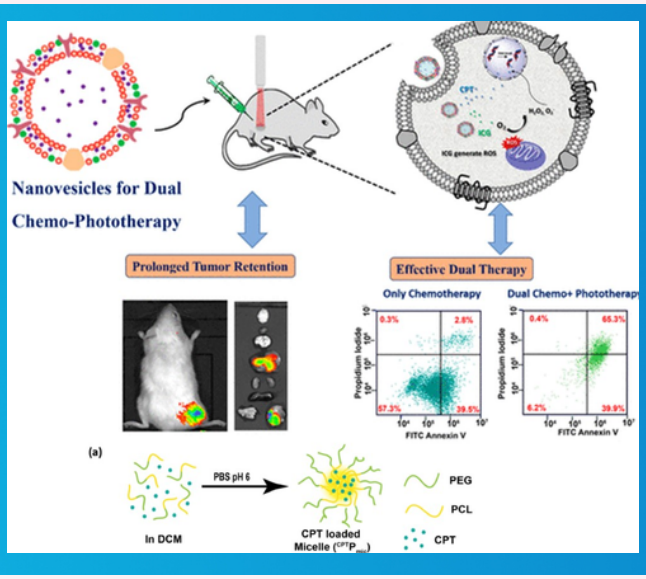


Figure 4

Biomechanics

In collaboration with IIT-Delhi and AIIMS-Delhi, the Biomechanics group works on diagnostics, testing, design and simulation of biological systems, and healthcare products development. Focus is on designing medical devices, validating their performance clinically, and developing associated manufacturing processes [Figure 5]. Diagnostic devices as well as implantable devices have been developed. The group also works on tissue biomechanics and developing musculoskeletal models. The aim of this group is to understand the biomechanics of the human body through simulation and experiments. Clinical studies are also carried out with individuals suffering from motor neuron disorders. The group also designs sensing systems to detect residual muscle activity, which would help to control sophisticated prosthetic and orthotic devices. Several projects are currently underway, which range from computational modeling of bones/tissues to devices that help human physiology.

Medical Imaging

In association with AIIMS, New Delhi, the Medical Imaging group at the Institute is working towards developing new analysis and post-processing methodologies for quantitative biomedical imaging. The group is actively working on the applications of Machine Learning in Healthcare for diagnosis, grading, and treatment monitoring of diseases such as Cancer/Tumor, Osteoarthritis, etc. The other research areas of the Medical Imaging group include development of quantitative methods, techniques, and software tools in the field of MRI, particularly perfusion-MRI, CEST-MRI, Susceptibility-Weighted-Imaging (SWI), Diffusion-weighted MRI [Figure 6]. The medical imaging group also works in Medical Image Processing for the segmentation and classification of tissues, image registration, and mitigation of noise and artifacts [Figure 6 & 7].

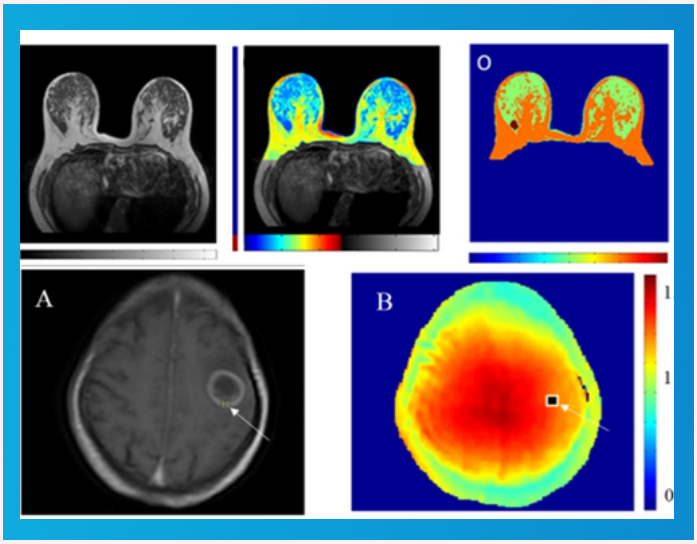


Figure 7

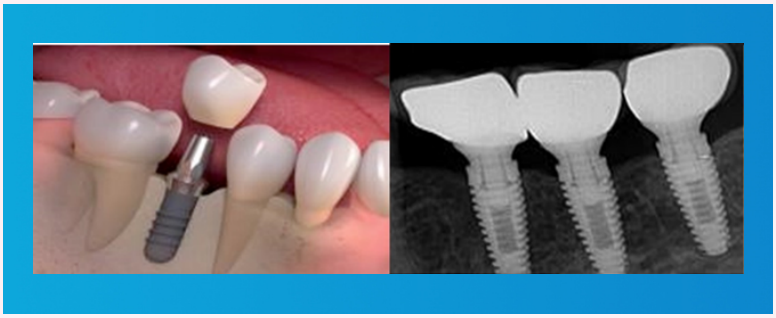


Figure 8

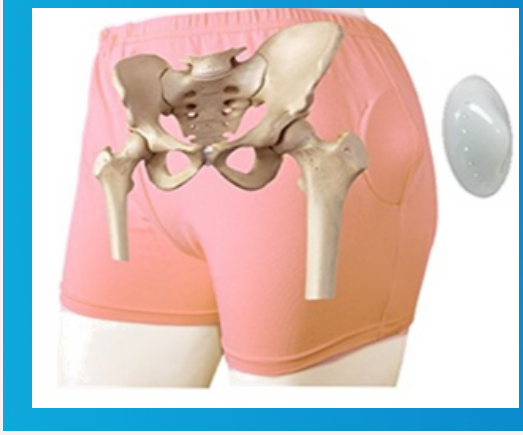


Figure 9

Figure 10

Medical Implants

The medical implants research group works for the development of indigenous medical devices to serve the Indian population. It focuses on developing affordable solutions for healthcare through a synergy of cutting-edge engineering and medicine.

Dental Implants

Designed from scratch, tested, and evolved in a period of 11 years supported by CSIR-NMITLI. It is the first dental implant system under the true spirit of "Make in India"[Figure 8].

Hip Protection Device

It is meant to prevent fracture of the hip joint due to a fall of an elderly above the age of 70 because of reduced bone density, Alzheimer, imbalance in walking or geriatric problems [Figure 9].

Orthotic Knees Joint

Made by injection molding of selected polymer composites for mass production as low-cost solution with light weight as an offset and gravity drop lock for polio patients.

Prosthetic Polycentric Knee Joint

Replacing metallic joints with mass produced injection molded knee joint for the above knee amputees. Initially single axis and then polycentric were designed and developed to perform with better gait and stability [Figure 10].

Bioresorbable Cardiac Stent

Fourth generation of CAD treatment, drug eluting and treating BVS is absorbed in the body within 1-2 years and do not require lifelong anti platelet medicines due to positive lumen modeling. Its designed and developed for the IMPRINT project in collaboration with AIIMS cardiology and sponsored by ICMR [Figure 11].

Breast Cancer Tumor Marker

A minimally invasive procedure using titanium markers developed with nano tubes deployed during FNAC with a small 18 gauge needle. The use of the marker, helps locate and dissolve the tumor precisely. As a result, mastectomy can be avoided. An added advantage is that no artifacts are seen during imaging and thus guiding the surgeon precisely to the site of the tumour [Figure 12].

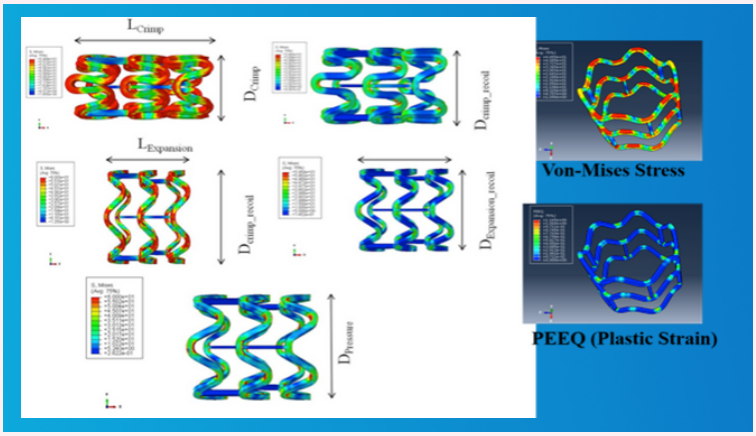


Figure 11

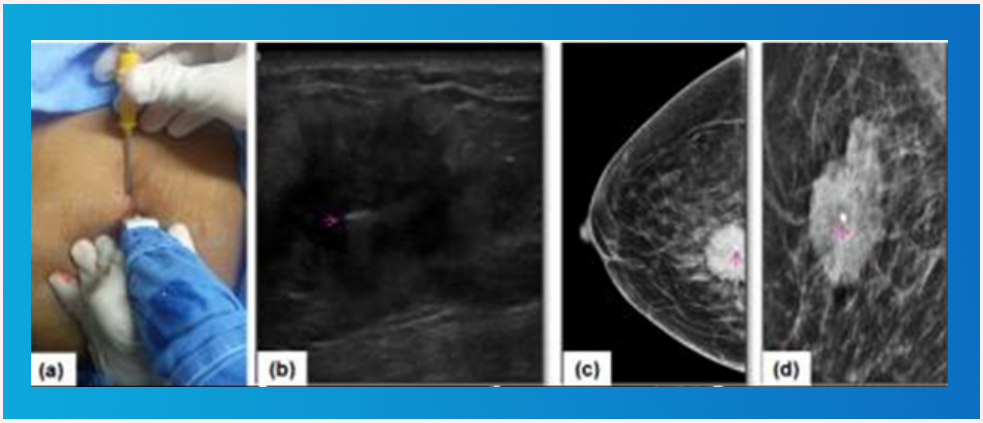


Figure 12

CENTRE FOR RURAL DEVELOPMENT AND TECHNOLOGY (CRDT)

RESEARCH AREAS

- Sustainable Biomass Production and Utilization
- Food Processing, Safety and Quality
- Sustainable Habitat and Green Solutions
- Rural Energy Systems
- Tools and Implement, Artisans and Livelihood
- Environment and Climate Change
- Water, Sanitation and Waste Management in Rural areas
- Rural Planning and Entrepreneurship Development
- Bio-economy and Panchgavya

Centre for Rural Development and Technology is one of the renowned academic units of IIT Delhi. It came into existence in 1979 with the aim of becoming an outreach centre of IIT Delhi to address challenges faced by rural communities and to improve their quality of life. It has made significant contributions by developing and transferring technologies in areas including algal bioenergy, biomass technologies, biogas technologies, ecological sanitation, food quality and safety, sustainable agriculture, sustainable housing, value-added food products, water and waste management etc.

Algal Wastewater Treatment and Biofuel Production

A cost-effective technology to dewater the algal biomass from suspended algal cultures and further use this biomass for biofuel applications has been developed. To make the process more techno-economically feasible, a simultaneous harvesting and pretreatment of algal biomass was done using AL-CC1 and AF-CP. A patent has been granted for this technology (India patent no. 324527) and the work was published in Green Chemistry & Biotechnology for Biofuels. Further the mechanism driving this attachment of algal cells to fungal hyphae was also deduced where N-Acetyl D-Glucosamine was pointed out to mediate this attachment. The study signifies the development of a novel and optimized algal harvesting process, which not only improves the biomass digestibility by in-situ pretreatment for biogas generation but also also reduces the cost of harvesting, pretreatment and biomethane production using the wastewater grown algal biomass. The developed process could be integrated with a thermal power industry and distillery industry [Figure 1]. A thermal power plant produces flue gases which could be used to cultivate the algae.

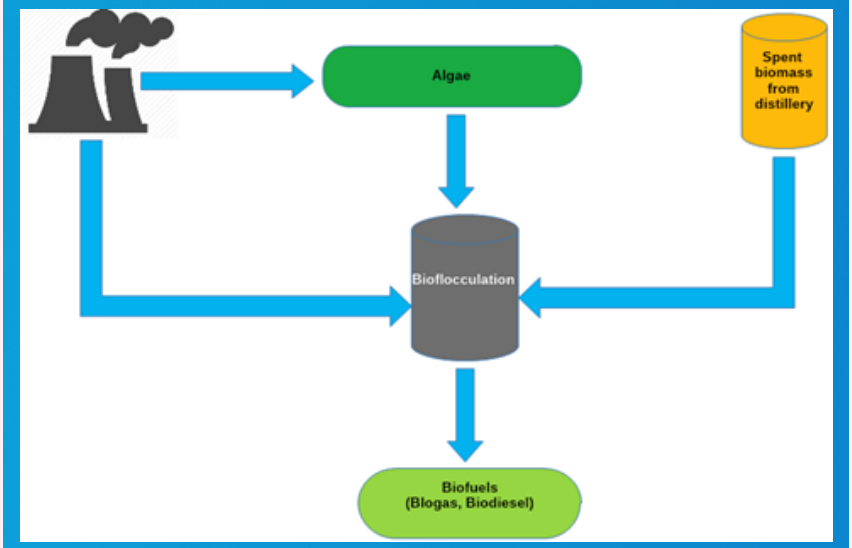


Figure 1

Algal Wastewater Treatment and Biofuel Production (Contd...)

Besides, the cooling water from the power plant could be used for providing the temperature for harvesting. The fungal biomass for harvesting would be derived from a distillery industry (spent biomass). The overall findings from the research are shown in Figure 2.

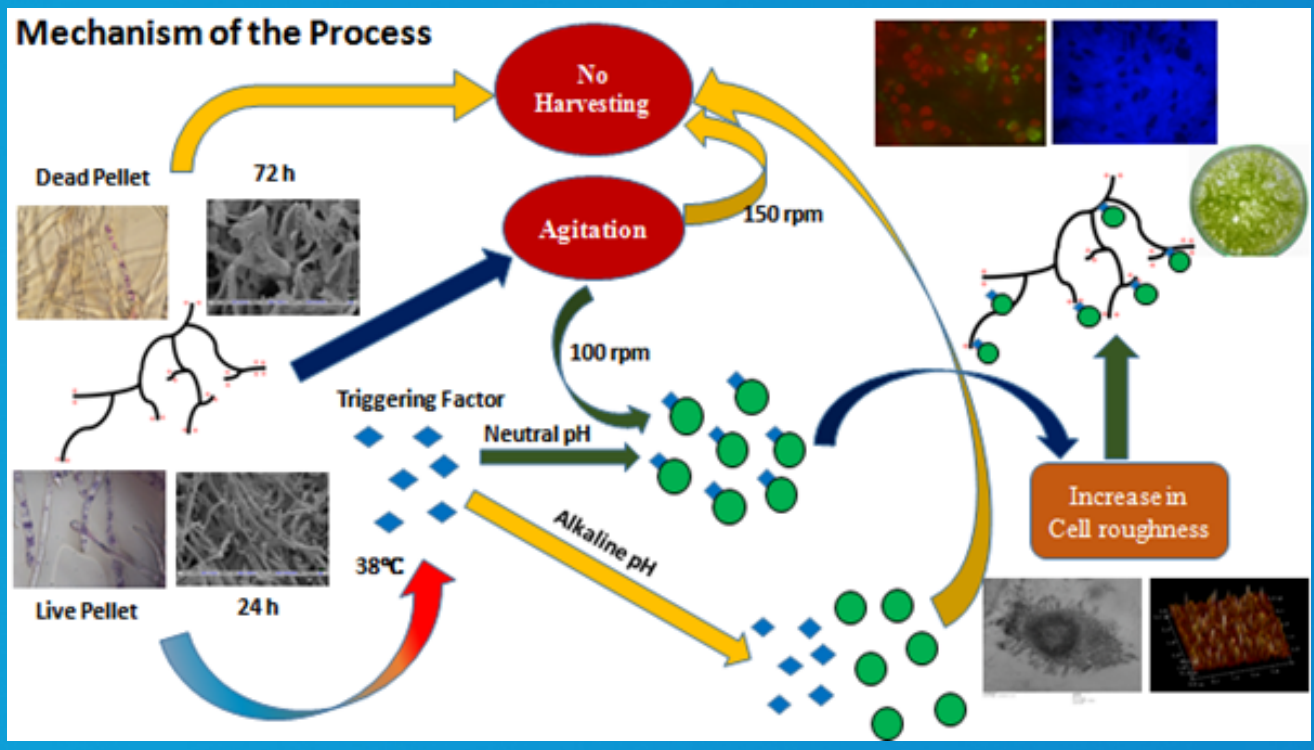


Figure 2

Plant-Based Mock Egg

Innovation of plant based mock egg secured first prize at Innovate4SDG contest by 'UNDP (United Nation Development Program) Accelerator Lab India'. According to the UNDP, this innovation addresses SDG 2 and 3 (Zero Hunger and Good Health & Well Being). The plant based textured foods which resemble egg, fish and chicken have been developed with an aim to address the longstanding battle for malnutrition and clean protein food for people. The mock egg has been developed from very simple farm based crop proteins, which not only looks and tastes like egg but also very close in nutritional profile to a poultry egg [Figure 3 & 4]. Meat analogues for chicken and fish were also developed from plant sources using fruits and vegetables. The products were tested on various parameters including appearance, taste, bite-size, texture, aroma, flavor, shelf life, nutritional profile and customer preference.

Figure 3

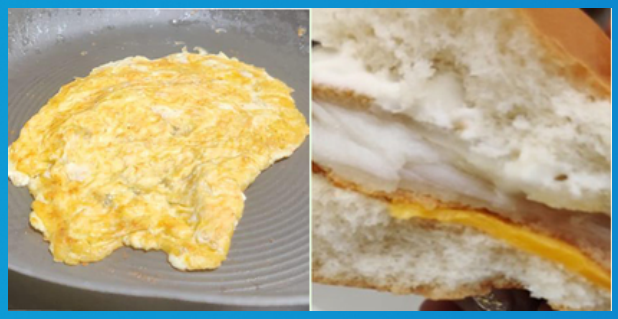
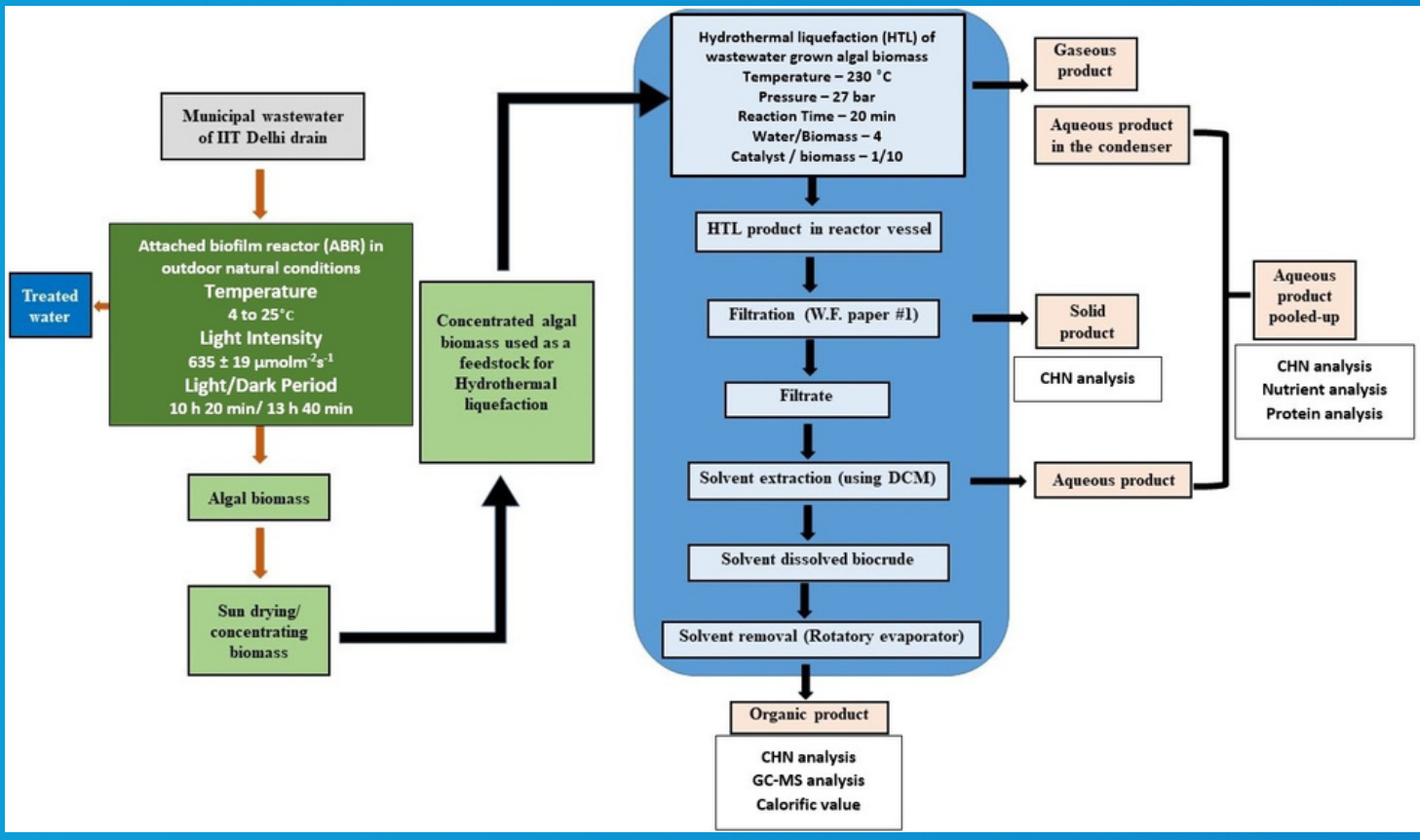


Figure 4

Microalgae-Based Biorefinery

Wastewater obtained from algal biomass cultivation is hydrothermally converted to Biocrude [Figure 5]. It has been shown to contain up to 50 % aromatics, 27 % akanes/alkenes, 55 % aldehydes/ketones, 17 % fatty acids, among others. On performing the LC-MS of the aqueous fraction, medicinally important compounds like Minoxidil, barbital, ethosuximide, thymol, pyrithyldione, betahistine, petethiene, estradiol, tyramine and a number di/tripeptides (Pro His, Val His, Ile His, Val Ala, Pro Ile, Gly Leu Ile, Ala Gln Pro, Leu Leu Ala, Pro Asn Val, Met Lys Lysg) were also detected in the biocrude. This biocrude has potential for use as a source of energy. The work was carried out in India and Brazil.



Bioremediation of Agrochemicals and Heavy Metals from Drainage Water

Unique microbial strains with ability to remove multiple metals have been obtained to select the most efficient strains. Molecular changes revealed in protein expression under metal and metal-pesticide stress. Native microorganisms present at the site have been enriched and acclimatized to design a microbial consortia for the treatment of wastewater. A 500 L/day bioreactor is already operational at the IARI field site for generating the treated water for irrigation [Figure 6]. A long term field experiment (2014–2017), to investigate the effects of drip and flood method of irrigation using untreated wastewater, and bioremediated wastewater on soil and crop quality showed that safer produce is harvested if bioremediated waste water is used for irrigation.

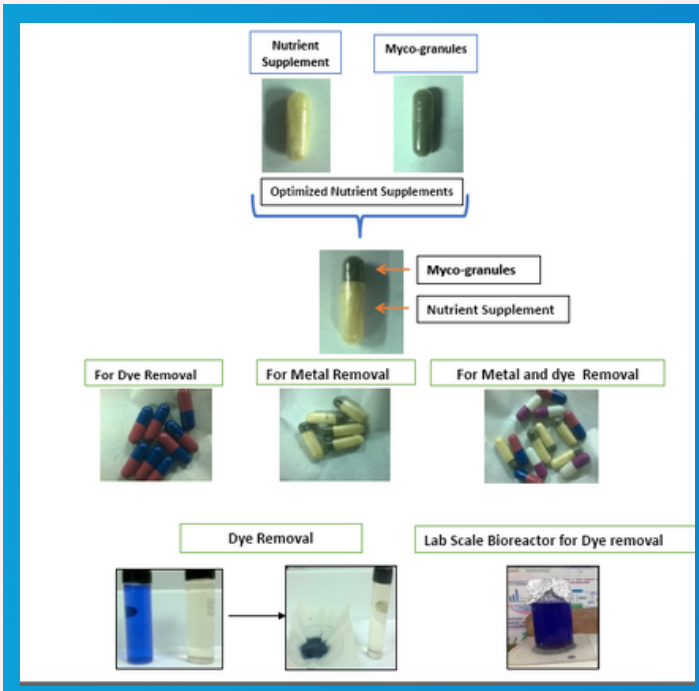


Figure 7

Myco-Capsules for Bioremediation of Wastewater

Microbial culture consortium of *Aspergillus* sp., *Rhizopus* sp., and *Beauveria* sp. were prepared and encapsulated along with the nutrient requirement inside the myco-capsule, thus eliminating the need for additional nutritional requirement for growth during bioremediation of the wastewater contaminated with dyes and/or metals [Figure 7]. The mycocapsules enhance shelf-life, are easy to store and transport under ambient conditions without any substantial loss in viability and pollutant removing ability.

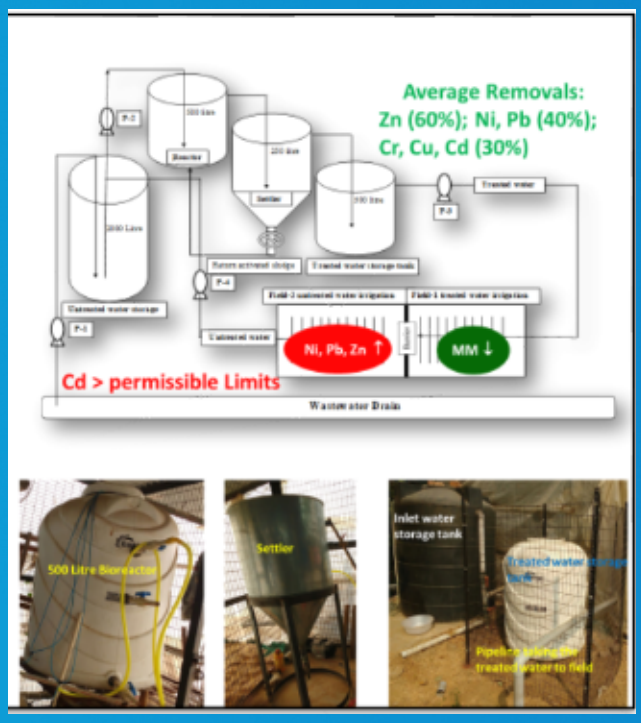


Figure 6

Biofuel Production by Combined Biomass Harvesting and Pre-Treatment

Harvesting and pretreatment are the two major hurdles in the microalgal derived biofuel production. The cost of biofuel production from microalgae mainly depends on these two steps viz., harvesting and pretreatment. To date, no process, either biological or physicochemical, has been reported which can simultaneously harvest and pre-treat the algal biomass. A single process for both these critical steps could provide a major breakthrough in algal biofuel production. The proposed technology involves bioharvesting of precultured microalgae using pellet forming filamentous fungi as the bioagent [Figure 8]. The bioagent used for harvesting also results in the pretreatment of biomass when incubated under controlled conditions. Hence, the present invention provides a suitable solution to two major hurdles of the microalgal based biofuel production routes. The invented process is efficient enough, irrespective of addition of any nutrient and carbon source. The present technology can biologically harvest microalgal cells within 3 h which is a significant improvement compared to 24-48 h reported in earlier methods.

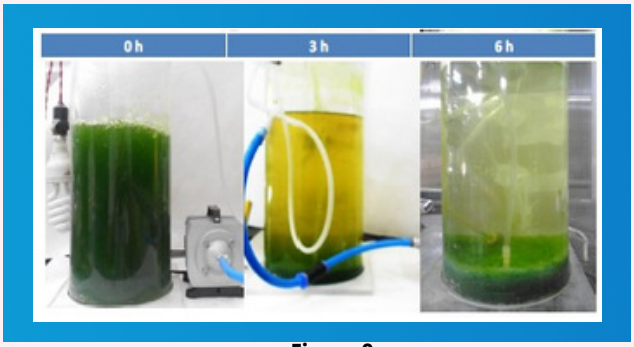


Figure 8

CENTRE FOR SENSORS, INSTRUMENTATION AND CYBER PHYSICAL SYSTEM ENGINEERING (SeNSE)

RESEARCH AREAS

- Optical Engineering
- Electronic System Design
- Advanced Optical Fabrication
- Micro-opto-electro-mechanical systems
- Sensor Technology
- Cyberphysical Systems

Freeform and Large Size Aspheric Optics for Thermal and Optical Imaging

Future optical systems require optics with more degrees of freedom to meet greater demands in their performance. A typical estimated freedom surface is shown in Figure 1. The use of off-axis aspheric optics and freeform optics in an optical system provides opportunities for numerous improvements in the performance. The fabrication and metrology of such specialised optics are the major challenges for their incorporation in optical systems. Under the DRDO-IIT Delhi initiative of Joint Advanced Technology Centre (JATC), complete manufacturing process along with metrology for freeform optics and large size aspheric optics is being developed. The developed optics will be used for the athermalisation of Infra-red imaging systems using wavefront coding techniques and zoom optics using Alvarez type optics. An ultra-precision machining facility for fabrication of aspheric and freeform surface is under establishment. It will include a five axis CNC diamond turning machine, a high resolution contact mechanical profiler, a phase-shifting interferometric high resolution optical profiler and a conventional CNC machine.

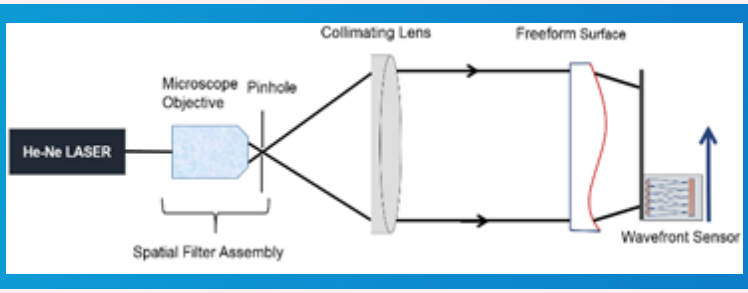


Figure 2

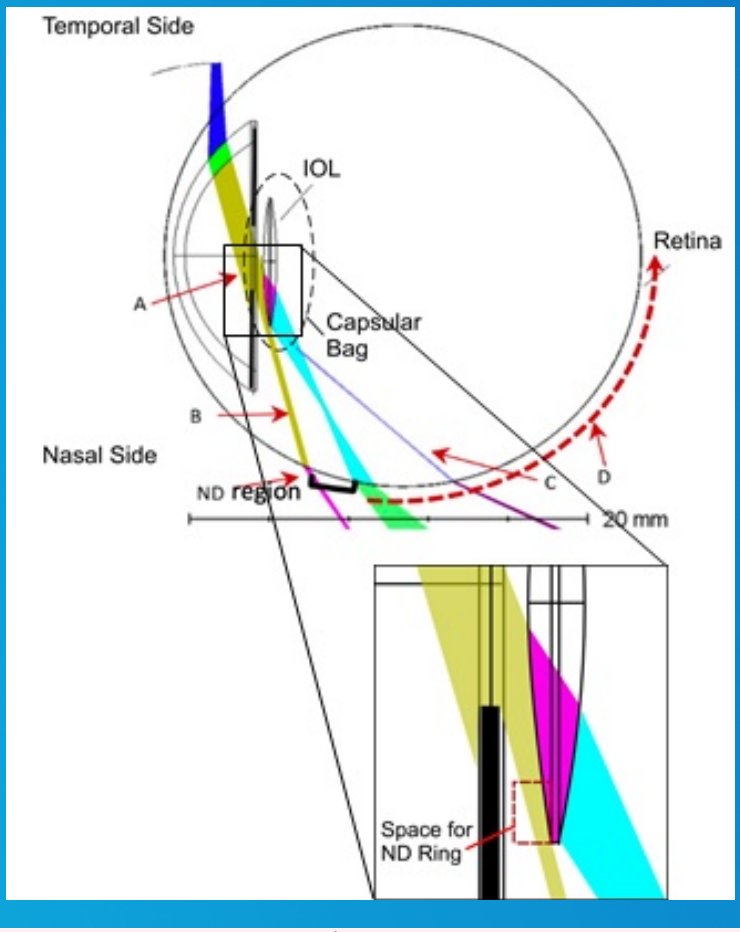


Figure 3

Centre for Sensors, Instrumentation and Cyber Physical System Engineering (SeNSE) was formerly IDDC that was set up in 1970. The Centre, interdisciplinary in nature, is engaged in design and development of instruments and other industrial and consumer products. It is engaged in sensing, monitoring and measurement for Defence spplications, Medical instrumentation and Industrial Application.

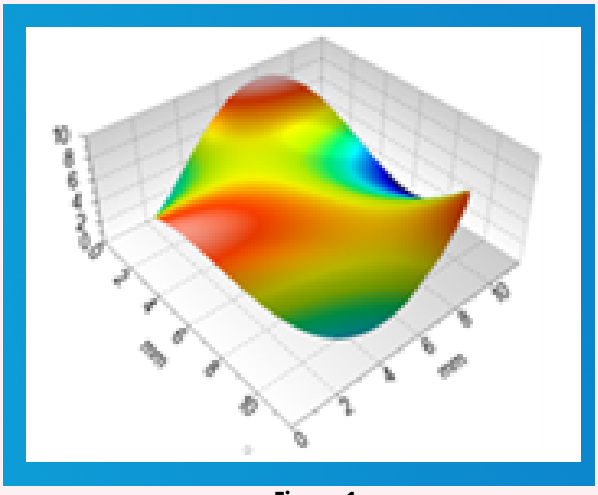


Figure 1

Wavefront Sensor for In-situ Measurement of Aspheric and Freeform Optics

The accuracy of fabrication of optical elements such as aspheric and freeforms are limited by the capabilities of the available metrology procedures. Though all the techniques available for testing of spherical optics have been extended for the aspheric and freeform surfaces by the researchers, but none of the techniques has yet been incorporated into the manufacturing machine for in-situ measurement. Therefore, a precise and in-situ metrology technique for their measurement is in demand. The most obvious reason is the complexities involved in the optical setups to be integrated in the manufacturing platforms. A wavefront - sensor based on slope measurement has been developed for metrology of specialized optical elements. It offers the potential to be incorporated into the machine environment due to its vibration insensitivity, compactness and the simple principle of operation. It can measure the slopes up to ~ 15 mrad in a single measurement. It is used as a metrology tool for the testing of aspheric and freeform optics in both the transmission as well as in reflection. A collimated laser beam incident on to the surface under test and the propagated wavefront from the test surface is measured using the sensor along X and Y directions [Figure]. The in-house software developed based on sub-aperture stitching has been used to reconstruct the wavefront from the slope data acquired by the sensor. The sensor can also be used for testing micro-optics, intraocular lenses and laser beam characterisation.

Freeform Edge Profile for Intraocular Lens to Control Negative Dysphotopsia

The use of intraocular lens (IOL) after the cataract surgery can create various post-implantation complications. Some patients complain of seeing dark shadow on the temporal side of visual field. It is termed as negative dysphotopsia (ND) and occurs despite a perfect cataract surgery. Negative dysphotopsia mainly depend on the shape of the IOL, width of the space between the iris and the IOL first surface, length of the shadow region and IOL refractive index. The temporal field rays, which do not reach some part of the nasal side of retina, results to a non-illuminated shadow region. The occurrence of these symptoms is defined as negative dysphotopsia (ND). The ray diagram illustrating the phenomenon is shown in Figure 3. A design method is developed to generate an optical edge profile to redistribute the input rays on the shadow region. Standalone ND Ring element can be used to correct negative dysphotopsia of already implanted IOLs, however, IOL with modified edge structure can help to avoid negative dysphotopsia. The optical model of an IOL with ND-ring element is shown in Figure 4.

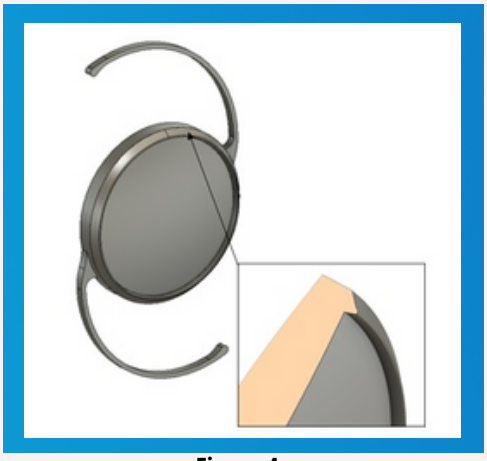


Figure 4

Figure 5

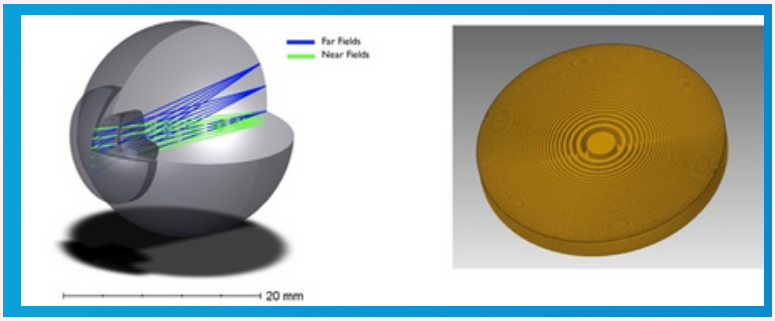


Figure 6

Artificially Reproduced Natural Light

Daylight is an immense source of energy comprising of sun light (direct) and sky light (scattered). Skylight due to Rayleigh scattering from atmospheric nano- particles gives cool bluish, diffuse effect (6500 K -10000 K) unlike direct sunlight (4000 K). No conventional light fixtures give this extraordinarily combined effect at a time. In this study nanoparticle based light diffusing film has been developed via chemical route followed by a novel direct mixing dispersion by extrusion technique [Figure 7]. The developed nanoparticle embedded optical film is being explored for creating Rayleigh scattering phenomena using an artificial white light source.

Artificially Reproduced Natural Light (Contd...)

Rayleigh scattering phenomena along with sky like bluish effect was created by the help of small size nanoparticles having high refractive index embedded with transparent organic polymers. A feasibility study is carried out to come up with a design, which gives both the effects simultaneously. A chromatic diffuser (non liquid material), transparent to visible spectrum was developed using a transparent organic polymer. The size of the nanomaterial is chosen in such a way that blue wavelength would be scattered more than red. Thus Rayleigh scattering was created artificially. Due to predominance of blue wavelength in scattered light, CCT of scattered light has been shifted to cooler zone than the direct transmitted light. Selection of size for nano-particles for blue wavelength was taken of order of $\lambda/10$, and same was optimized by monitoring the output performance.

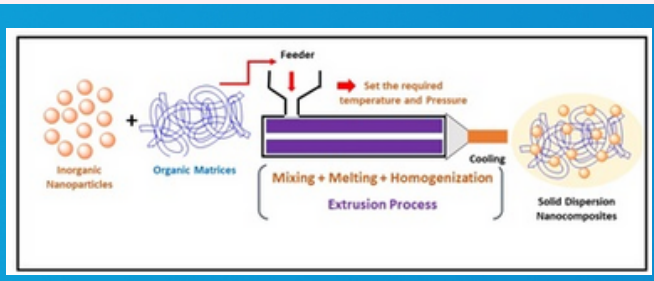


Figure 7

Figure 8

Phakic and Diffractive Intraocular Lens

A phakic IOL is implanted into the posterior chamber of eye while the eye's natural lens remains intact. The implanted lens can reduce the person's need for glasses and contact lenses. A customised phakic IOL design is shown Figure 5. While phakic IOLs here are of mono-focal nature, the diffractive IOLs are multi-focal in nature and are implanted by removing the natural lens in some cataract surgery. To achieve the primary goal, the control of the fabrication process is necessary. The challenges in implanting a phakic IOL are the post-operative risks of glaucoma, cataract, and ovulation of the iris in the patient's eye. The current phakic IOL design has prepared considering all these challenges. The development of diffractive multifocal IOL has challenges like the introduction of the apodization in diffraction efficiencies to emphasise distant vision in mesopic conditions and reduce glares and holes; apart from design challenges, metrology for multi-focal IOLs is not available locally. Tool selection and tool path generation are other associated challenges. The bi-focal diffractive IOL that has been designed overcomes most of these challenges [Figure 6].

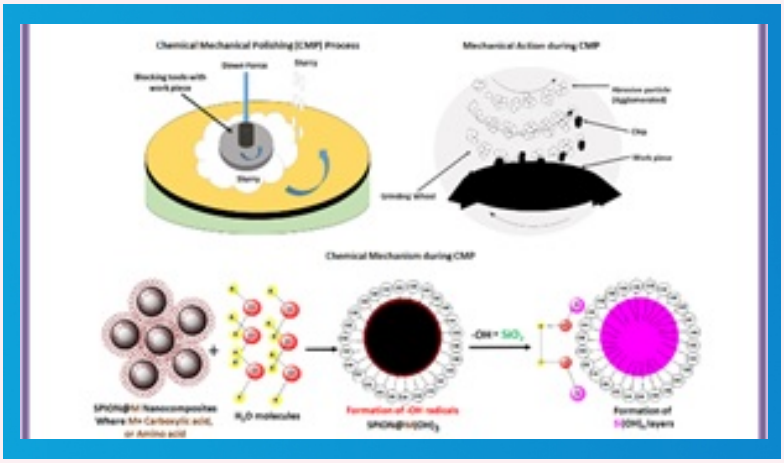


Figure 10

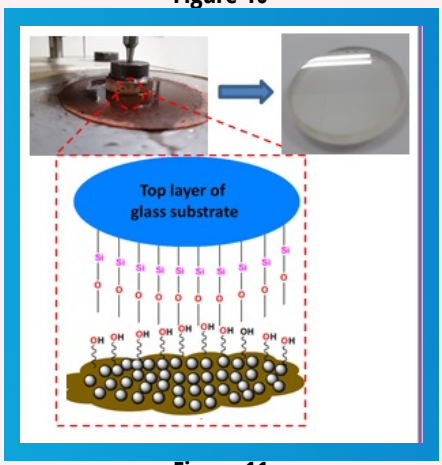


Figure 11

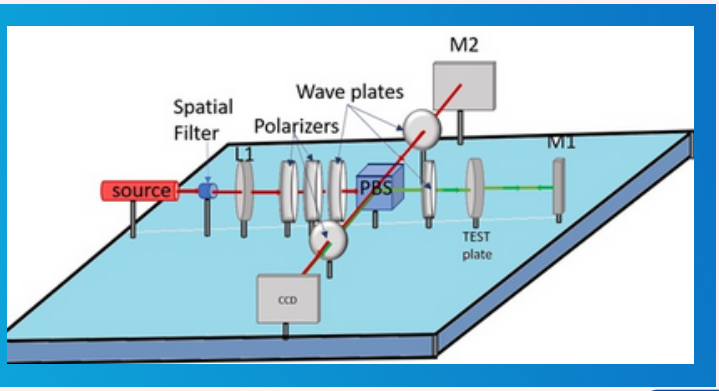


Figure 12

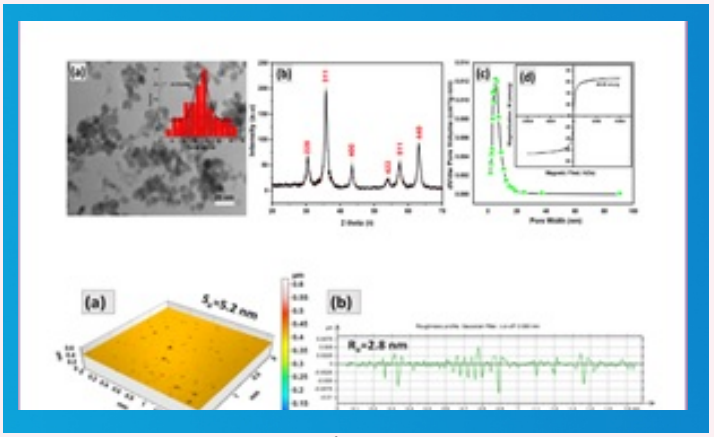


Figure 9

SPION Functionalized Nano-Abrasive for Precision Optical Polishing

Optical components having superfine surface quality with nanometer-level shape accuracy are in great demand for use in advanced optical engineering applications such as defense equipment, astronomical telescopes, synchrotron beamline, semiconductor industry, extreme ultraviolet lithography systems, high power laser etc. Therefore, fabrication of such high-quality optical components is the today's major priority. Nano-size particles are most preferable for enhancing the chemical as well as mechanical removal mechanism of the polishing process and result in sub-nano finishing effect. Owing to their larger surface areas, nanoparticles as compared to micro-size abrasives, offer a more homogeneous cutting effect and removal rate. This also enhances the surface roughness quality of the desired optical surfaces. The objective of the project is to develop a series of simple and cost-effective nano-size abrasives conformation by which easily recoverable, reusable, highly efficient, and highly monodispersed nano-size polishing abrasive can be developed for Chemical Mechanical Polishing (CMP) that can provide a very precise and angstrom level (1-10 Å) surface roughness within the estimated time. The method shown in Figures 9-12 is not only more straight forward but is also cost-effective.

Interferometer for Academic and Industrial Applications

Interferometers are investigative tools used in many fields of science and engineering to test surface profile, measure thickness of components, refractive index etc. They are called interferometers because they work by merging two or more light beam to create an interference pattern, which can be measured and analyzed. Twyman-Green is a variant of the Michelson interferometer principally used to test optical components. The light source for a Twyman-Green is a quasi-monochromatic point source that is collimated by a collimating lens into a plane wave. This plane wave is split into a reference beam and a test beam by a beam-splitter. The basic setup is for the testing of flats, in which case the reference beam reflects from a known reference flat and returns to the beam-splitter. The test beam is incident on the surface under test and reflects back. The two reflected beams interfere after beam splitter by an imaging lens combination to the observation plane.

Interferometer for Academic and Industrial Applications (Contd...)

For Fizeau both reference surface and surface under test are kept under same arm. So, this type of interferometer is called common path interferometry. For this project, a table top compact polarization-based T-G set up is proposed for academic and industrial use. The schematic of the set-up is shown. The setup is useful for testing optical flats / curved surface- find surface waviness. The software supplied with it will give peak to valley errors of the optical components. A polarization based Twyman-green Interferometer setup is shown in [Figure 12].

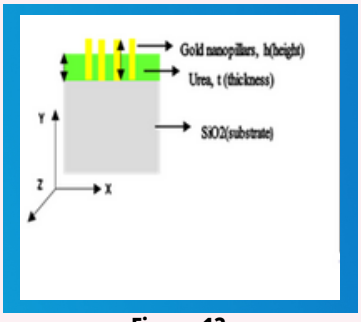


Figure 13

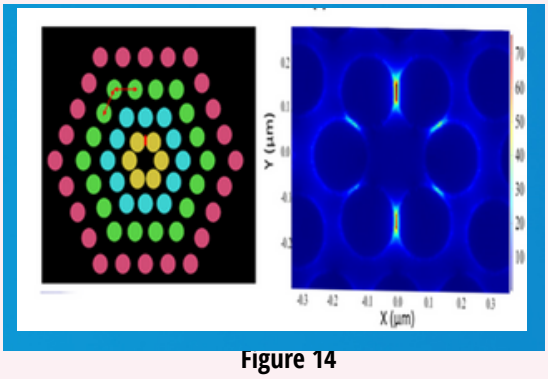


Figure 14

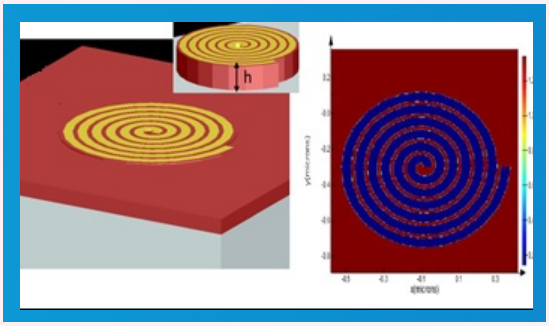


Figure 15

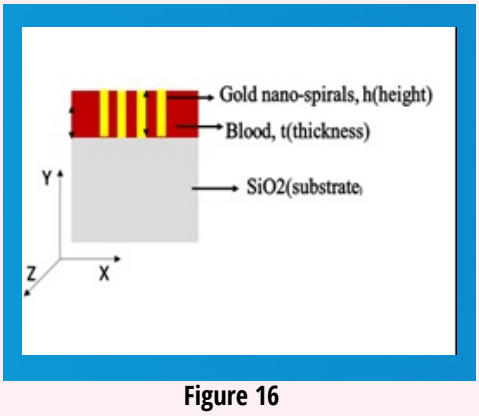


Figure 16

SERS-Based Explosive Detection System

Raman spectroscopy technique combined with plasmonics of nanomaterials is emerging as a new technology to probe individual molecule, traces of explosive molecules, and DNA structures. Optical cross-sectional area of individual molecule is ~10^{-30} cm^2/molecule, which is about 14 orders of magnitude smaller than florescent dye (~10^{-16} cm^2/molecule). Thus, single molecule detection by Raman spectroscopy could be possible, with a 10^{14} fold signal amplification. This can be achieved by surface enhanced Raman spectroscopy (SERS) technique, which is based on recording the Raman signal of individual molecule in the vicinity of plasmonic nanomaterials. SERS could possibly be employed to detect individual molecule, RDX/DNA at very low concentration (between picogram to atto-gram level). In this project, proto-type optical chip equipped with calibrated nano-antenna has been designed and fabricated to acquire signal from explosive molecules at very low concentration with a quick response time and a favourable signal-to-noise ratio. Design of SERS active substrate using Numerical methods (FDTD-Finite-difference time-domain), fabrication of the designed SERS substrate using currently available nano-fabrication techniques, and experimentation for the detection of SERS signals for trace molecules are underway. A photonic crystal-based SERS substrate which gives precise location of hotspots with EF~ 10 for Urea has been developed [Figure 13 & 14]. Besides, a polarization independent nano-spiral SERS substrate for analyte detection was also developed for more realistic evaluation by expressing Raman gain in terms of Purcell factor and local field intensity [Figure 15 & 16].

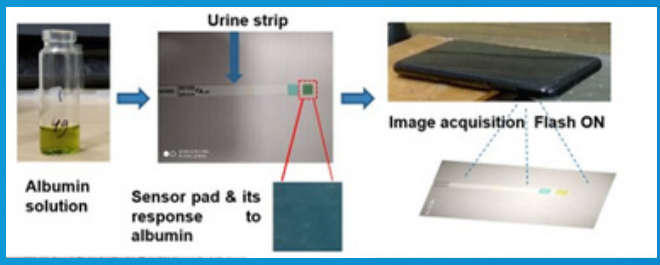


Figure 17

Figure 18

Smart-Phone Based, Accessory-Free, Rapid Quantification of Urine Albumin

Albuminuria is a well-known marker for early stage renal and cardiovascular disease. Urine dipsticks that are widely used for rapid screening of albumin, lack sensitivity and specificity in lower concentrations (< 300 mg/dl) which is clinically very significant for early diagnosis and often provide qualitative or semi-quantitative results. Precise quantification of lower concentrations is based on urinary analyzers that are not portable and cannot be used in low point-of-care (PoC) resource. settings. Here, an accessory free smartphone-based colorimetric detection method based on machine learning algorithms has been proposed to quantify albumin at lower concentrations [Figure 17]. Amalgamation of a smartphone with a dipstick will enable rapid and inexpensive diagnosis. The main objective of the project was Mobile Diagnostics-Direct quantification of urine strips using mobile phones. It enables the use of cell phones as urine strip readers by developing a mobile and device independent add-on-platform for strip-based decentralized diagnostic testing. The expected outcomes include imaging model and analysis framework, developing algorithms for illumination, non-uniformity and spectrum correction, calibration procedures and build robust measurement schemes [Figure 18]. The HSV color space turned out to be the best color space for classification of albumin concentration. The developed algorithms have exhibited good correlation with the gold standard. Clinical validation of the system will be done.

Digital Holographic Microscopy for Cell Imaging

Biological specimens induce shift in the phase of light and different phase contrast microscopy methods such as Zernike phase contrast microscopy and Nomarski differential interference contrast microscopy have been developed that transform phase information into amplitude or intensity information. But these microscopy methods only provide the amplitude/intensity information and do not provide quantitative phase information of the biological specimens. So, these techniques are not suitable for evaluating the cells morphology, refractive index distribution inside the biological cells and also the spatial and temporal changes in the morphological structure and physical properties of biological samples. Interferometric techniques for quantitative phase imaging of the non-contact, non-invasive type provide full field information of cell morphology and refractive index distribution inside the biological specimen. In this work, a Mach-Zehnder configuration-based, off-axis Digital Holographic Imaging Microscope (DHIM) has been developed for phase imaging of biological sample such as the RBCs. In DHIM, the object wavefront can be reconstructed at different distances (i.e. numerical focusing is possible in DHM) [Figure 19]. Besides this, the distortions due to aberrations in the optical system are avoided by the interferometric comparison of reconstructed phase with and without the biological sample. It provides the transverse resolution of the order of 2.19 µm.

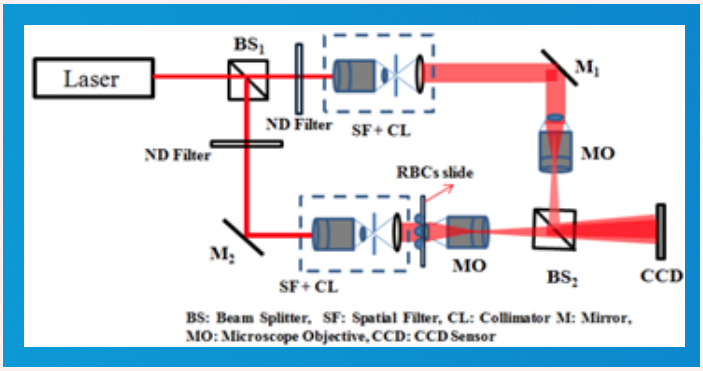


Figure 19

Digital Holographic Microscopy for Cell Imaging (Contd...)

A coherent laser light beam in the two arms of the interferometer is expanded and collimated by assembly of spatial filter and collimating lens, which are used as reference and object beam. The resulting interference pattern created by reference and object beam, the digital hologram, is recorded by the CCD camera as shown in figure. It provides both the amplitude and quantitative phase information of the light transmitted through the phase object from a single digital hologram by the use of numerical reconstruction methods. The developed system can be used for diseases diagnostics such as malaria, cancers and diabetes etc. The DHIM can also be applied to study cell dynamics.

Micro Optics Testing Using Digital Holographic Interferometry

Micro-optical components such as micro-lenses and micro-lenslet array have numerous engineering and industrial applications for example collimation of laser diodes, imaging for sensor system (CCD/CMOS, document copier machines etc.), for making homogeneous beam for high power lasers, a critical component in Shack-Hartmann sensor, fiber coupling and optical switching in communication systems. Also micro-optical components have become alternative to bulk optics for applications where miniaturization, reduction of alignment and packaging costs are detrimental. In this work, the potential of Mach-Zehnder based off- axis digital holographic interferometric microscope (DHIM) as a metrological tool for the characterization of the micro-lenslet array has been demonstrated. Measurement of diameter (D), sag height (h), shape of micro-lenses, radius of curvature (ROC), and focal length (f) has been calculated. The height profile of micro-lenses measured by DHIM is compared with commercially available Coherence Correlation Interferometer (CCI) from Taylor Hobson Ltd. UK with axial resolution 0.1 Å. The root mean square error (RSME) between the measurement carried out by DHIM and CCI is 0.12%. The advantage of using the DHIM is that the distortions in the wavefronts due to aberrations in the optical system can be avoided by the interferometric comparison of reconstructed phase with and without the micro-lenslet array.

Micro Optics Testing Using Digital Holographic Interferometry (Contd...)

Schematic of Mach-Zehnder interferometer based Digital Holographic Interferometric Microscope (DHIM) used for the characterization of micro-lenslet array is shown in Figure 20. 2D and 3D unwrapped phase difference map of micro-lenslet array and ambient air are shown in Figure 21.

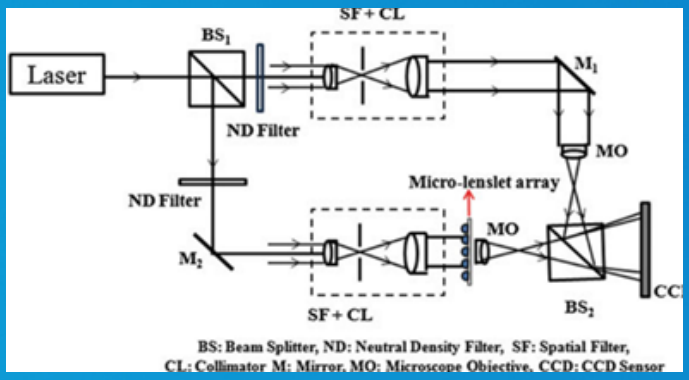


Figure 20

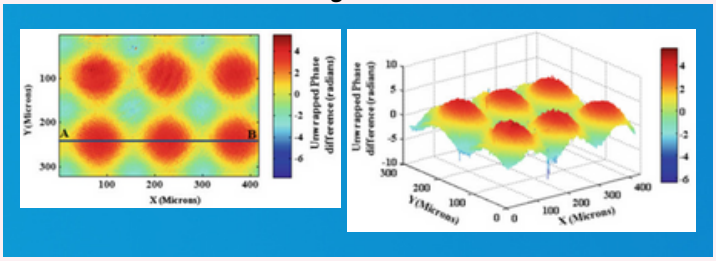


Figure 21

Virtual Stabilization of Platform of Commanders Cupola Tank T-72

While the tank turned by 90 degrees, the NSVT Gun Direction is unchanged [Figure 22]. Aiming of the NSVT Gun is stabilized by elimination of Yaw, Roll and Pitch disturbances caused by movement of the tank.

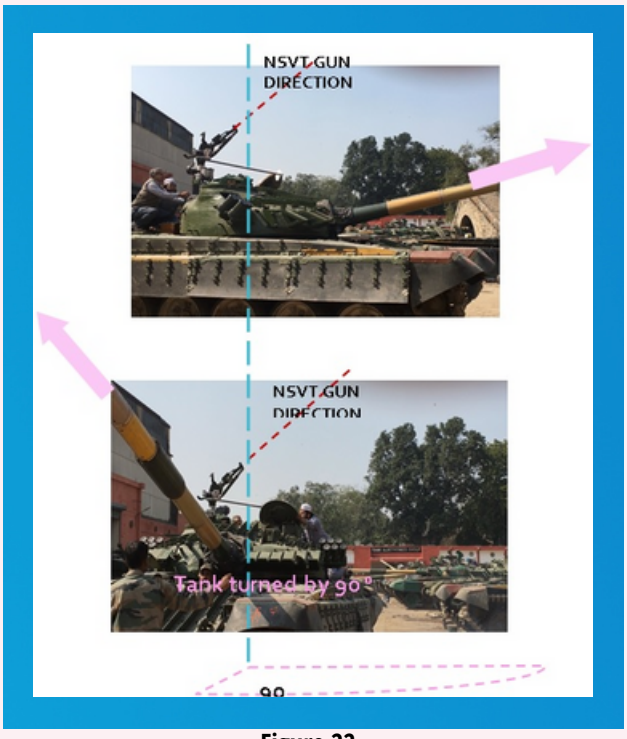


Figure 22

Radio Relay Link Automated System

An automated system for determination of Line of Sight of Mobile Communication Antennas, their Automatic Height & Bearing Alignment using GPS & special LOS determination and Control Hardware Software for Antenna Orientation for hilly Regions was developed and handed over to the Signals Unit of the Indian Army in working condition with software, hardware, design and operating manuals as per approval of design and operating manuals as per the approval of ARTRAC 2018 [Figure 23 & 24].

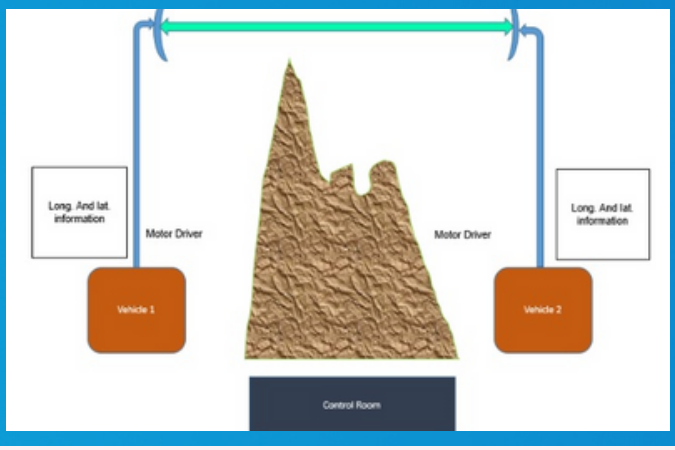


Figure 23

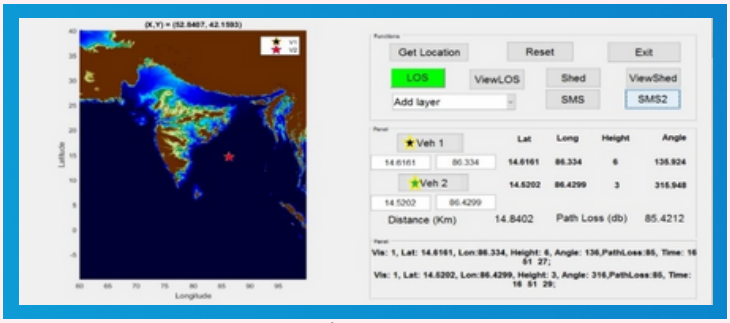


Figure 24

Electronic Voting Machines M3 EVM

M3 EVMs have been used successfully in General Elections 2014 & 2019 and Assembly Elections. VVPAT – Voter Verified Paper Audit Trail had key sensors designed at SeNSE, IIT Delhi. Key Security Modules for CU BU and VVPAT were also designed. Specialised Quality Assurance Tests for EVMs have also been implemented that have significantly enhanced reliability of M3 EVMs. Over twelve lakh EVMs have been manufactured by BEL & ECIL. 10 Joint Patents were filed for the M3 EVM.

Automated Production System for Kshara-Sutra

An automated production system for parasurgical applications was developed between 2012 and 2018. The design and the system were then handed over to ACRI, Delhi. The project was sponsored by CCRAS, Ministry of AYUSH, GoI [Figure 25].

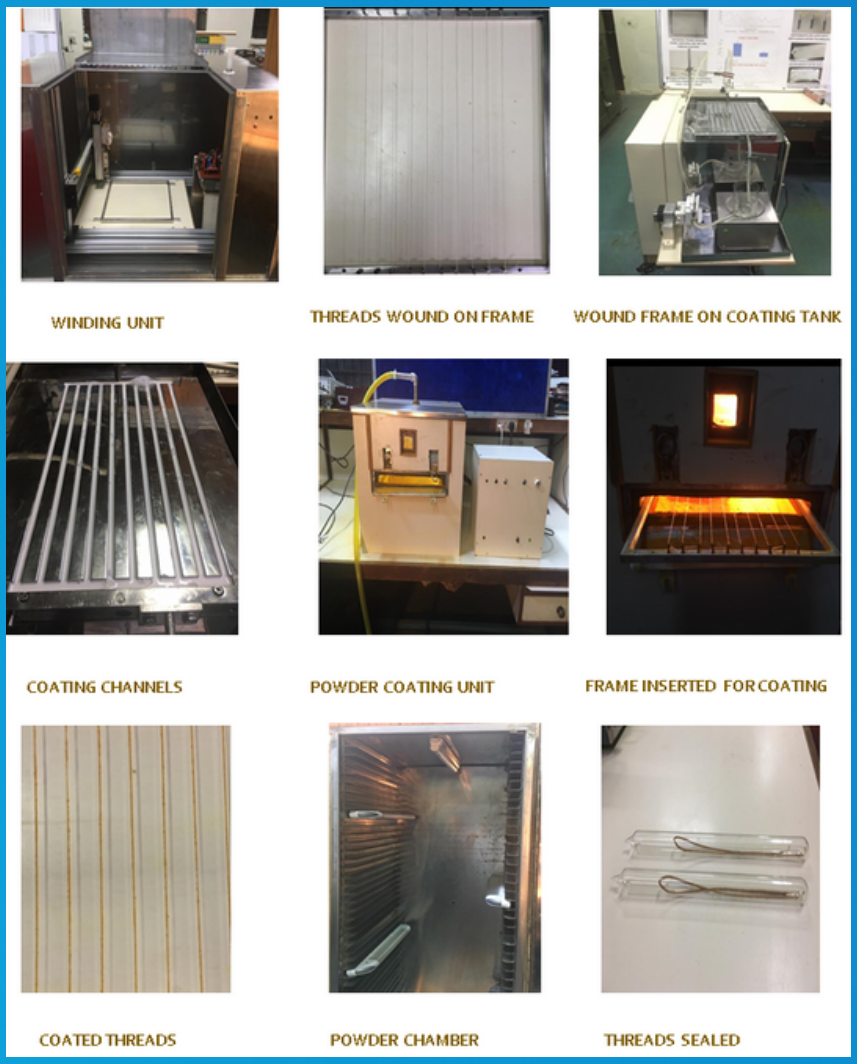


Figure 25

A Portable Operative Microscope for Visualizing and Recording

A fluorescence spectroscopic device was developed using NIR light source peak wavelength at 808 nm and blue light at 410 nm LED. NIR light at 808 nm is used for the excitation of indocyanine green (ICG) fluorescent dye which is administered into a patient intravenously. Exciting the ICG dye with 808 nm light produced fluorescence at approx. 820 nm. Both NIR excitation light and fluorescence emission at 820 nm are safe for human body because they are not penetrative. So far, fluorescence imaging has been done using ICG and NIR light only and these imaging devices are not only bulky but are also expensive. Both imaging and spectroscopic devices developed here, use NIR light (808nm) as an excitation source for ICG fluorescence dye [Figure 26]. The NIR light from laser is coupled into a 2 m long fiber optical coupler and the probe side can be placed close to the operating area (5 –10 mm). The NIR light excites the sample and the same probe collects the fluorescence light which is recorded by a hand held spectrometer. The recorded spectrum of NIR laser source is shown in Figure 27. Another dye used during intra-operative procedure is 5-aminolevulinic acid (ALA), which is a naturally occurring amino acid. After administering into the patient, it generates red fluorescence on excitation with blue light around 410 nm. Fluorescence navigation by photodynamic diagnosis (PDD) using ALA provides good visualization and detection of gastric cancer lesions and is a potentially valuable diagnostic tool for gastric cancer for evaluating both the surgical resection margins and extension of the lesion.

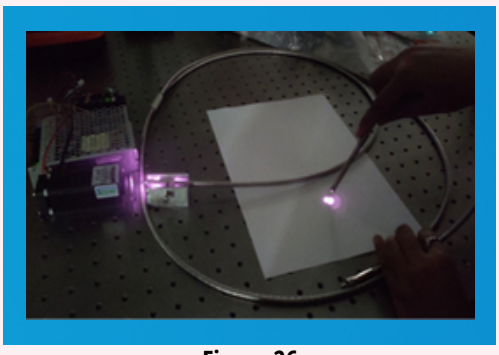


Figure 26

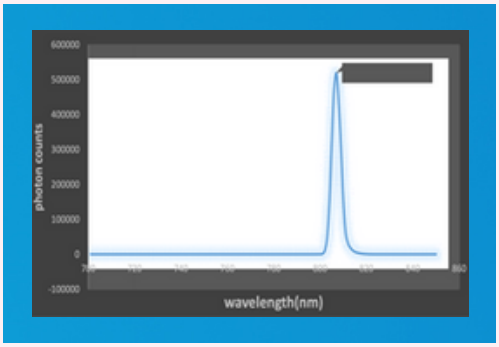
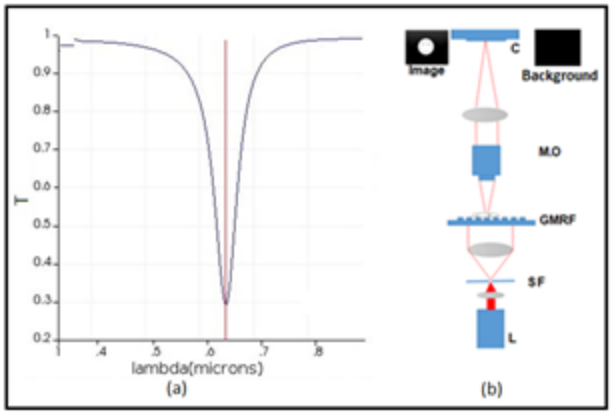


Figure 27

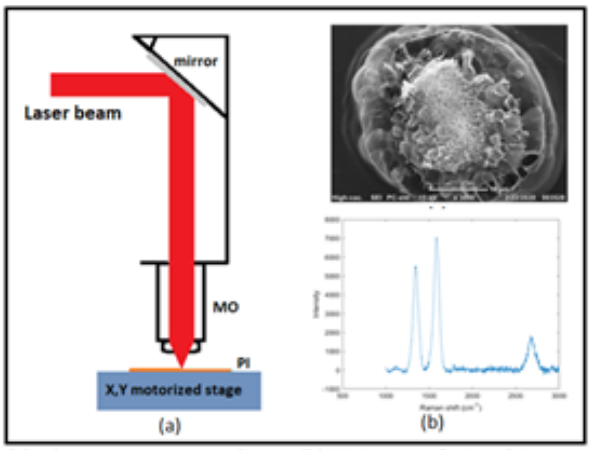
Photonic Structures and Laser-Induced Graphene for Sensing Applications

The study deals with the design, fabrication, and utilization of Photonic crystal structures (PCs) and laser-induced graphene for sensing applications. Interestingly, similar to the electron waves propagating through the periodic potential wells in a crystal arrange themselves into valence and conduction bands, photons also, when traveling into a medium with periodic dielectric constants, experience frequency gaps. Such medium with periodic dielectric permittivity is known as a Photonic Crystal. Photons within the frequency gap cease to propagate through the crystal. The periodicity for a particular semiconductor material is fixed; however, it can be changed for a PC. Thus, PCs can be designed to cover a broad frequency range, including the visible spectrum. PC-based sensors offer superior sensitivity levels resulting in precise detection limits. Implementation of 1D photonic crystals for sensing applications was attempted in this work. Another technology that has evolved recently and has the potential to be used in modern sensors is the ability of lasers to write Graphene foam directly on the surface carbon-based precursors. Precursor materials like polyimide can be directly graphitized using IR and UV lasers in an ambient environment, bypassing all the chemical routes for graphene generation. Graphene produced using the technique is a multilayered graphene foam called Laser-Induced Graphene (LIG). LIG is generated using a one-step laser irradiation process. The current work focuses on studying the properties and applications of LIG. The technology has a potential to address various issues related to efficient energy storage, terahertz optics, and sensor technology [Figure 28 & 29].



Contrast enhancement using Guided mode resonance filter,
(a) Transmission spectrum for typical GMR filter (b) Experimental setup

Figure 28



(a) Schematic experimental setup (b) SEM image of LIG and Raman Spectrum

Figure 29

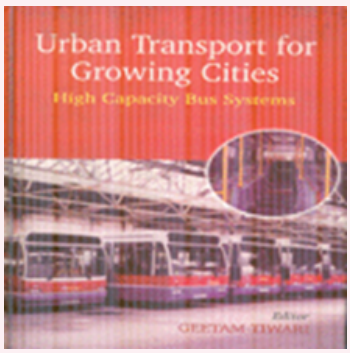
Network of Smart Silos for Rice and Wheat - A Proof of Concept

Spoilage of stored grains (rice/wheat) is a major economic loss in the post-harvest cycle. A smart silo with sensors to (a) identify temp and humidity thresholds for triggering spoilage (b) build a lab scale silo test bed (c) build a real-time DAQ for temp, RH and CO monitoring within the silo and (d) build a real time model for surveillance and management of grain health. Sensors have been developed for detecting temp, RH and CO_2 in the past and will adapt them to in-silo monitoring requirements. The system, which requires a minimum number of sensors/sensor clusters to be installed within the silos at crucial locations, allows for an understanding of trigger conditions for spoilage of grains w.r.t. the temperature, relative humidity, carbon dioxide and acts as an integrated system for surveillance and remote management of grain micro-environment and health of rice and wheat in distributed silo network.

Transportation Research and Injury Prevention Programme (TRIPP) Centre

- Transportation planning
- Traffic flow analysis
- Optimising mobility to minimise accidents and pollution
- Public transport
- Traffic management
- Road design and land use planning
- Vehicle technology
- Engines to minimise fuel consumption and pollution
- Vehicle crash modelling
- Road safety studies
- Safer vehicle and helmet design
- Epidemiology of factors associated with road traffic injuries injury analysis & pre hospital care

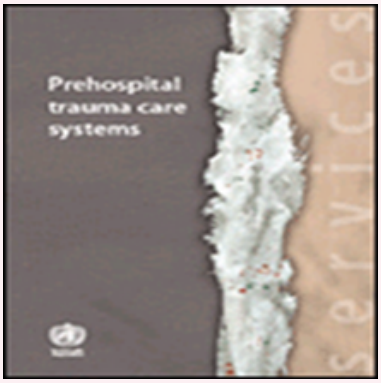
The Transportation Research and Injury Prevention Programme was established as a project in the year 1997 and formalized as an inter-disciplinary programme in the year 2002. It has been operational for two decades since then and has now been established as the TRIP-Centre. It is an interdisciplinary academic unit focusing on the reduction of adverse health effects of road transport. Research focus is on safer urban and inter-city transportation systems, and developing designs for vehicles, safety equipment and infrastructure for the future. Activities include applied research projects, special courses and workshops, and supervision of student projects at postgraduate and undergraduate levels. Projects are done in collaboration with associated departments and centres at IIT Delhi, government departments, industry and international agencies. The centre attempts to integrate all issues concerned with transportation in order to promote safety, active mobility, cleaner air, and energy conservation and focuses on reducing the adverse health effects of road transport.



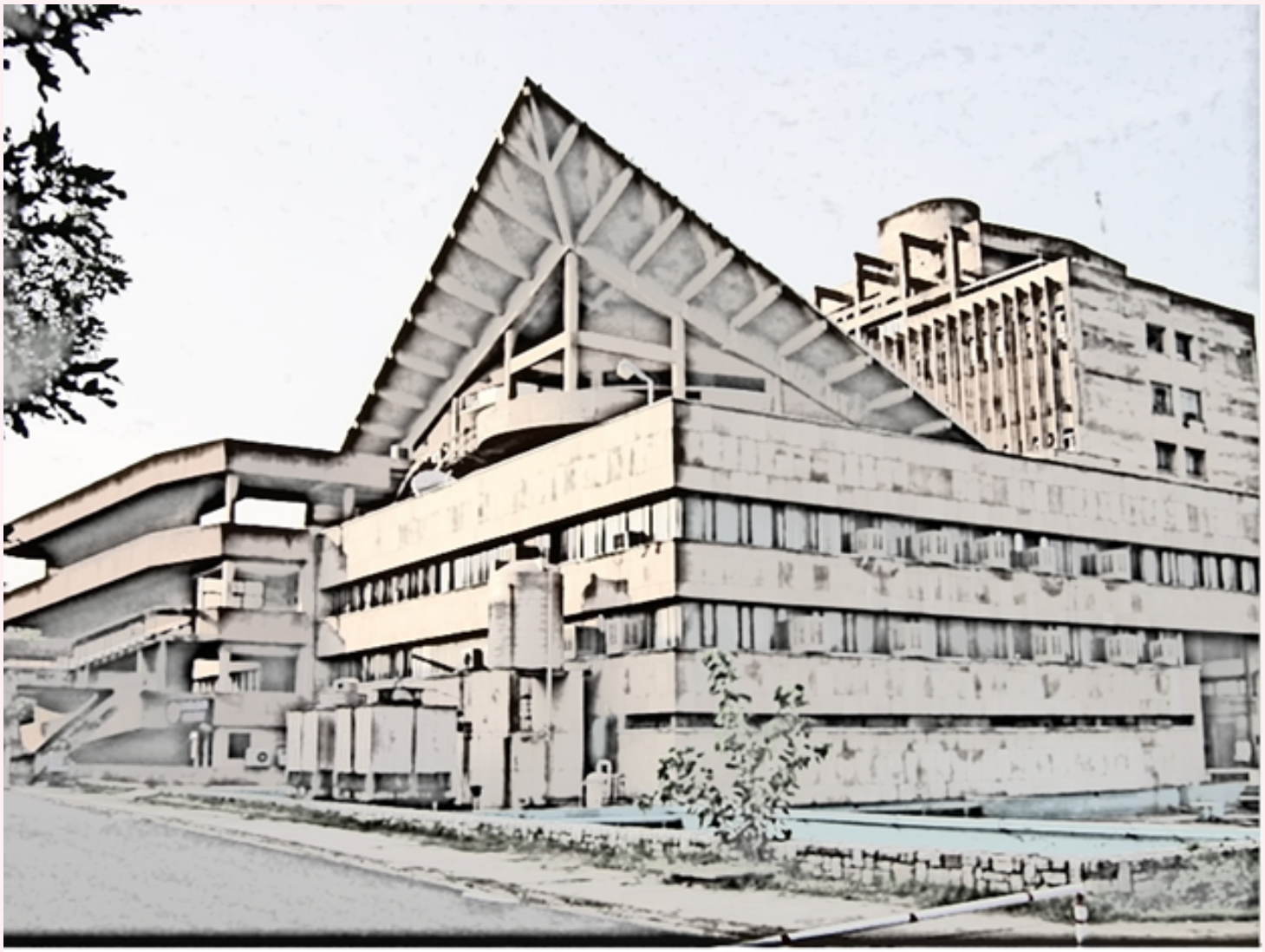
The centre has expertise in traffic and transportation planning, biomechanics, highway safety, epidemiology intelligent transportation systems and safety

Interdisciplinary research drawing from various departments (Civil, Mechanical, Computer Science, Mathematics, Humanities and Management) is conducted at the centre. At any given point of time there are ten on-going projects. The centre runs an annual (road) safety course by highly successful and reputed international faculty. The course attracts participants from all over the world. Annually 3-4 training programmes are conducted for nearly 100 participants.

Key contributions by the Centre include National Urban Transport Policy, Safer School buses - Eicher, Norms for low floor buses - Tata Macropolo, Change in BIS specifications of helmets, Code of practice for urban road standards, Tool Kits – Urban Road Safety, Public Transport Access, and the Indian Roads Congress Codes.



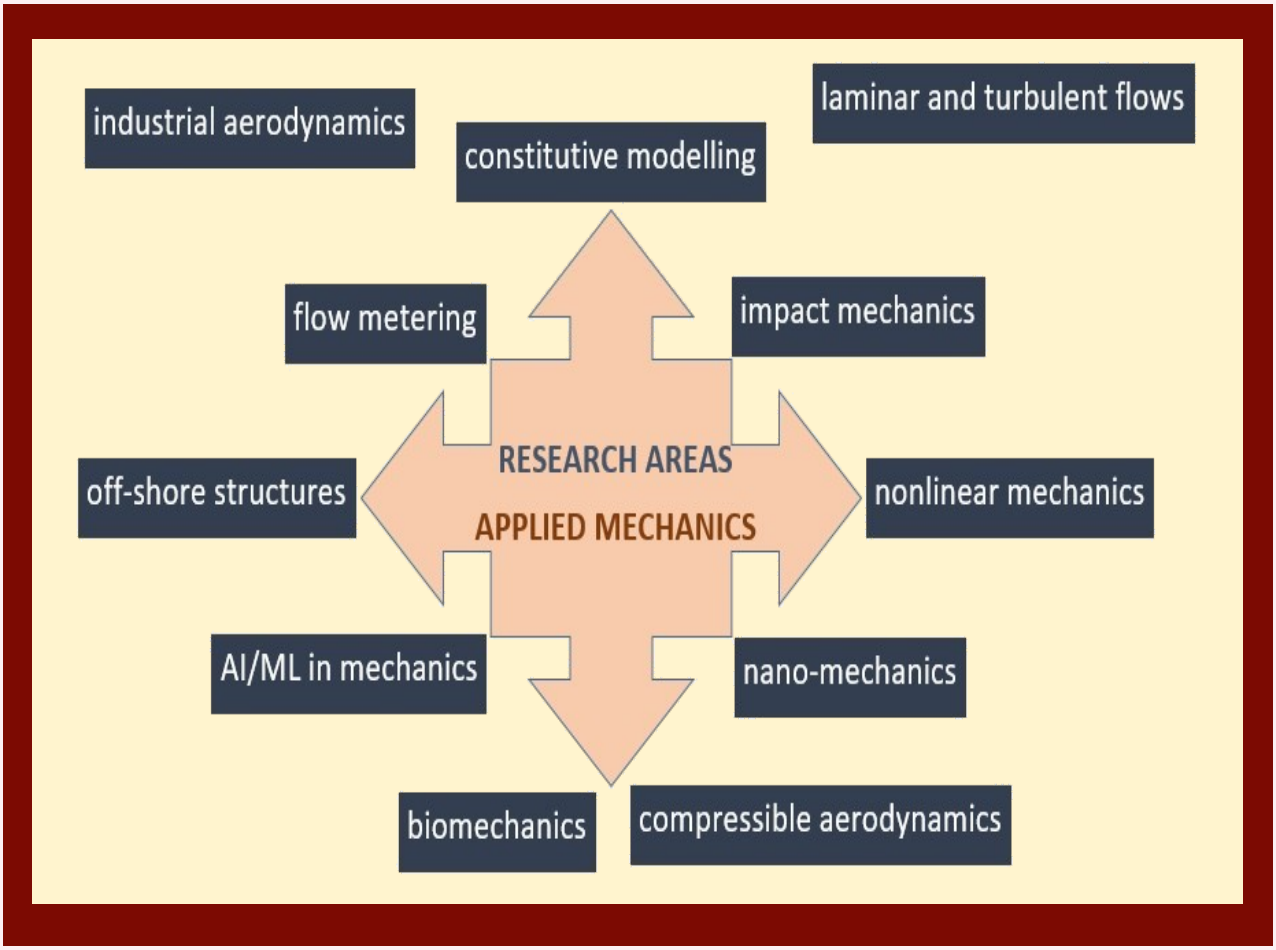
The Centre conducts research on a variety of topics such as transportation planning and traffic flow analysis for optimising mobility and minimising accidents and pollution. Studies are related to public transport, traffic management, road design and land use planning. Studies on vehicle technology and engines to minimise fuel consumption and pollution, vehicle crash modelling, road safety studies, safer vehicle and helmet design, epidemiology of factors associated with road traffic injuries, injury analysis and pre hospital care were done. In these areas, the Centre has 13 books, 27 monographs and reports, 3 documentary films and 300 peer-reviewed publications to its credit.



DEPARTMENTS

- Applied Mechanics
- Biochemical Engg. & Biotechnology
- Chemical Engg.
- Chemistry
- Civil Engg.
- Computer Science Engg.
- Design
- Electrical Engg.
- Energy Science Engg.
- Humanities & Social Sciences
- Management Studies
- Materials Science and Engg.
- Mathematics
- Mechanical Engg.
- Physics
- Textile & Fibre Engg.

APPLIED MECHANICS



The primary focus of the Department of Applied Mechanics at IIT Delhi, set up in the early 1960s, is to apply the fundamental principles of solid and fluid mechanics to real-life problems through an analytical, computational and experimental approach. These include constitutive modelling, impact mechanics, nonlinear mechanics, nano-mechanics and biomechanics, AI/machine learning in mechanics, off-shore structures, flow metering, laminar and turbulent flows, industrial aerodynamics and compressible aerodynamics. Besides research, these principles and methods are also integrated into the teaching pedagogy. Over the last five decades, specialized laboratories have been set up for solid mechanics, fluid mechanics, and computations equipped with state-of-the-art equipment.

Interdisciplinary Research - AI/ML-Based Algorithms

The first focus is on AI/ML based algorithm development that addresses problems in mechanics. New AI algorithms for interfacing physical laws and experimental measurements have been developed in recent years. An entirely new area of research called Physics-informed-Artificial Intelligence (pAI) has emerged and is being actively pursued in the department. A deep-learning framework that learns from low-fidelity physics and high-fidelity data has been developed [Figure 1]. Technologies such as the digital twin, have been included in the course curriculum to make the students industry-ready. These technologies involve seamless integration of computational techniques such as FEM (Finite Element Method), Computational Fluid Dynamics (CFD) etc. and modern AI for a system-level process simulation.

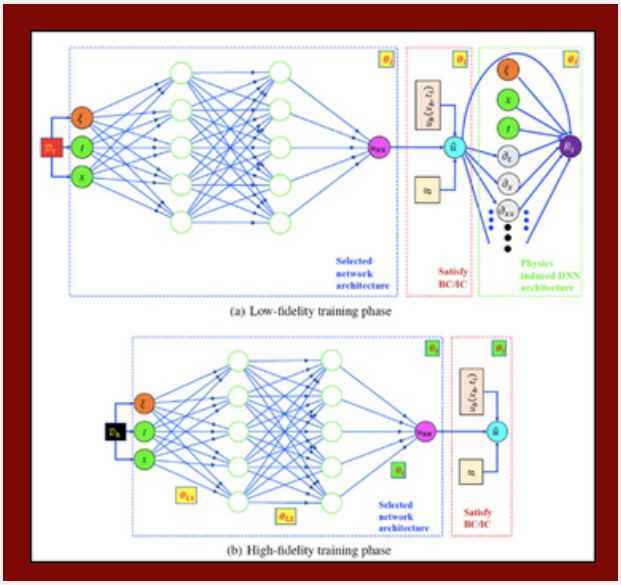


Figure 1

Interdisciplinary Research - Biomechanics

The second focus is on studying the human body mechanics and devising solutions for cardiovascular, neurological, orthopaedic and musculoskeletal issues. Blood flow hemodynamics and coupled fluid-structure interaction in vascular mechanics, modelling studies on the interaction of particle and cilia, with applications to flow sensing are actively pursued areas of research in the department. The department has recently secured prestigious research funding from ICMR to collaborate with AIIMS, New Delhi, for human brain tissue material characterisation and. develop a tissue-device-interaction-based neurosurgical simulation tool. DRDO-funded research on soft robotic wearable technologies and its effect on human musculoskeletal biomechanics is also underway in the department. This effort has led to a new direction in research related to simulation-based design and the development of wearable technology and human-machine interaction.

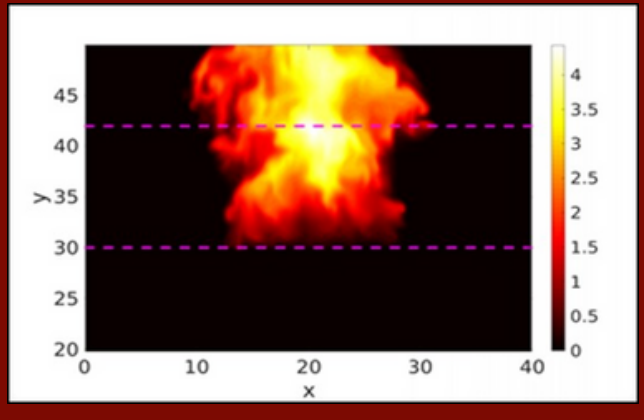


Figure 2

Fluid Mechanics Research

Some on-going sponsored research projects related to fluid mechanics include the development of wall models for turbulence, applicable for engineering flows funded by DST-SERB, a ReNew Power CoE-funded project on Large Eddy Simulations (LES) of horizontal axis wind turbines. Iso-contours of temperature field for LES of a volumetrically heated jet are shown in Figure 2. Besides, currently the following aspects of fluid mechanics such as first-principles modelling of entrainment rate in the atmospheric cloud, numerical modelling of nucleate boiling heat transfer using a level-set method, characterizing energy extraction efficiency of energy generators based on vortex- induced vibrations, modeling micro-fabrication of mesh-like liquid films, using Hele-Shaw cells, numerical and experimental studies on rotating convection and studying interfacial instabilities in core annular flows are currently being studied.

A few other topics being studied in fluid mechanics include the effects of wake confinement and buoyancy on flow transitions and heat transfer for a square cylinder, influence of obstacles on large scale flows: climatic aspects, a computational study of turbulent forced plume in a stratified environment, and CFD Simulations of coal gasification in an entrained flow gasifier.

Another research group is working on aspects such as theoretical investigations of the physics of key turbulence processes in compressible flows, translating these investigations into improved turbulence closure models for compressible flows, and improved turbulence modelling for bridging methods of turbulence. R&D of several design and analysis software tools for the steam turbine industry (Bharat Heavy Electricals Limited) is also underway.

Structural Health Monitoring

In lamb wave-based baseline-free structural health monitoring using Piezoelectric Wafer Transducers (PZTs): modelling and experiments [Figure 3], a novel Refined Time-Reversal Method (RTRM) has been developed. The method uses lamb waves for accurate baseline-free damage detection and localization in thin plate structures [Figure 4]. In this method, lamb waves are excited in the thin plate with the help of surface-bonded piezoelectric wafer transducers using narrowband Hann window-modulated voltage signals. Establishing RTRM as a structural health monitoring technology is a seminal contribution by the group.

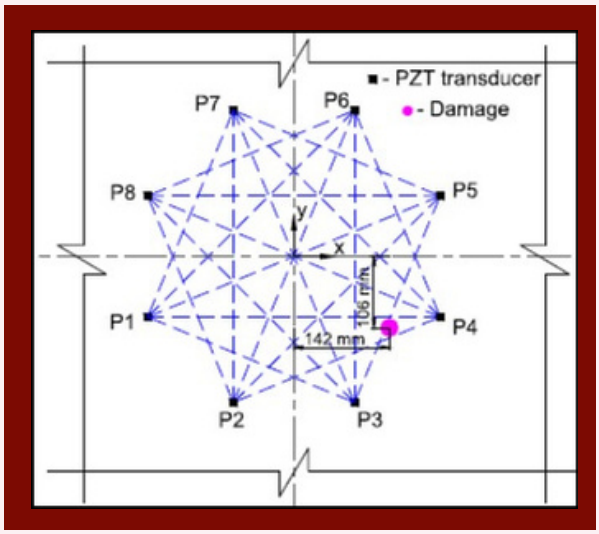


Figure 3

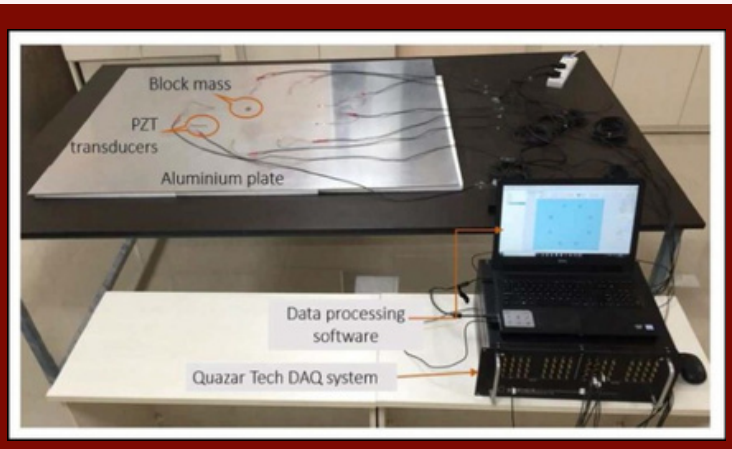


Figure 4

Ballistics Impact

In high velocity impact research, many teams are involved in computational modelling of a high-velocity impact seen in the ballistic impact of a bullet-proof jacket. They perform analytical and numerical studies using x-ray tomography to study strain in porous media and develop their constitutive models to understand the effect of shock in layered media. Many research projects are collaborative and involve national and international collaborators like the DRDO and the Denmark Technical University.

Composite Mechanics

Multi-scale homogenization of composites is an on-going area of research and has provided analytical and numerical models for prediction of continuum damage during low velocity impact on composites such as the cause of erosion due to rain and fatigue, repair, curing and setting up of residual stresses in composite wind turbine blades.

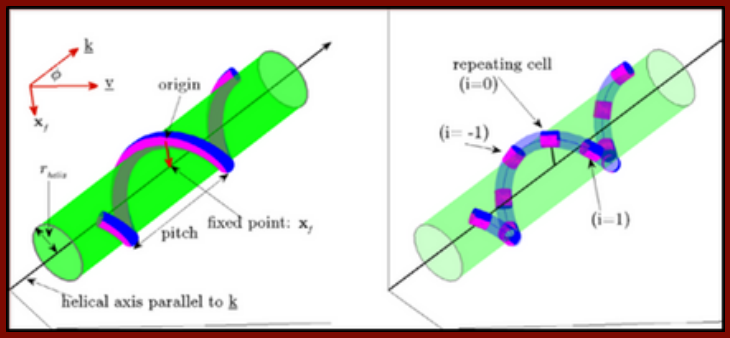


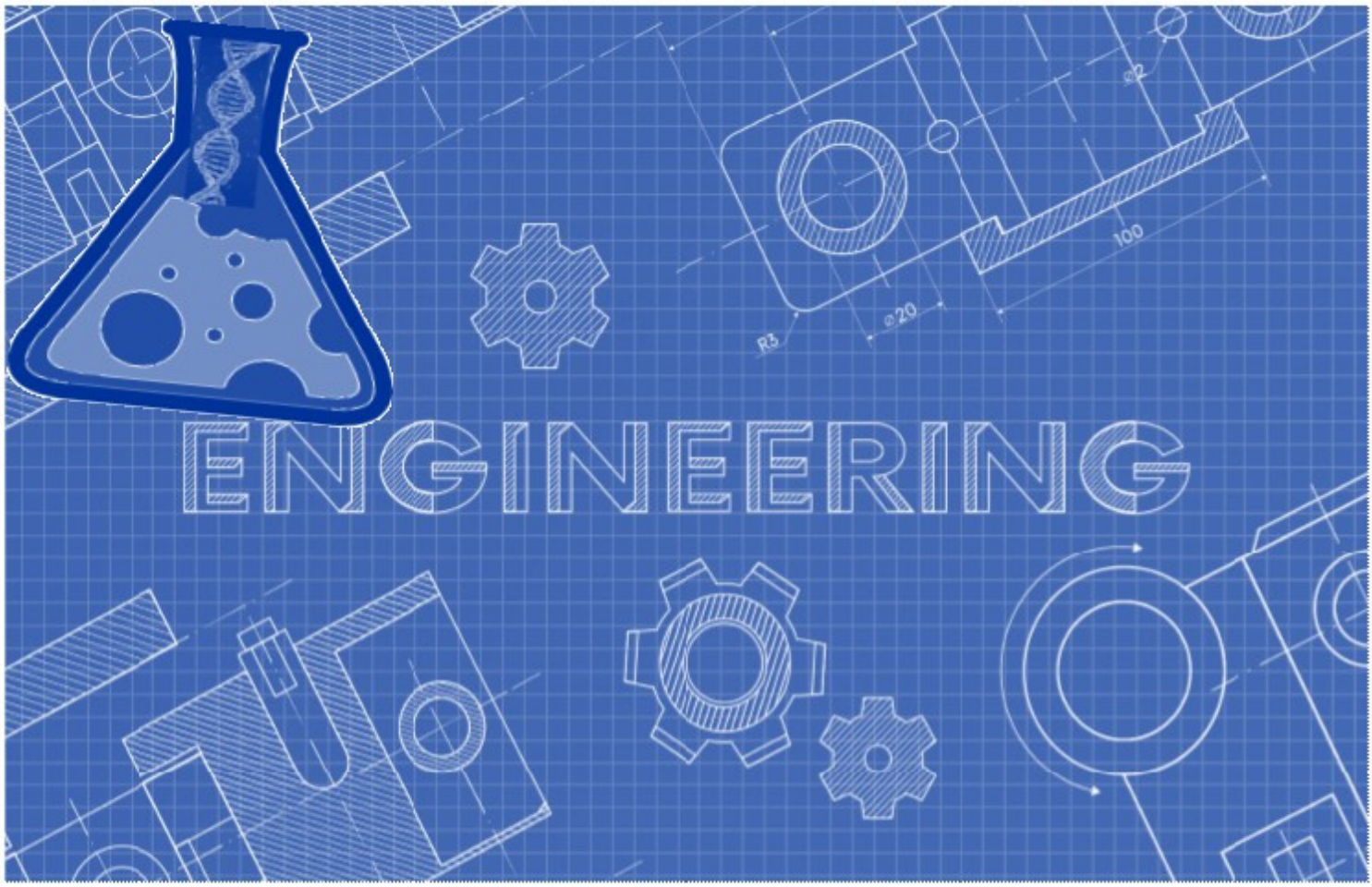
Figure 5

DMRCL

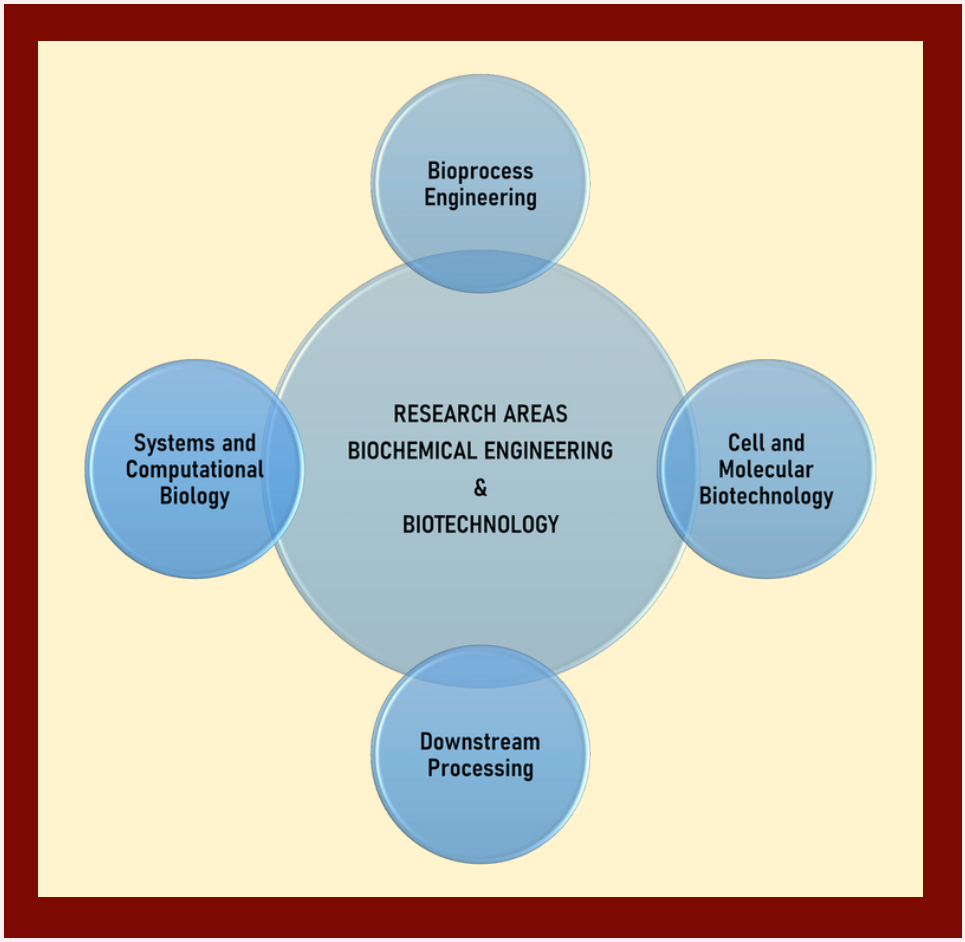
The Dynamic Material Research Characterization Laboratory (DMRCL) offers a unique set of home-grown facilities in India. The response of materials and structures towards the dynamic loading conditions such as high strain rate behaviour, dynamic fracture toughness, structural response related to projectile impact and shock, the effect of extreme temperature (-200 °C to 250 °C) on the dynamic mechanical properties, etc., are regularly conducted at DMRCL. The success of DMRCL can also be judged from the number of high value sponsored research projects and high impact publications by the faculty.

Continuum Mechanics

Researchers in the solid mechanics' division of the department are involved in continuum mechanics of slender rod-like structures. In this regard, novel one-dimensional beam-like nonlinear theories have been developed to account for the elasto-plasticity, electro-elasticity and magnetoelasticity in slender structures. These developed theories have application in the modelling of soft continuum robots. Multi-scale modelling techniques such as the Helical Cauchy-Born rule to obtain continuum-equivalent mechanical constants of one-dimensional nanostructures, e.g., nanorods and nanotubes have also been developed [Figure 5].



BIOCHEMICAL ENGINEERING AND BIOTECHNOLOGY



The Department of Biochemical Engineering & Biotechnology at IIT Delhi provides a model for an integrated approach towards education as well as research and development of various bioprocesses. Foreseeing the significant role that would be played by biochemical engineers and biotechnologists in future, the Institute initiated activities in this direction in 1968.

Metabolic Engineering of Microbes for Industrial Applications

Zymomonas mobilis has been metabolically engineered for the development of a microbial platform for the production of industrially important compounds. A *Bacillus subtilis* based cell factory for the production of renewables has also been developed. Enzymatically constrained genome scale metabolic models of microorganisms for improved prediction of metabolic engineering targets have been engineered.

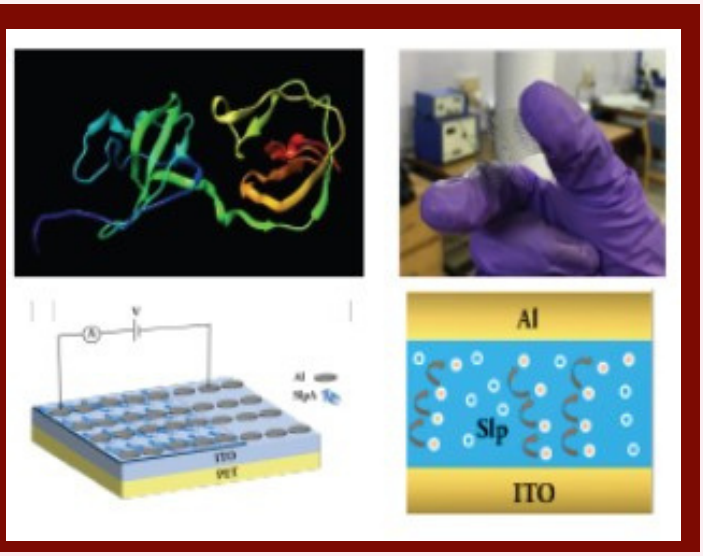


Figure 2

Biodesulfurization of Petroleum Fractions

Bacteria-mediated highly efficient biodesulfurization of petroleum fractions successfully demonstrated using a lab isolate *Gordonia* sp. IITR100. The promoter for the desulfurization genes was identified in the bacterium and replaced with a stronger, auto-inducible promoter which was not repressed by inorganic sulfur. A patent was filed for this in 2019. A novel bacterial cell surface display system was developed which had desulfurization enzyme expressed on the surface for faster conversions. A patent for this was filed in the year 2017. A patent for a bifunctional enzyme construct developed by fusing OszA and OszB with several fold enhanced desulfurization, was filed in the year 2018. A novel transcriptional regulator was identified for the dsz operon, which activated the desulfurization operon and caused a 15-fold increase in the biodeslfurization activity [Figure 3].

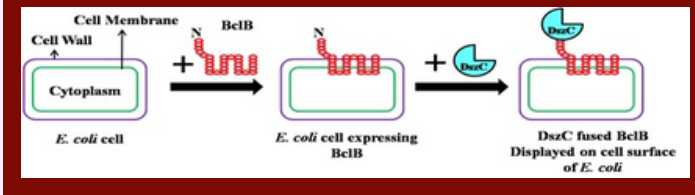


Figure 3

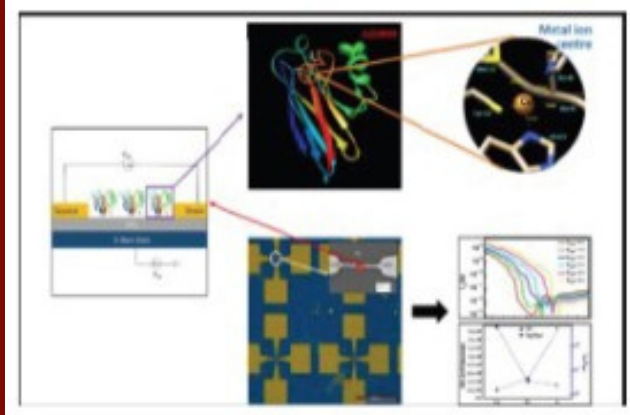


Figure 1

Biochemical Engineering & Biotechnology

The research group developed recombinant protein-based nanoelectronics, fabricated nanodevices for microbe detection in clinical samples, designed novel biosensing elements, carried out molecular imprinting and synthesized nanomaterials for enantioseparation and culture-free pathogen detection in collaboration with different departments within IIT Delhi and outside.

These include Field-Effect Transistors (FET) in collaborative work with CARE, IIT Delhi using the recombinant metalloprotein azurin [Figure 1]. This p-type FET device has the advantage of low sub-threshold swing, high on-off current ratio and a consistent behaviour in a highly stable mode.

A backgated transistor based on a 300 nm channel of azurin-TiO hybrid nanostructure for high-efficiency ultraviolet detection, was also fabricated by the group. Resistive $_2$ switching and flexible nonvolatile memory device using a recombinant S-layer protein shown in Figure 2.

A novel vancomycin functionalized WO thin film-based impedance sensor and an MoS_2/TiO_2hybrid nanostructure-based FET were developed for the efficient capture and highly selective detection of Gram positive bacteria. Both devices can be used under physiological conditions. Smartphone-based detection of viable bacteria using an Ag nanorod array, has been achieved in collaboration with the Department of Physics. A SERS platform has been developed for dengue diagnosis using a hand-held Raman spectrometer, in collaboration with the Department of Physics and the NIMR. Various nanoformulations for antibacterial and anticancer activity have been standardized and tested. Surface molecularly imprinted nanoparticles for enantio-separation and culture-free detection of pathogenic bacteria were also synthesized.

Rapid Diagnostics of T.B, Typhoid

A highly sensitive, portable set-up called 'SeeTB' has been developed for tuberculosis diagnosis [Figure 4]. Besides, the specificity of SeeTB is comparable to conventional methods of diagnosis. The device was constructed by converting a bright-field microscope into fluorescence microscope with minimal interventions. SeeTB, a total internal reflection-based fluorescence excitation system allows visualization of auramine-O stained bacilli efficiently with a high signal-to-noise ratio and a higher sensitivity than fluorescence microscopy (FM). Thus the system provides a valid alternative to traditional FM. Unique advantages of the SeeTB system are its sensitivity, high negative predictive value, affordability, deployability and scalability, thus offering the most realistic option for improved TB case identification in resource-limited IMC²(Immuno Magnetic Cell capture) technology is a one-step diagnostic solution for bacterial infections like typhoid, pulmonary tuberculosis etc. which gives results within 60 min [Figure 5]. The system has a user-friendly interface and operation, comes fully equipped with a rechargeable battery and is also network-enabled.

Figure 4

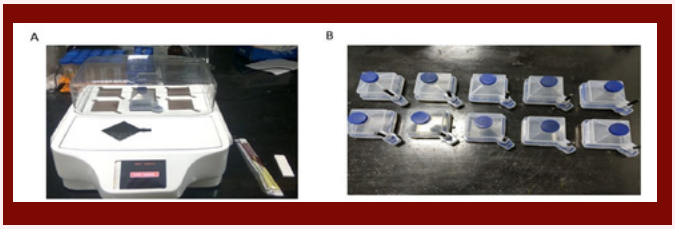


Figure 5

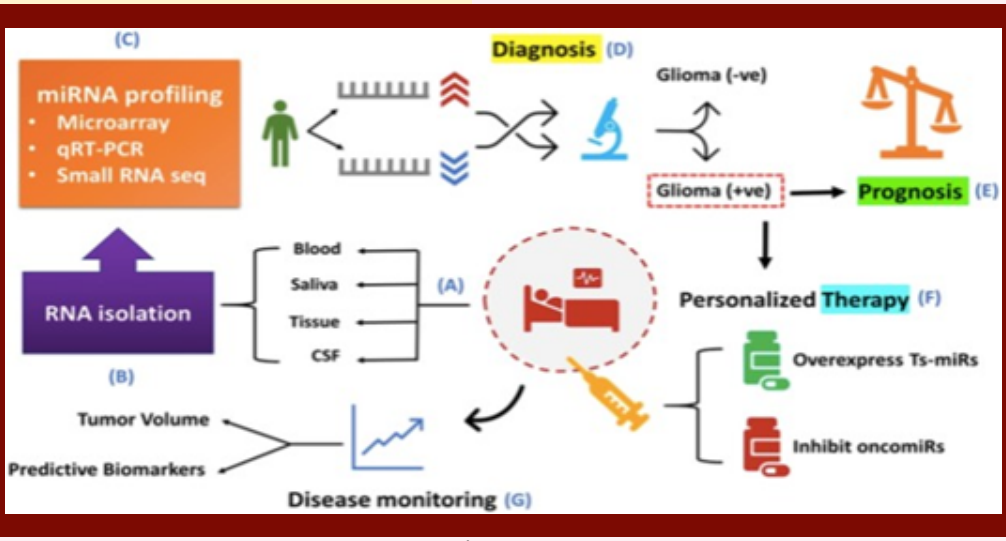


Figure 6

MicroRNA-Based Cancer Treatment Strategies

The crucial role of microRNAs in breast cancer and glioblastoma was unraveled [Figure 6]. Key oncogenic/tumor suppressive miRNAs that serve as diagnostic and prognostic biomarkers, and attractive targets for cancer therapy of breast cancer and glioblastoma (GBM) have been discovered. The microRNA signature of hypoxia in glioblastoma was shown for the first time. miR-210 and miR-196a were identified as important mediators of hypoxic response that positively affect the HIF pathway as part of a feedback loop and function as oncomiRs. These micro RNAs target several cancer related genes and pathways and act as attractive targets for GBM therapy. The overlaps and differences in pediatric and adult glioblastoma patients w.r.t miRNA and snoRNAs profiles have been highlighted and the downregulation of snoRNA, HBII-52 cluster observed, which has a prognostic significance for GBM. A peptide based nanocarrier was developed for miRNA delivery in GBM cells. In collaboration with IIT Kanpur novel drugs are being developed for GBM and many natural products are being tested for GBM therapy in collaboration with Shoolini University.

Recombinant Laccase Enzyme - Mediated Effluent Treatment

Multiple isoforms of laccase enzyme have been obtained by cultivation of the basidiomycete fungus *Cyathus bulleri*, on agricultural wastes such as wheat bran, wheat straw, rice straw and domestic wastes such as orange, potato and pea peels. The purified Laccase I isoform as well as the extracellular culture filtrate are able to remove the chromophoric groups in dyes and detoxify textile effluents. The gene for Laccase I has been overexpressed in *Pischi pastoris* and the protein product, engineered for maximum activity.

Figure 7

Bioformulation for Crop Care

An environmentally sustainable bioformulation has been developed for combating biotic as well as abiotic stress faced by crop plants, promoting their growth and rejuvenating the soil health by stimulating the growth of indigenous soil micro fauna. These formulations are a strategic mix of beneficial rhizobacteria along with their cell-free culture supernatants and target metabolites. They act by enhancing the abundance of indigenous soil microbes in natural field conditions [Figure 7].

Molecular Basis of Ayurveda

Ashwagandha has been proposed to serve as a cheap, economic anticancer drug especially when modern medicine is either not available or is limited by severe side effects based on evidence. Cell-based functional screening was undertaken to identify the anticancer bioactive compounds in both alcoholic and aqueous extracts from the Ashwagandha leaves by chemotyping. The identification of protein targets and elucidation of their mechanism of action were done through bioinformatics. Molecular insights revealed that the extract/component activates tumor-suppressor genes and induces an oxidative stress. Based on their studies, the group has formulated a combination of active anticancer components and developed a method of extraction of the active component for better yield and also furnished evidence in favour of Ashwagandha as a prospective anti-COVID-19 drug.

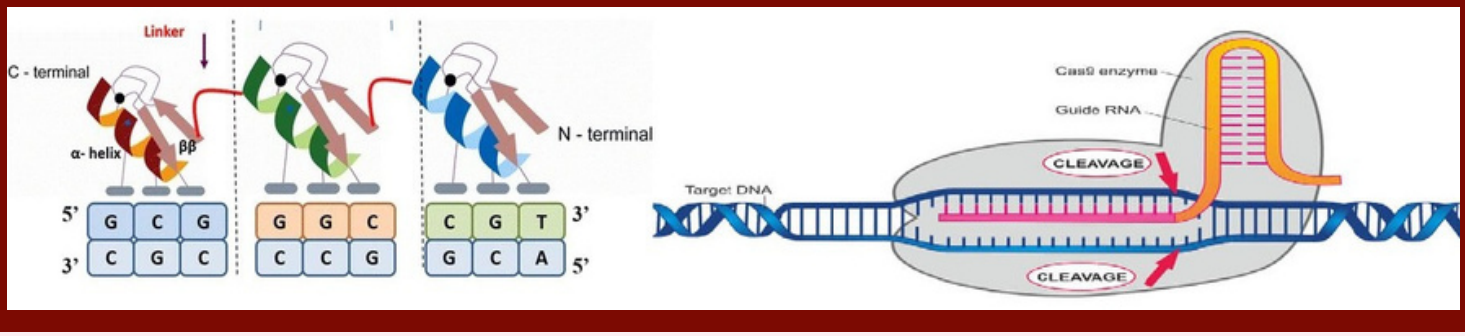


Figure 9

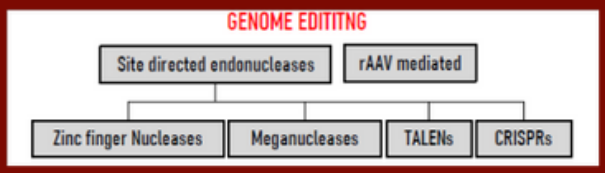


Figure 8

Programmable Genome Editing Tools

Genome editing is a group of technologies that give scientists the ability to change an organism's DNA. These technologies allow genetic material to be added, removed, or altered at particular locations in the genome [Figure 8]. Tools for Zinc Finger Nucleases (ZFN) and CRISPR/Cas system have been developed for genome editing. Statistical methods were developed to estimate the binding-specificity of ZFNs, target unique locations in the genome and design ZFNs for application in synthetic biology. Workflows that identify synthetic lethal targets and off targets in the CRISPR/Cas9 system have been developed [Figure 9]. Off-target prediction ability of the sgRNA designing tool have been improved using curated datasets and advances in Machine Learning (ML) [Figure 10].

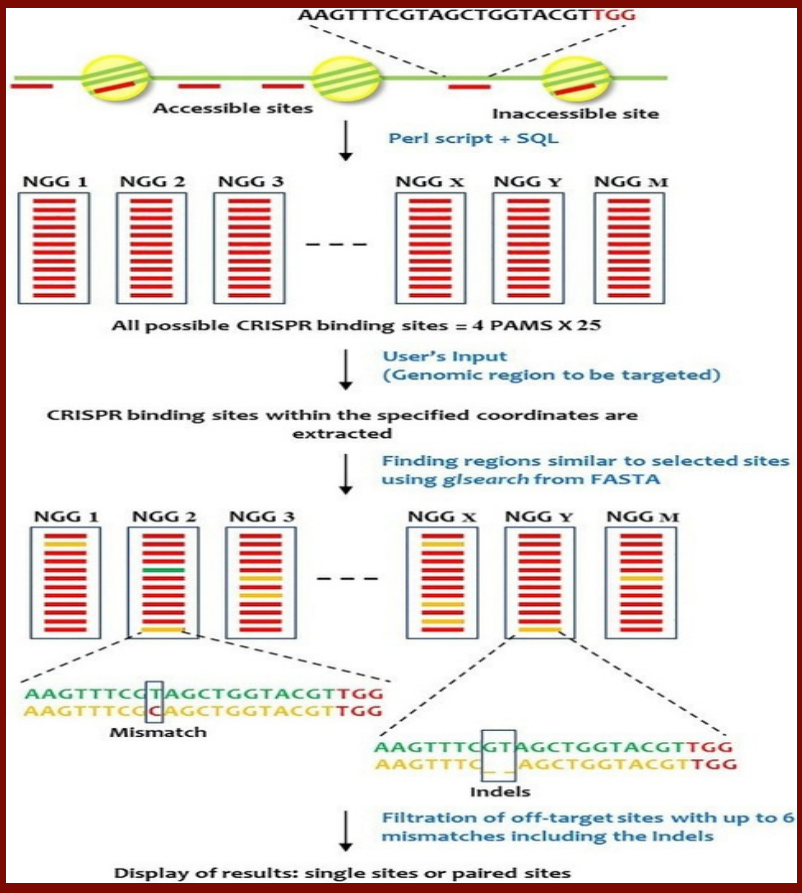


Figure 10

AI/ML-Enabled Multi-Omics Data Integration for Drug Discovery

A robust multi-omics based neural network model to predict clinical outcomes and candidate drugs has been built. This seeks to generate effective ML-based solutions through superior and efficient embedding frameworks that extract predictive information from data such as survival estimation, drug target identification and segmentation differential analysis. It also enlists methods to identify high risk cancer patients based on their genomic profile and recommends drugs [Figure 11 & 12].

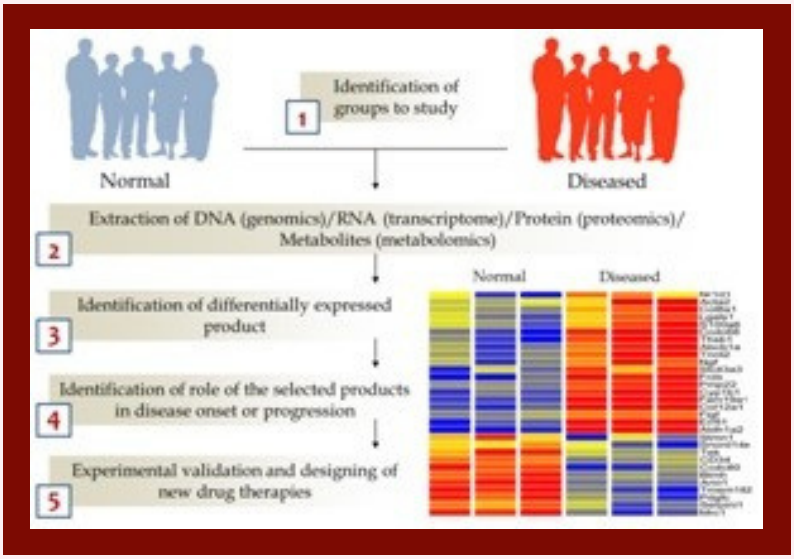


Figure 11

Exploring Biological Activity of Natural Drugs

Identification of big data based leads for drug development from traditional home medicine for cancer prevention and treatment. Understand the molecular mechanism of action of natural compounds by integrating the computational simulations and modern experimental assays.

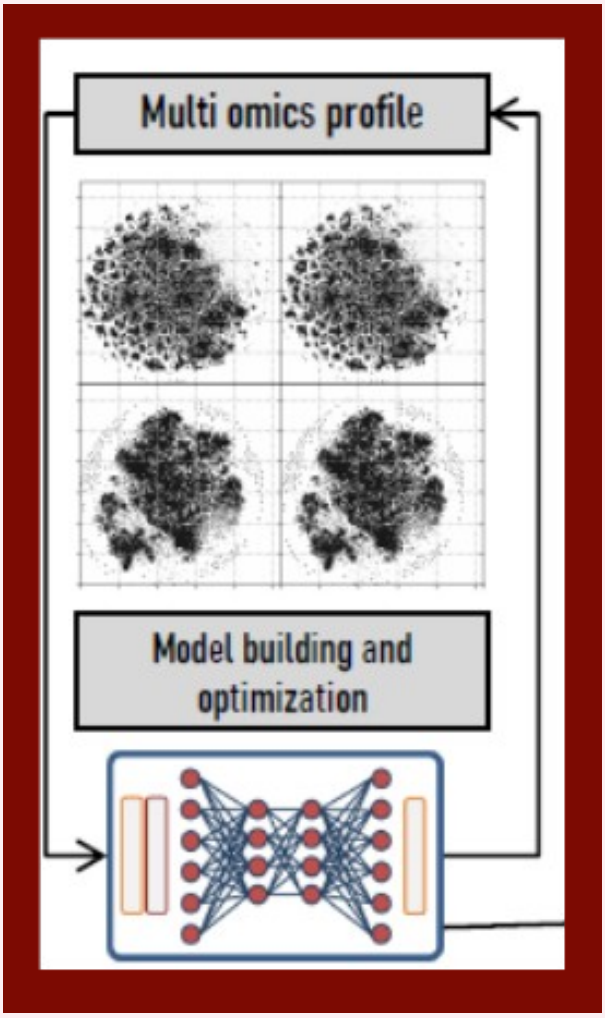


Figure 12

Molecular Mechanism of ATP Synthesis

Based on pioneering molecular systems engineering approaches "Nath's torsional mechanism of energy transduction and ATP synthesis" and "Nath's two-ion theory of energy coupling and ATP synthesis" have been formulated to explain the exact molecular mechanism of ATP synthesis and hydrolysis thus answering a century old question in biochemistry. The human ATP synthase enzyme with the FOF1-ATP synthase is illustrated in Figure 13.

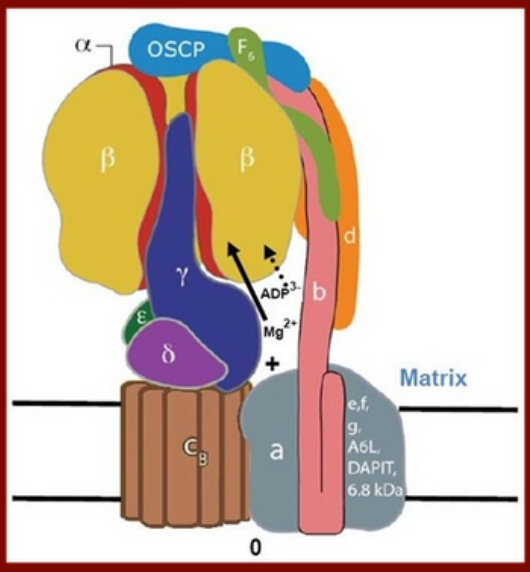
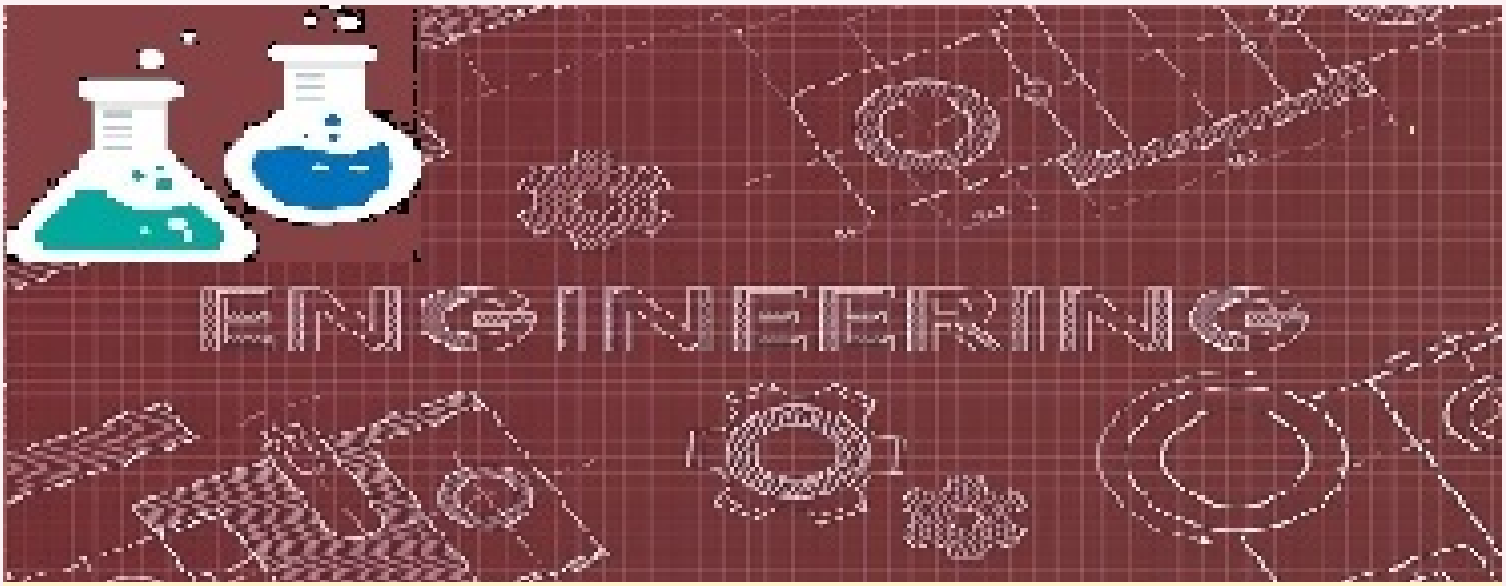
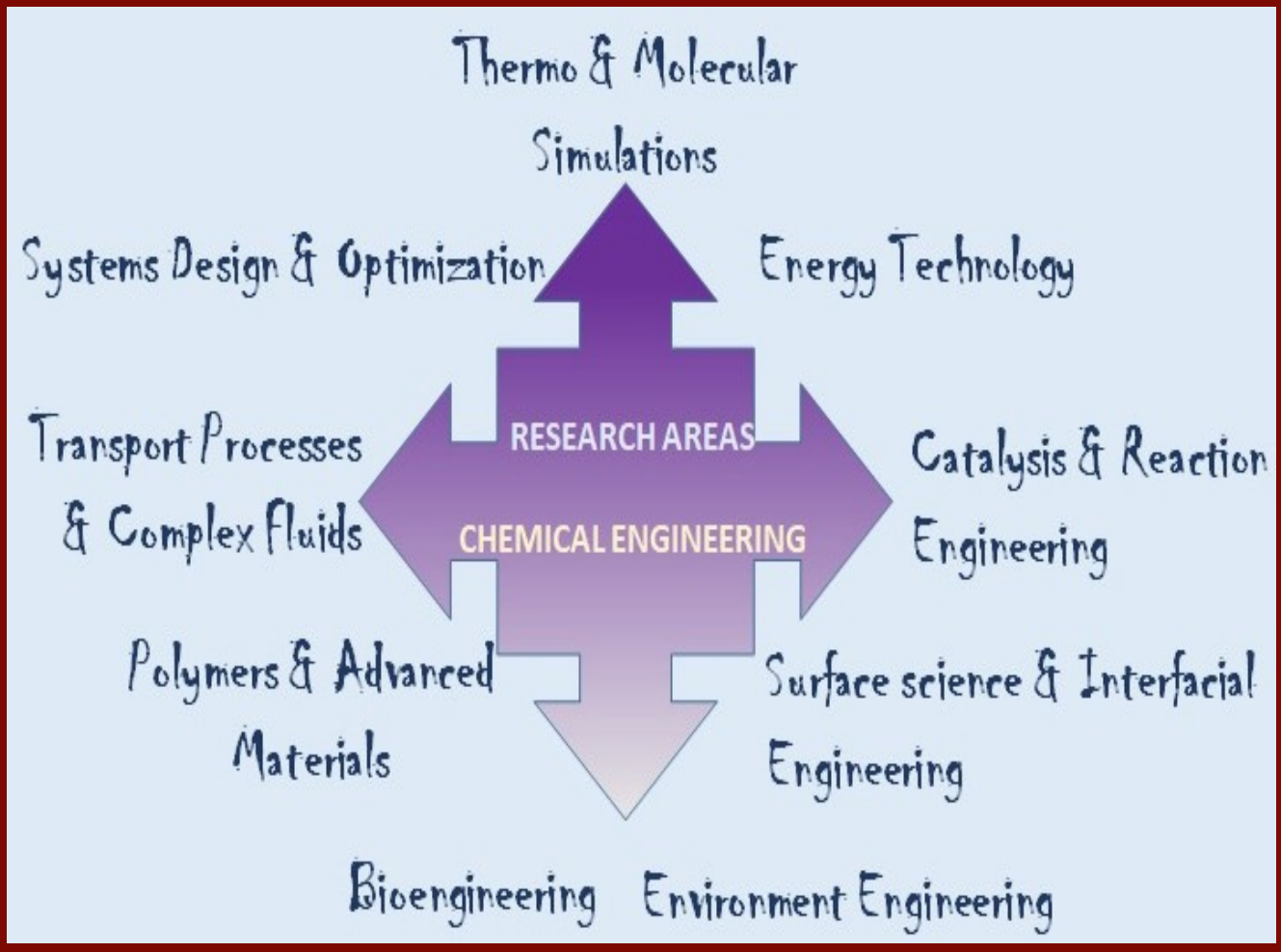


Figure 13



CHEMICAL ENGINEERING



The Department of Chemical Engineering at IIT Delhi is 60 year-old, vibrant department. It has cast its footprints in new frontier areas of materials, renewable energy, waste-to-wealth, biopharmaceuticals, nanoscale materials, and computational research. It is uniquely placed to drive research in many areas relevant to society such as climate, green chemicals, clean energy, medicine, and consumer goods. The department has established strong interactions with leading Indian and multinational companies through sponsored research and consultancy projects and it is well equipped with the state-of-the-art experimental and computational facilities to pursue cutting-edge research and a synergy with other academic units.

Coal to Methanol

The project on 'Coal to Methanol' aims to build energy security of the nation using abundantly available coal and richly available renewables (solar and biomass). Research is also underway to add the renewable energy component to capture and utilize the carbon dioxide. The twin objectives of this project on Coal-to-Methanol is to build energy security of the nation using abundantly available coal and richly available renewables (solar and biomass), so that India can free itself from clutches of the crudes oil lobby, while also meeting the deep cuts that we have taken as part of our INLD climate changes commitments. While the focus of the current project is to achieve a technology demonstration on converting the high-ash Indian coal to methanol, there a is plan underway to add the renewable energy component in future, to capture and utilize the balance CO_2, Makes this project a perfect platform for developing India-centric technologies [Figure 1-3].

Figure 1

Figure 2

Micro-Engineered Device Facility

Development of a multi-disciplinary state-of-the-art fabrication and characterization facility called 'Micro-engineered device facility' to provide space and equipment to design, fabricate, characterize, and conduct experiments with microfluidic devices, is in the pipeline. Applications pervade from classical catalyst design to novel materials, providing solutions for clean energy, chemicals, green environment, energy devices, etc. The impact of research depends on the quality of new knowledge based on fundamental mechanistic analysis and on the pace of delivering new technologies to industry.

Figure 3

Multiscale Modelling

Development and implementation of approaches employing multiscale modelling using first-principle approaches in design of new materials and processes has been achieved. Further, highly coarse first-principle models, optimization and analytical techniques for advanced process automation suited for real-time operations have also been developed and implemented.

Figure 4

Waste-to-Wealth

Current issues related to solid waste management have been solved by developing sustainable technologies for the beneficial reuse of wastes as resources and the safe disposal of solid waste streams. A pilot plant having a capacity of 10 kg/h has been successfully installed and operational to process different kinds of waste streams such as e-waste, plastic waste, agro residues, etc. Furthermore, a 1 ton/day plant is proposed for the recovery of precious metals from e-waste under the PSA sponsored research project [Figure 4].

Molecular Discovery

Development of novel techniques for early-stage molecular discovery, identification and characterization of pharmaceutical and biopharmaceutical products is an area of research. Novel in vitro diagnostic assays, studying protein-protein interactions, and correlating drug discovery with orthogonal support to molecular dynamics in understanding drug stability under a single roof can go a long way in shortening the bench-to-market cycle for any biological system. This research is being used for synthesis and elucidation of novel molecules, advanced proteomics, metabolomic research, drug delivery of biologics, vaccines and cancer therapies, studying cell-cell interactions and developing miniaturized biosensors [Figure 5].

Figure 5

Hydrogen Production

In collaboration with the ONGC Energy Centre, successful splitting of water by a process known as Sulphur-Iodine (SI) thermochemical cycle has been accomplished. The main objective of this work is to successfully demonstrate, for the first time in India, an integrated, Sulfur-Iodine (S-I) closed loop process of water splitting for continuous production of the renewable fuel hydrogen using indigenously developed and patented efficient catalysts in the various catalytic reaction sections of the process.

Figure 6

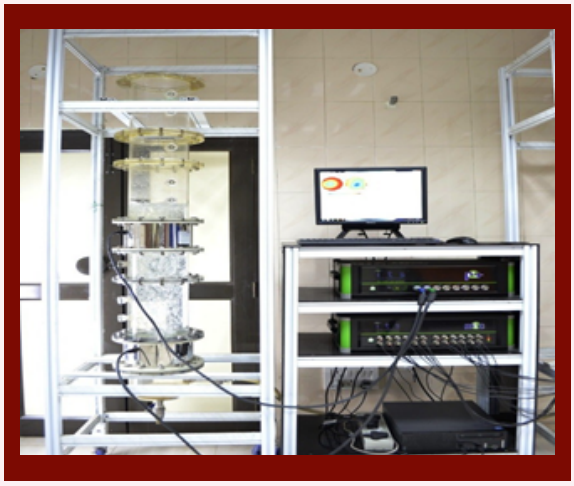


Figure 7

CO_2 Conversion

Cutting-edge research work is ongoing in Electrochemical Engineering Devices such as Flow Battery; Supercapacitors; Solid-state Batteries; Fuel cells; Electrochemical reactors for CO_2 conversion; Battery Management System etc. The primary focus is on fundamental and translational research work on electrochemical devices. A DST-IITD Centre on Energy Storage Platform on Batteries (ESPOB) has also been established {Figure 6].

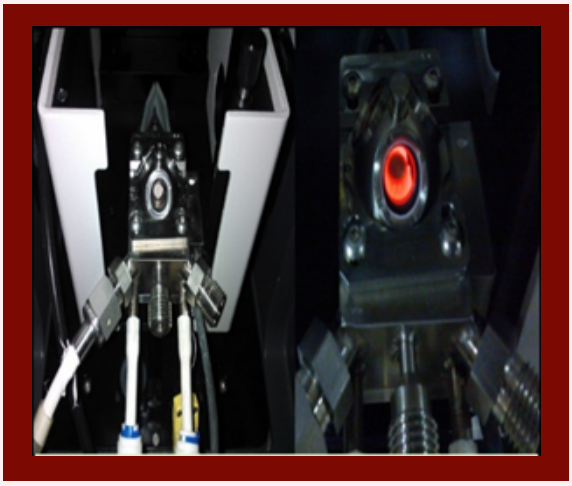


Figure 8

Bioanalytical Characterization

An 'Incubator for Bioanalytical Characterization' has been established under the existing DBT COE for Biopharmaceutical Technology with funding from Agilent Technologies. The incubator aims to establish global best practices in identification and characterization of biopharmaceuticals, examine and report out quality of biotherapeutic products in the Indian market, train researchers from academia and industry on protein characterization, support incubated start-ups at IIT Delhi, and continue to provide critical information to influence policy making to ensure safe and efficacious biotherapeutic products on the Indian market [Figure 7-11].

Figure 9

Figure 10

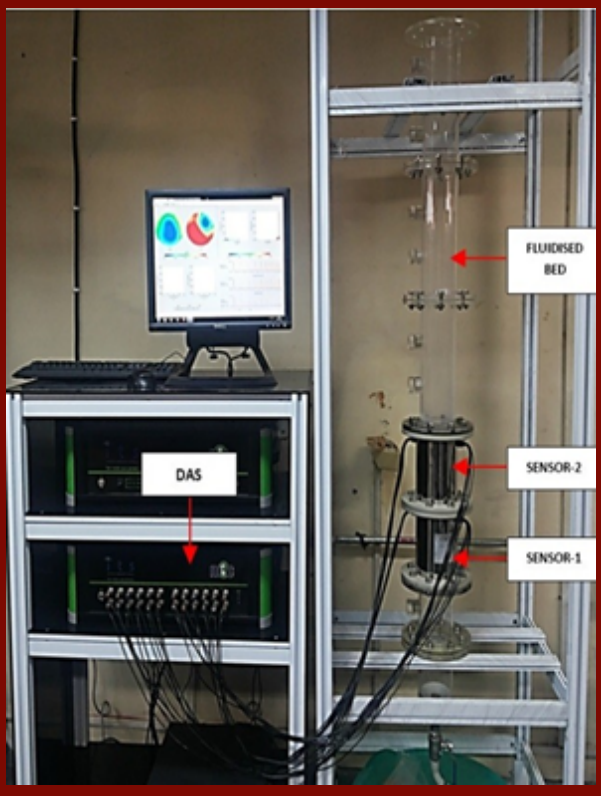


Figure 11

Biotherapeutics

A research group is engaged in implementing 'Continuous Processing towards Manufacturing of Biopharmaceutical Products'. Manufacturing of biotherapeutic products is a key component of the "Make in India" campaign. Continuous processing promises significant increases in productivity and resulting reduction in cost of manufacturing of biotherapeutics. Sponsored by both government agencies (DST, MoE) and industry (Pall Life Sciences, Biocon Limited, Tata Consultancy Services), ready-for-licensing continuous platforms for production in both microbial and mammalian hosts are now ready [Figure 12].

Figure 12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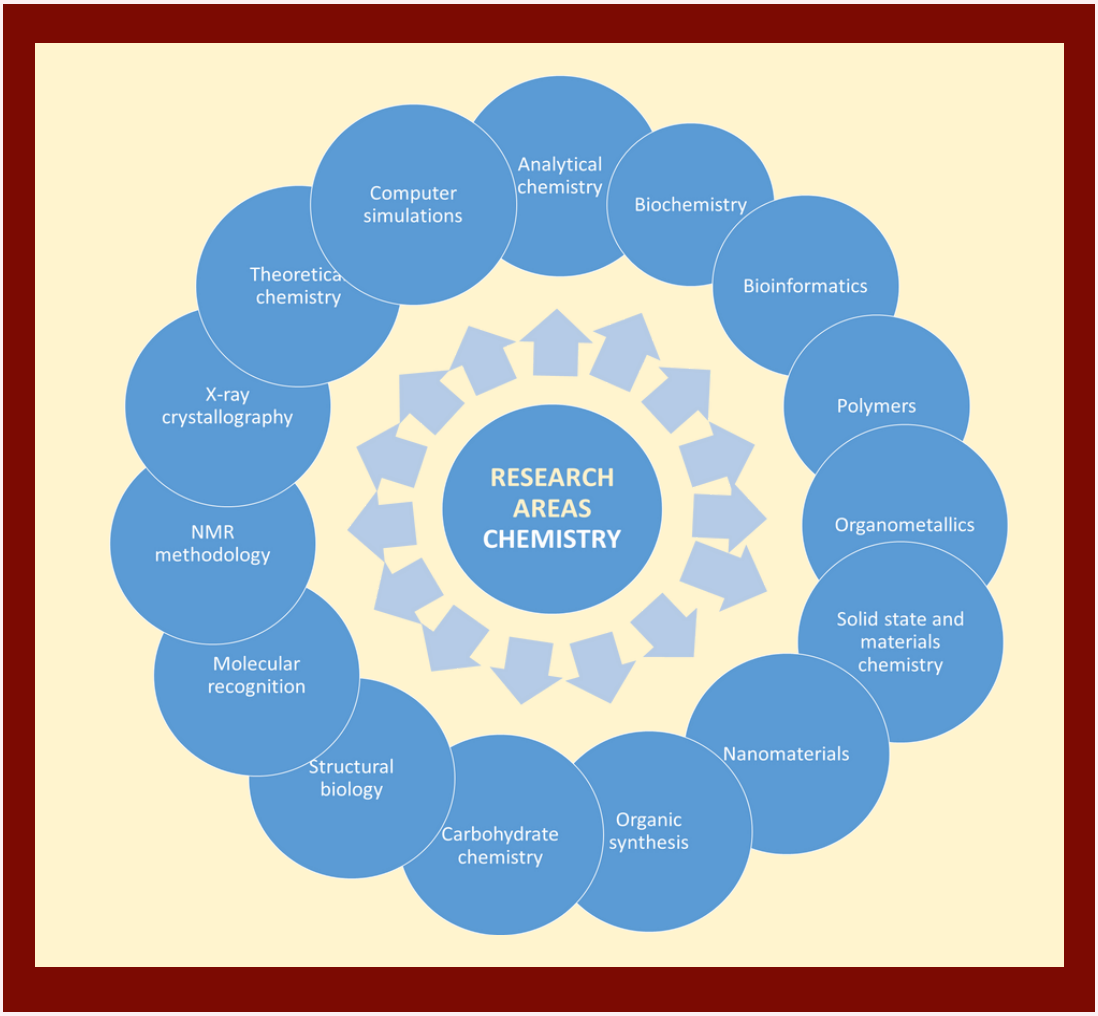
CHEMISTRY


RESEARCH AREAS CHEMISTRY
Analytical chemistry
Biochemistry
Bioinformatics
Polymers
Organometallics
Solid state and materials chemistry
Nanomaterials
Organic synthesis
Carbohydrate chemistry
Structural biology
Molecular recognition
NMR methodology
X-ray crystallography
Theoretical chemistry
Computer simulations

The Department of Chemistry was established in the year 1963. Research is carried out in all major areas of chemical and allied sciences. The Departmental faculty are experts from renowned Institutes in India and abroad, attract significant financial support for their research activities from both government and private agencies. Many faculty members of the department are fellows of prestigious scientific academies and have earned recognitions of distinction in their respective areas of research. The faculty members are active in organizing scientific meetings from time to time, and they deliver invited lectures at prestigious national and international conferences and symposia.

Table Salt as Catalyst

In a novel method, organic alcohols and diols are converted into monocarboxylic acids and dicarboxylic acids in an environment-friendly and inexpensive manner. The method uses table salt as a catalyst in aqueous medium [Figure 1], Products are important bulk chemicals for the pharmaceutical, fine chemical and polymer industries. The group further extended the work for the highly enantioselective olefination of methyl substituted N-heteroarenes with benzyl amines and alcohols. They showed that this method can be used for the green synthesis of a few pharmaceutically relevant conjugated olefins based on N-heteroarenes.

Figure 1

Nano-Electrocatalysts for Water Splitting

Electrocatalysts for electrocatalytic water splitting emphasizing on HER, Oxygen Evolution Reaction (OER), and Overall Water Splitting (OWS) studies are being explored, albeit using copper through the design of bifunctional copper catalysts. The group is currently fabricating several nanostructured materials for electrocatalytic water splitting and CO_2 reduction studies [Figure 2].

Figure 2

Robust Electrolyzers

Efficient and durable electrolyzers have been developed for green hydrogen production at a large scale. Such technologies which can convert renewably generated electricity into other forms of energy, such as fuels, heat, are crucial to decarbonize the transport sector, chemical and steel industries and make the world climate-neutral by 2050. The electrolyzer consists of nanostructures made of molybdenum (Mo) carbides, nitrides, sulphides and phosphides and their composites with conducting carbon i.e. reduced graphene oxide (rGO). It is an efficient, low-cost, non-corrosive, green technology for hydrogen production from water. The better efficiency of these structures in the hydrogen evolution reaction (HER) is attributed to the development of heterojunctions between the sulphides and nitrides of molybdenum. At the heterojunctions, the Mo centres were coordinated with both S and N. This is because, the hetero anions contribute not only the electronic effects, but also to the hydrogen binding, as demonstrated by DFT calculations. Besides, graphene also enhances the electrical conductivity and the electrochemical stability of Mo-based compounds during catalysis. The graphene layer has been shown to block direct interactions between the active electrocatalyst and electrolyte. This only leaves the protons on the catalysts surface for undergoing reduction in HER [Figure 3].

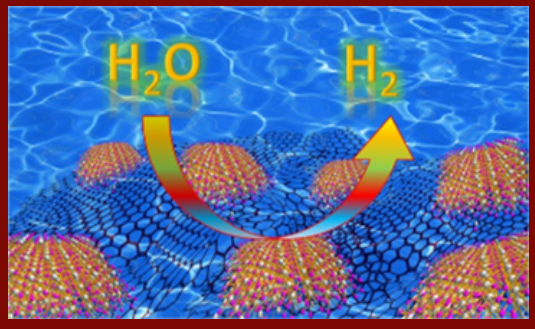


Figure 3

Physico-Chemical Fingerprinting of RNA genes

Utilizing physico-chemical property of DNA sequences, 7.6 million RNA genes comprising ~ 7.3 million mRNA genes (magenta, circle), 255524 tRNA genes (cyan, star), 5250 mi RNA (green, pentagon), 3747 snRNA (blue, square), 13997 16S rRNA (brown, diamond), 13745 23S rRNA (purple, triangle), and 12907 5S rRNA (orange, cross) have been characterized [Figure 4].

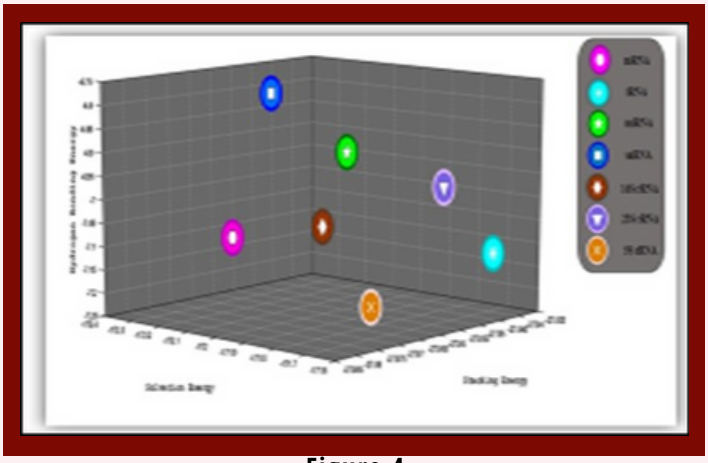


Figure 4

Intron-Exon Boundaries

Utilizing physico-chemical property of DNA sequences, the research group has successfully characterized the Intron-Exon boundaries in the human genome, an otherwise difficult task for conventional statistical, mathematical, and bioinformatics tools [Figure 5]. Additionally, the group has also worked on detecting intron-exon boundaries in eukaryotic genomes which is challenging for the conventional statistical, mathematical and bioinformatics tools.

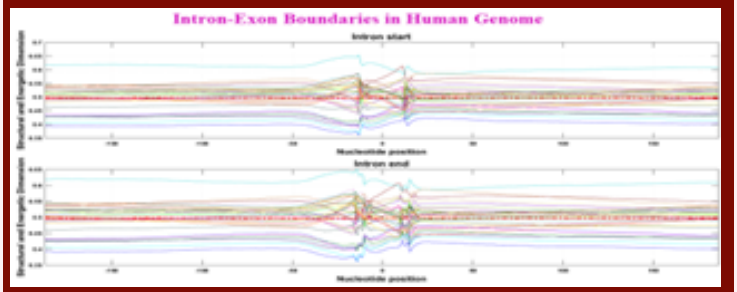


Figure 5

Dhanvantari Pipeline

Further, in a first-of-its-kind, a comprehensive Genome-to-Drug computational pipeline known as the 'Dhanvantari' has been developed, to incorporate novel scientific methods and highly efficient algorithms along which combines the principles of chemistry, biology and Information Technology for targeted drug designing. The pipeline covers all aspects from genome through genes, proteins, active site to a lead molecule. The pipeline is being tested for viral genomes and the average estimated time is 3 h starting from a viral genome to potential lead molecules for the control of the virus. Automation at every step facilitates the naive users to use the pipeline with set default parameters, which would render scientifically significant output in most of the disease cases. Also, the users are allowed to tweak the parameter sets in the pipeline as per their respective requirements. In short, the pipeline bridges the gap between an unknown disease to its potential treatment [Figure 6].

Figure 6

Homegenous and Heterogenous Catalysis

Amino acid-functionalized metal-organic frameworks (MOFs) for sustainable asymmetric catalysis based on earth-abundant metals, such as Iron, have been developed. The MOFs provide safe, environment-friendly, highly active and economic heterogenous catalysts for the production of pharmaceutically important, optically active compounds - the Active Pharmaceutical Ingredient (API) in a drug, also known as chiral APIs, are essential building blocks in the production of pharmaceuticals, agrochemicals and biologically active molecules due to the increasingly strict safety, quality and environmental requirements of bulk scale synthesis, the development of highly active and enantioselective heterogeneous catalysts based on earth-abundant metals and inexpensive chiral feedstock in the pharmaceutical and chemical industries for environment-friendly and economical production of optically active compounds. The amino acid-functionalized MOF based catalyst addresses these issues and offers a sustainable solution for these asymmetric organic transformations. Constructed from metal-cluster secondary building units and organic bridging linkers, MOFs provide a unique platform for the simple preparation of single-site chiral catalysts via site-isolation owing to their porous and crystalline nature as well as modular and tunable properties [Figure 7]. A chemoselective, heterogeneous earth-abundant, reusable, single-site nickel(II) hydride metal catalyst essential for environment-friendly chemical synthesis has also been developed. These catalysts are highly efficient, specific and reusable and robust catalysts fabricated from porous aluminum metal-organic frameworks (DUT-5). The DUT-5 catalysts are used for hydrogenation of nitro and nitrile compounds to the corresponding amines and hydrogenolysis of aryl ethers under mild conditions. DUT-5-NiH is also an active catalyst for chemoselective hydrogenolysis in the production of hydrocarbons under atmospheric hydrogen in absence of any base, which is important for the generation of fuels from biomass [Figure 8].

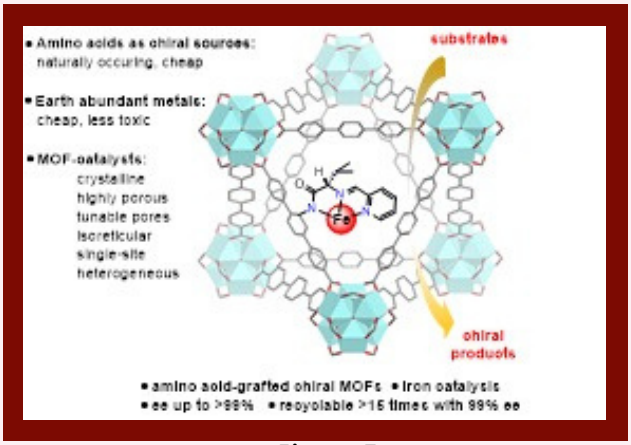


Figure 7

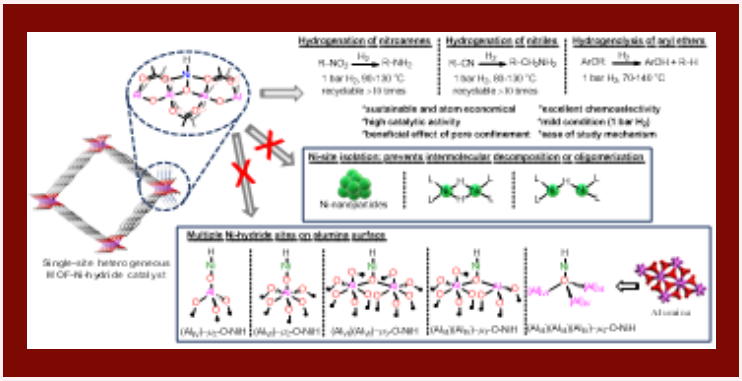


Figure 8

Germylenes

The first air, water, and culture-medium stable germylene (DPMGeOH) was isolated and its first biological application also demonstrated. Germylenes or Germacarbonyl compounds are inorganic compounds with germanium atoms in a formal +2 oxidation state that are the germanium analogues of carbonyl compounds [Figure 9]. They are unstable in air and water, need inert conditions for their existence, and are challenging to isolate . Hence, their chlorides, esters or amides are unknown. These factors limit their applications in biological systems. A dipyrrinate ligand framework developed through research , however offers stability to these compounds. Using donor-acceptor stabilization, germaacid chloride, germaester and N-germaacyl pyrrole have now been isolated by the group. The application of germylenes in biological systems has been shown through a collaboration with IIT Delhi's Kusuma School of Biological Sciences. When tested on human cancer cell lines HeLa, MCF7, and Huh7; its effects on HeLa cells were found to be comparable to the currently used anticancer drug cisplatin and marginally better on MCF7 and Huh7 cell lines. Its cytotoxicity on normal epithelial cells (Vero cells derived from a healthy African monkey) is comparable or marginally lower than that of cisplatin [Figure 10]. This has laid the foundations for biogermylene chemistry and broadly for bio low-valent main-group chemistry.

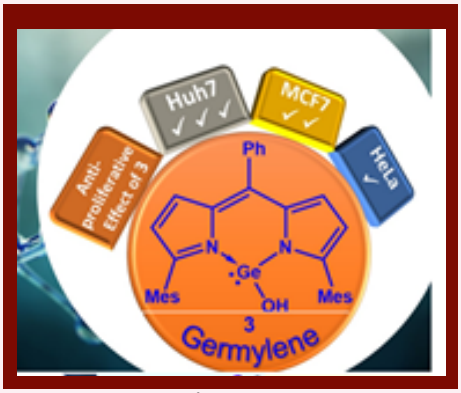


Figure 9

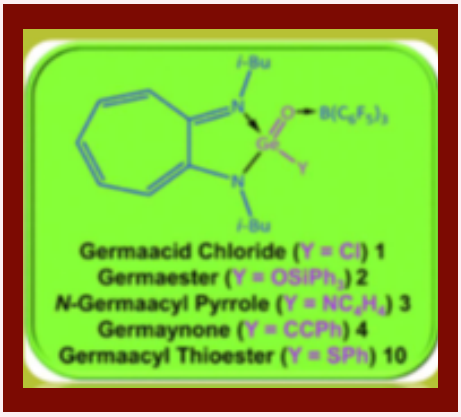


Figure 10

Organic Synthesis

Development of strategies for direct functionalization of C-H bonds in heterocycles and small organic molecules has been a focus area of research and efficient methods for constructing C-C, C-N and C-S bonds through copper and palladium catalyzed direct C-H activation as well as chelation assisted approaches have been demonstrated [Figure 11]. Regioselective alkylation, acylation, thioalkylation and amination of biologically potent molecules has been achieved under relatively mild conditions using non-toxic components. Another focus area is photoredox chemistry that has unique and empowering features, and recently a multicomponent reaction in visible light for construction of quaternary carbon centres has been demonstrated. Innovative metal-free synthetic methods using hypervalent iodine reagents are also underway that offer solutions through new bond disconnections to the challenges faced by medicinal chemists.

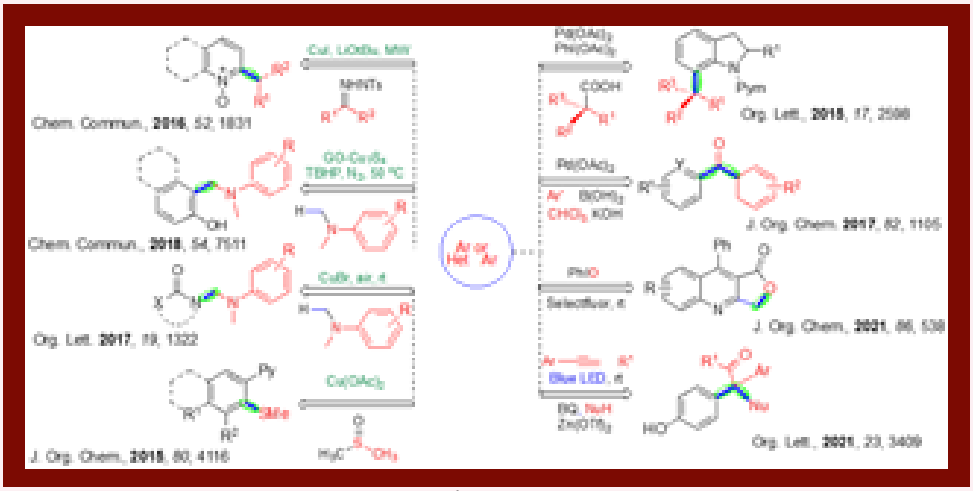


Figure 11

Inhibitors for Fibril Formation

Inhibitors for the protein fibril formation responsible for Amyotrophic Lateral Sclerosis (ALS), a lethal neurodegenerative disease characterized by the progressive death of motor neurons of the motor cortex, brainstem and spinal cord have been developed. Deposition of amyloid of superoxide dismutase (SOD1) is a pathological hallmark of ALS. Using various biophysical techniques, the group has demonstrated that curcumin, inhibited the in vitro fibrillation of SOD1. Moreover, quercetin and baicalein not only inhibited fibrillation but also destabilized the existing fibrils by fragmenting them into shorter fibrils. They have also established that intermolecular disulfide bonds or intramolecular disulfide shuffling are not required for aggregation and SOD1 fibril. The potential of another polyphenol, Scutellarin, as an inhibitor for fibril formation has also been shown with fibrils of α-synuclein, associated with Parkinson's disease [Figure 12]. The group is further working on the targeted delivery and controlled release of potential fibril inhibitors.

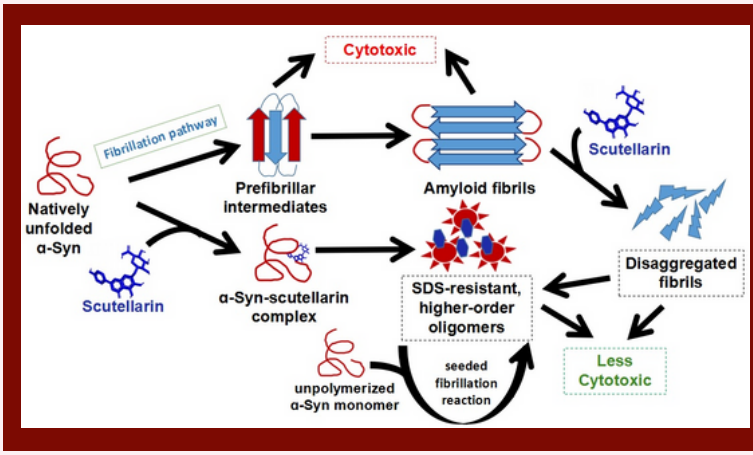


Figure 12

Transforming Growth Factor-β Ligands

With respect to the diversity and interaction with receptors of the Transforming growth Factor-β ligands, it was found that TGF-β1 and TGF-β3 interact with receptor II with high affinity, whereas TGF-β2 binds TβR-II with low affinity [Figure 13]. Despite the similarity between TGF- β1 and TGF- β3 in their sequences and structural homology as well as the fact that they both interact with the same receptors with high affinity, some functional differences are reported suggesting that they may not be fully redundant. At the origin of this difference is the H3-helix. Its sequence and degree of structuration seem to govern the outcome of TGF dimerization. Binding studies are being carried out between TGFβ3 and (wild type) using isothermal titration calorimetry (ITC).

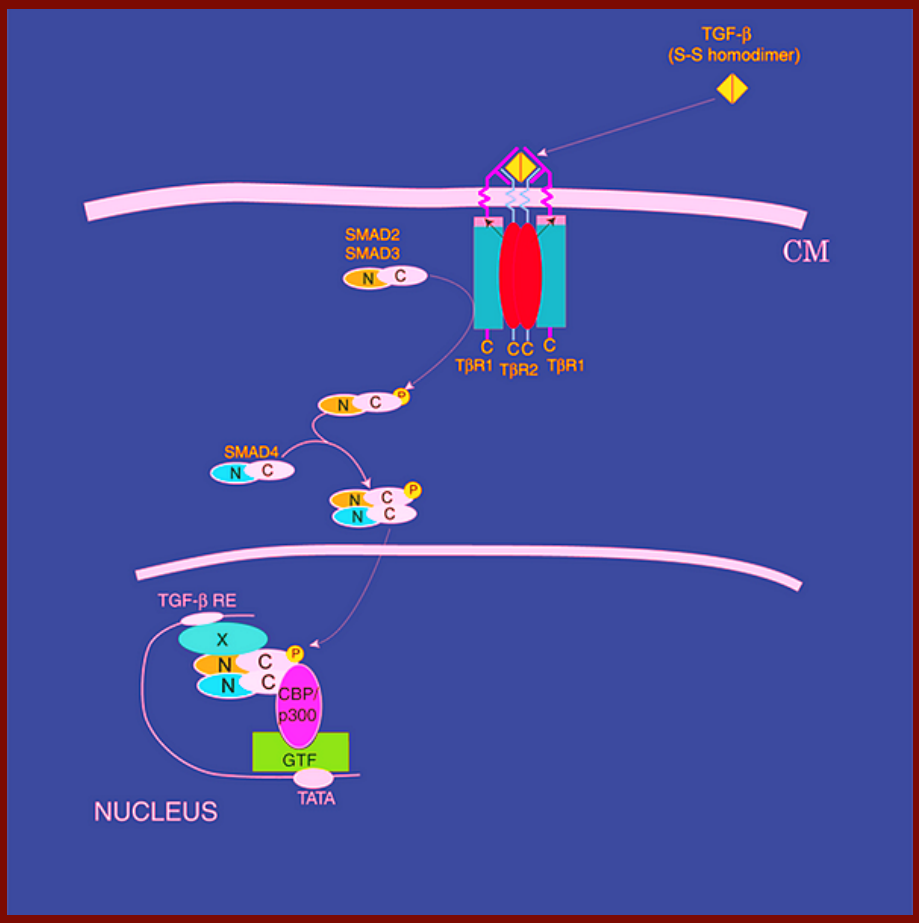


Figure 13

Figure 14

Redox Cycling Catalysis

Researchers in the Main Group Organometallic Lab are investigating the use of main-group compounds in redox-cycling catalysis and small molecule activation has resulted in pincer ligand supported compounds of group 15 elements (P, Sb, Bi). The work is significant considering the fact that promising stoichiometric and catalytic transformations, redox-cycling catalysts based on main-group elements are extremely rare. The group's finding that pincer type ligand-supported geometry constrained main-group compounds are capable of acting as redox catalysts similar to those of the transition metals will address the need of main group element-based redox catalysts that can function at par with transition-element based catalysts [Figure 14].

Enzymatic Nanoflowers for Drug Delivery

Transglutaminase nanoflowers as Doxorubicin/anti-miR210 cargos for site-specific release in cancer cell lines are seen through confocal laser scanning fluorescence microscopic in a work done with the Department of Biochemical Engg. & Biotechnol., IIT Delhi. These protein nanoflowers were developed by the Enzyme and Microbial Biochemistry research group. These protein nanostructures are called flowers because of their nano-dimensions and floral architecture. These floral molecules possess a high surface area and cage-like cavity, enabling high drug loading capacity and effective targeted release. Cytotoxicity was evaluated using MTT assay; these nanoflowers showed no cytotoxic effect on normal cells. The enzymatic nanoflowers potentiate the possibility of targeted delivery of high drug cargoes, which is being investigated in mice models in collaboration with NII. The process of developing these nanoflowers as cargo (heavy metals/drugs) delivery vehicles has been patented by the group in the year 2020. The porous petals represent the cargo loading pockets [Figure 15]. Confocal fluorescent images of glioblastoma cancer cell lines show cellular uptake of drugs facilitated by transglutaminase nanoflowers in Figure 16.

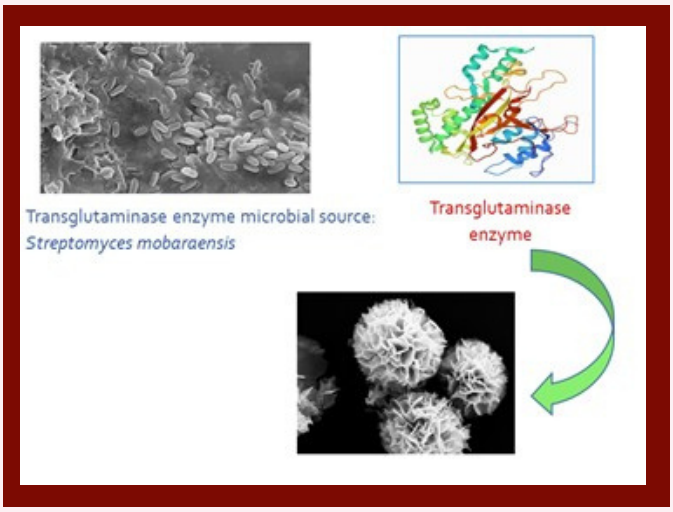


Figure 15

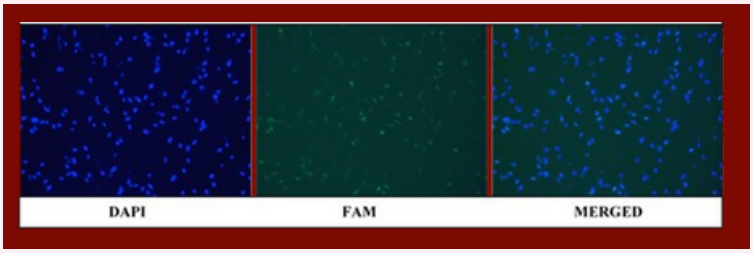


Figure 16

Mechanism of Protein Aggregation

Findings that have merged with respect to the mechanism of protein aggregation are that modulation of solution conditions is crucial for inducing protein aggregation, use of guanidinium hydrochloride (GdnHCl) as an additive in the solution can delay and alter the inherent aggregation pathway of bovine serum albumin (BSA) from a downhill polymerization to a nucleated polymerization, glycerol has the potential to transform the secondary pathway of aggregation of insulin from fragmentation to heterogeneous nucleation in a concentration dependent manner. Further, salt ions alter the monophasic aggregation kinetics of HCA II to biphasic at 328 K., mannitol affects rate of nucleation whereas sucrose and ethylene glycol affect both the rate of nucleation and as well as the elongation of insulin, trehalose stabilizes the protein by interacting by encompassing flexible polar residues on the protein surface and also has a tendency to bind to acidic residues in the protein. It delays the aggregation process of prion peptides. α-synuclein coincubated with trehalose fibrillates faster than in its absence. Molecular dynamics simulations suggested that this initial acceleration is a manifestation of trehalose's tendency to perturb the conformational transitions between different conformers of monomeric protein.

Stabilization of p-Block Element Radicals

The utility of carbene ligands for the isolation of main-group radicals by tapping the dual nature of the cyclic (alkyl)(amino)carbenes (cAACs) as a promising tool for the isolation of main-group radicals is being explored. This is due to the nitrogen and carbon attached to the carbene center in cAACs that have better sigma-donor and pi-electron accepting properties than conventional NHCs. This is because the empty p-orbital of cAACs can engage in pi-back bonding interactions and delocalize the electron density and, at the same time stabilize an electron-deficient centre by sigma-donation.

Phosphinidine Chemistry

Phosphinidenes are the phosphorus analogs of carbenes and nitrenes, having the general structure R-P (where the phosphorus atom is in +1 oxidation state and has two active lone pairs). Phosphinidenes have shown their potential as very strong sigma donor ligands like N-heterocyclic carbenes (NHCs) are also capable of binding two metal centers simultaneously because of their two available lone pairs of electrons. Using phosphinidene as a ligand to stabilize unusual metal complexes and utilize them as catalysts in various organic transformations is another area of research. Besides, the magnetic properties of lanthanide-phosphinidene hybrid materials are being investigated.

Thermostable Laccases

Laccases have emerged as environment-friendly multifaceted biocatalysts for diverse biotechnological applications. They have successfully shown the application of a laccase purified from *Brevibacillus agri*, isolated from Sohna Hotspring Gurugram. in the bleaching of denim at a much higher efficiency than well-known chemical methods Reflectance spectrums of denims treated at pH 4.0 and pictures of denim with or without laccase treatment are shown in Figure 17.

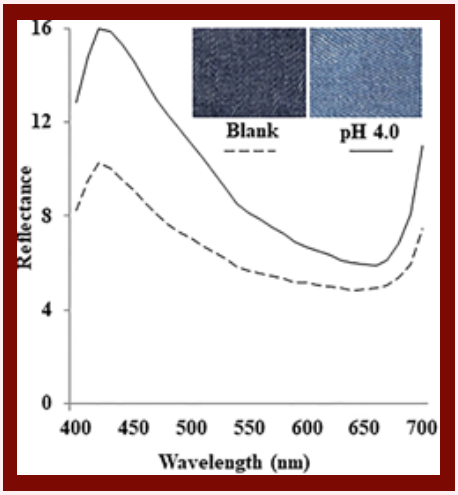


Figure 17

RNase-mediated Regulation of Bacterial Toxin: Antitoxin system

Research on the SraC/SdsR (RyeA/RyeB) toxin/antitoxin (A/T) system predominantly present in *Escherichia coli* and *Salmonella* sp revealed that in the stationary phase or stress conditions SraC normalizes accumulation of SdsR toxin by acting as an RNA sponge. Systematic investigations further revealed that the SraC expression is regulated neither by RpoS (σS) nor by RNA chaperon Hfq. Instead a dual function ribonuclease RNase BN/Z mitigates its expression in the exponential phase. Deletion of rbn gene promoted the stability of SraC in the exponential phase. Conversely, SdsR in the stationary phase acts as an RNA decoy leading to SraC degradation. Consequently, the preclusion of SdsR in the E. coli genome elevated SraC. RpoS-independent induction of SraC at low pH essentially normalizes the toxic SdsR accumulation in the cell. The group further investigated the mechanism of SraC induction at low pH and found that RNase BN/Z, which catabolizes SraC in the exponential phase, is highly sensitive to low pH. Both mRNA and the protein levels of RNase BN transcribed, decreased to <10% of their initial population. They concluded that the expression of SraC under acid stress is regulated by a feed-forward mechanism to normalize the SdsR profusion [Figure 18].

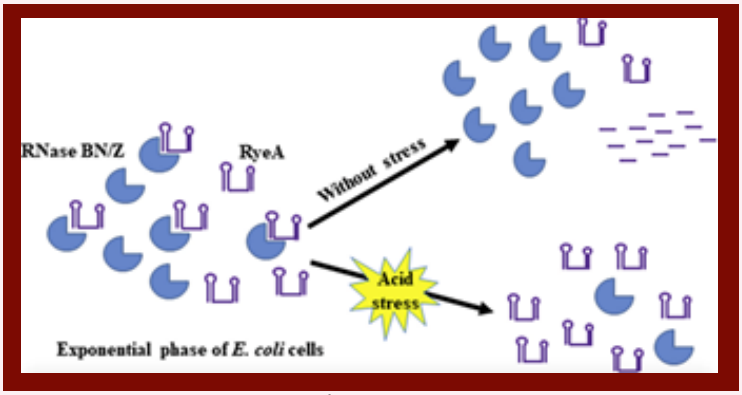
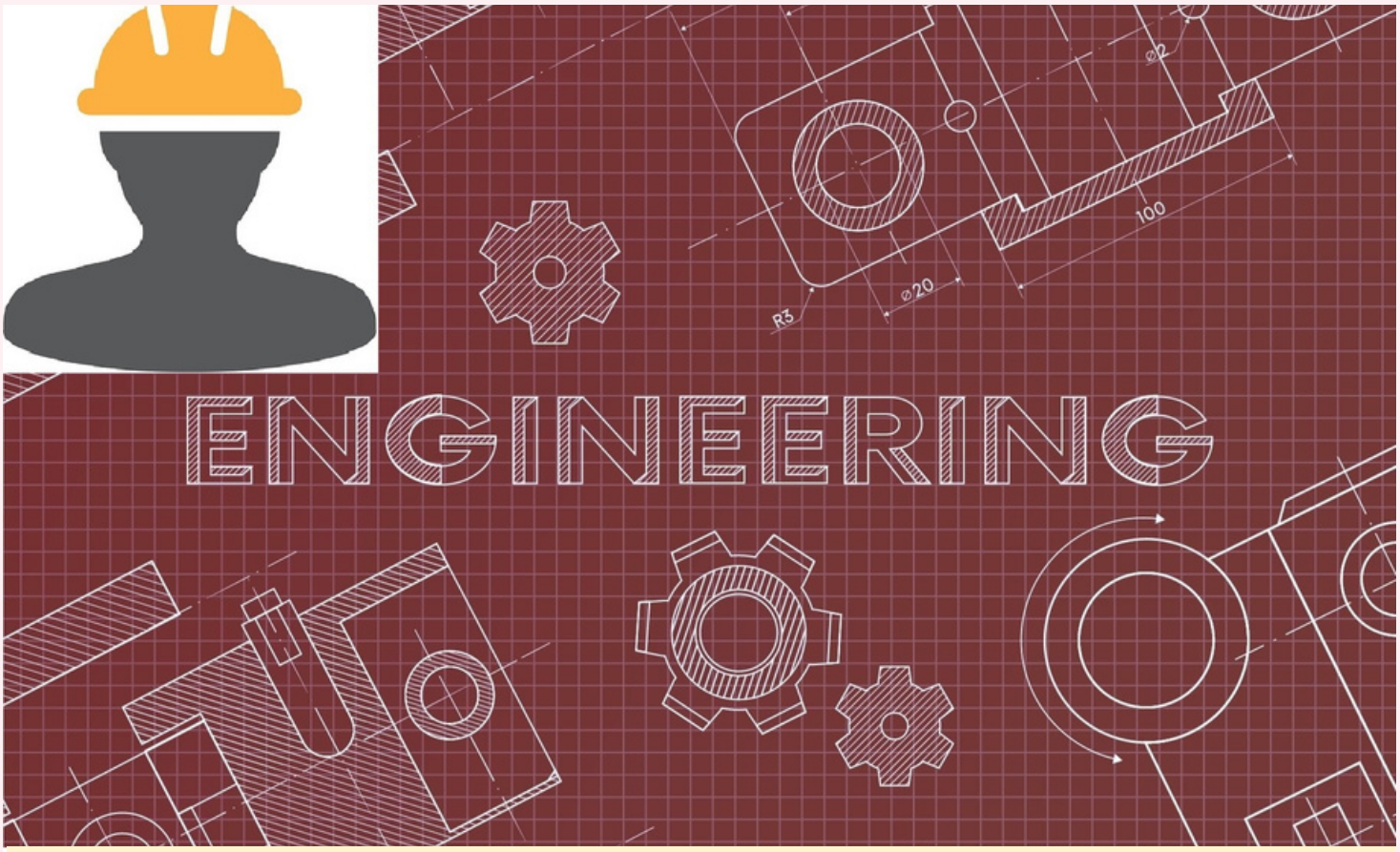


Figure 18



CIVIL ENGINEERING

RESEARCH AREAS

- Geoenvironmental Engineering
- Waste Management
- Disaster Prevention & Mitigation
- Urban Development
- Construction Materials
- Structure evaluation
- Modelling
- Transport
- Remote sensing and GIS
- Policy Analysis and Risk Assessment
- Water Resources Systems
- Air Pollution

The Department of Civil Engineering was established in the year 1961 at the Institute. The department is engaged in cutting-edge inter-disciplinary research in the realm of Infrastructure and Built Environment. It seeks to improve and maintain the quality of human life by adopting safe and sustainable technologies.

Sustainable Urban Infrastructure

Limestone Calcined Clay Cement (LC3) is a low carbon, innovative ternary cement, developed in three phases, that incorporates materials such as calcined clay and limestone to replace a large proportion of the energy-intensive and the more expensive, clinker. The synergic effect of these materials allows for a reduction in the clinker requirement by more than 50%, leading to significant savings in CO_2 emissions and costs. Composition and benefits of OPC and LC3 are summarized in Figure 1. CO_2 Saving: LC3 saves up to 40% of CO_2 as compared to Ordinary Portland Cement (OPC). This is significant since the production of cement alone contributes to 7% to 8% of global anthropogenic CO_2 emissions. Low-cost raw materials: LC3 can utilize low-grade waste materials like rejected kaolinitic clay, low-grade limestone which is usually rejected by the industry, stone wastes, etc. Improved Performance: Despite the low clinker content, the mechanical properties of the cement are at par with OPC and the cement has shown better durability in most environmental conditions. IIT Delhi has contributed to a major part of the research and development of LC3 in collaboration with EPFL Switzerland, CIDEM Cuba, IIT Madras and TARA. The seed fund was provided by SDC and later developments could be accomplished with industrial support. Despite being a relatively new product, LC3 is in demand in the market in many countries. Various outreach activities undertaken by the research group and their collaborators such as international conferences, workshops, the establishment of pilot production plants in many cement companies, etc. have helped disseminate knowledge about the product. As a result, this cement has become one of the most researched subjects in Sustainable Urban Infrastructure development now. The cement is not only an economical and sustainable solution for developing countries but promises to be a high-performance material of the future for the developed world also.

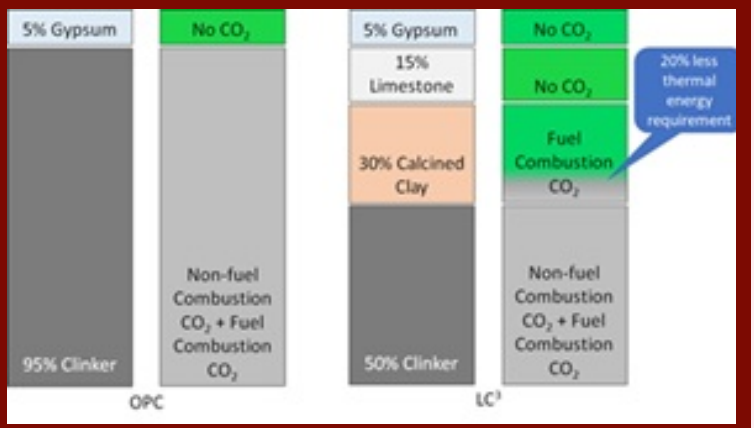


Figure 1

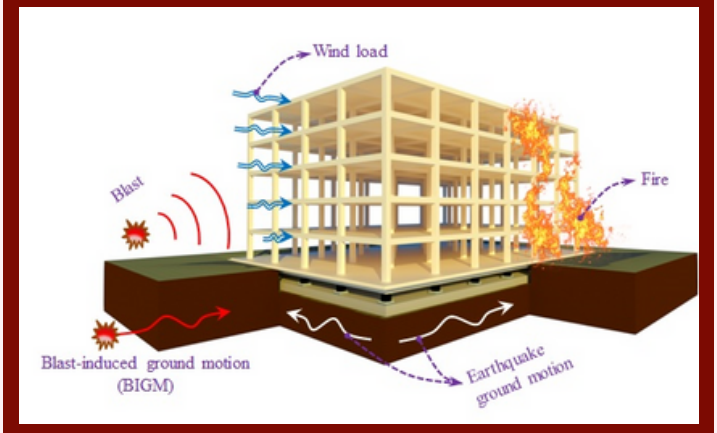
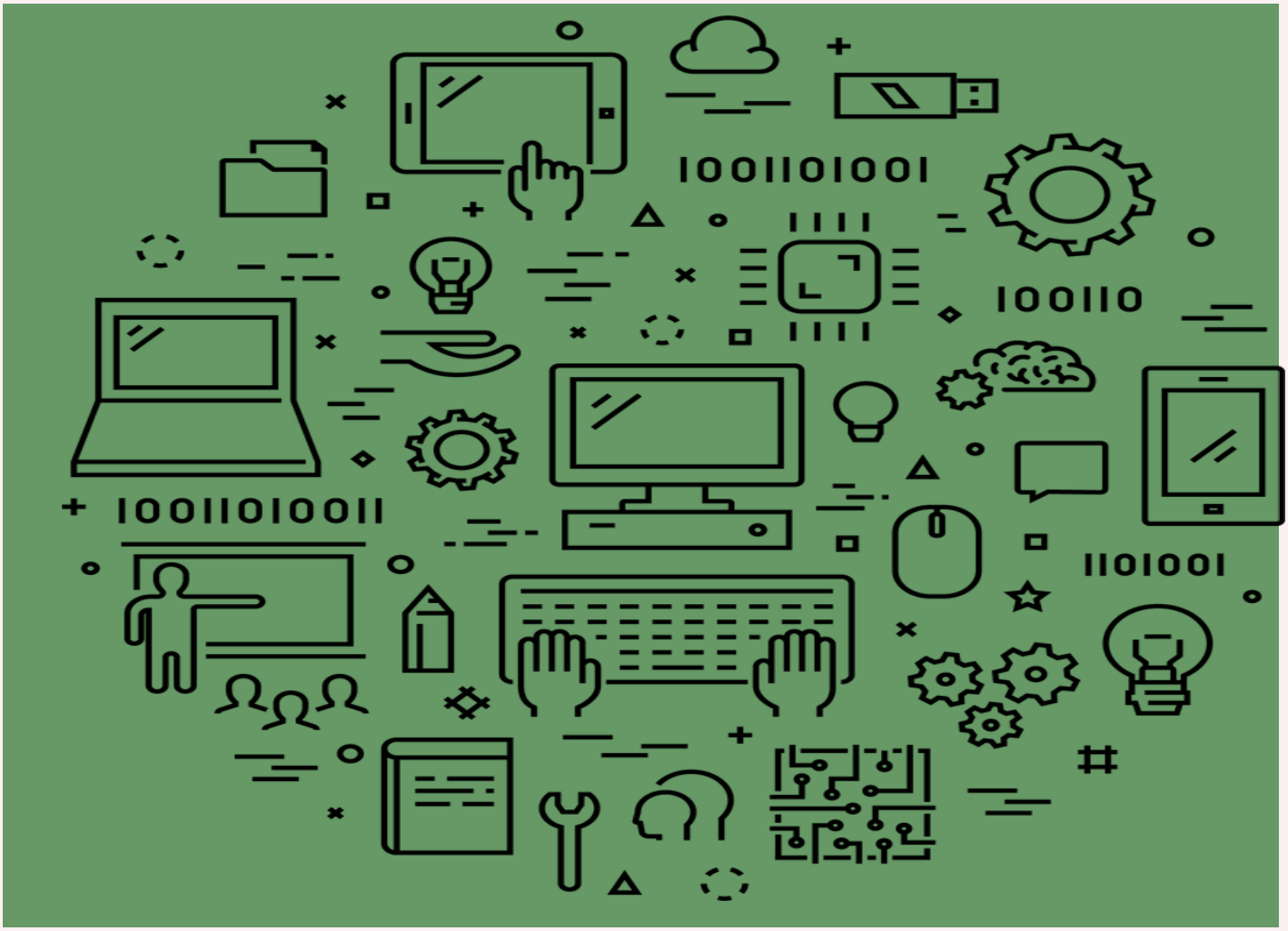


Figure 2

Protection Systems Against Multiple Hazards

In the Geohazards and Mitigation Technologies category, Professor Vasant Matsagar's research group focuses on developing technologies to protect communities against various natural, accidental or man-made hazards such as earthquakes, windstorms, blasts or fire events. To this end, the group has developed advanced engineered materials and structural systems equipped with new devices and high-fidelity computational models. Breaking convention, the group works to mitigate multiple hazards through their design philosophy creating more holistic structures that are resilient under a diverse set of environments. A model of structures resilient under multiple hazards is shown in [Figure 2]. In the new generation smart cities and towns, the built infrastructure is required to be designed such that not only life safety of the community is to be assured but also the civil life needs to remain unaffected. Presently, after any calamity hits a locality, disruption in the civic life is caused, inflicting economy and property loss. The present research efforts by the research group are geared towards developing technologies to make multiple-hazard resilient community.



COMPUTER SCIENCE AND ENGINEERING

RESEARCH AREAS

- Algorithms and Complexity Theory
- Artificial Intelligence (AI) and Machine Learning (ML)
- Natural Language Processing (NLP)
- Databases and Data Analytics
- Architecture and Embedded Systems
- Graphics and Vision
- Computer Networks and Distributed Systems
- Programming Languages, Semantics and Verification
- Operating Systems, High Performance Computing and Systems Software

Virtual Tours of Digital Heritage Sites

3D recreation of heritage sites with present technology offers a powerful tool to communicate archeological features and cultural knowledge to an expert and to an amateur, alike. Advances in the field of virtual reality over the years have enabled the coupling of 3D digital recreation and visualization with an effective and immersive interactive communication. It offers additional degree of freedom beyond the mere presentation of static visualizations. It can allow real time interaction with the environment and give users a sense of immersive experience. A user interaction interface using both 3D printed models and virtual models is shown in Figure 1. Techniques have been developed and implemented for demonstrable interactive applications with in-built 3D recreations and reconstructions of a digital heritage site for use in public spaces offering in collaboration with other partner institutes of the Indian Digital Heritage project. An application developed for the Vittala Temple Complex, Hampi, a UNESCO declared heritage site, different modalities of acquisition of data have been used to help in the processing of 3D recreation. Acquisition was done by physically visiting the site several times. Subsequently, the group has given ways to combine different modalities for the purpose of 3D reconstruction of the site of interest, including single view reconstruction, multi view reconstruction, and multimodal reconstruction using depth cameras. One of the main outcomes from the project was to offer techniques and tools to design walkthrough which are useful for performing virtual tours. To this end, tools that provide real time interaction and the exploration of the recreated 3D models have been developed. In addition, a unique interface mixing real (physical) models and virtual models have been developed to give a sense of immersion and a novel method of exploration with physical models augmented by virtual models. In addition, they provide specialized rendering of artifacts, which helps in enhancing aspects relevant for artistic and non-photorealistic rendering. A view of the Hampi reconstruction as unorganised point cloud data has been shown in Figure 2.

Figure 2

Neurosurgery Simulation

Neurosurgical procedures involve minimally invasive endoscopic or microscopic approaches, which require highly specialized skills like grasping, cutting, dissecting and dilating using delicate instruments. A Collaborative Neuro-Engineering platform for Excellence in Innovation and Translational Research in Neurosurgery Simulation is being developed to handle the complexity of neurosurgical procedures and constraints of present education demand for alternative methods of training [Figure 3]. A simulation-based neurosurgery training programme would help trainee neurosurgeons to learn in a controlled environment, and automate the process of evaluation of their acquired skills. In particular, virtual reality simulations, when combined with advanced imaging technologies such as magnetic resonance imaging (MRI), can enable realistic rehearsal of an individual patient's surgical procedures prior to actual surgery. The project aims to develop electro-mechanical physical simulators and 3D graphics haptic-based virtual reality simulators for training for minimally invasive neurosurgery to provide unsupervised computerized evaluation of surgical skills and provide feedback to trainee neurosurgeons to improve their performance.

Figure 1

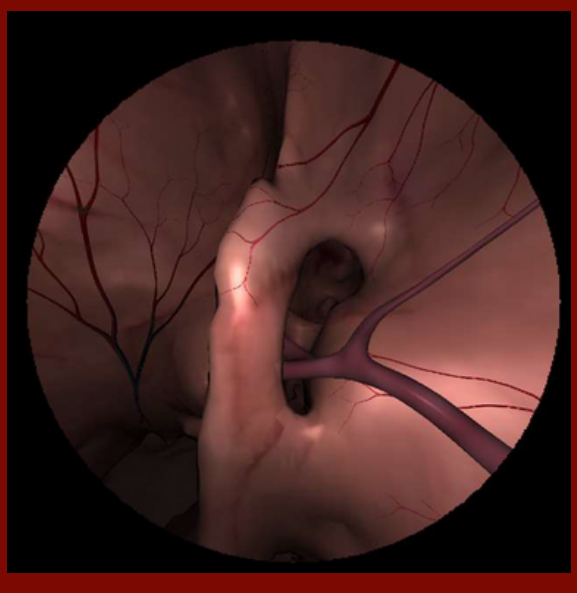


Figure 3

Neurosurgery Simulation (Contd...)

To this end, the team has developed novel algorithms to automatically locate and track the medical instruments inside the narrow anatomical cavities, using a deep convolutional neural network (CNN) algorithm which combines both spatial and temporal cues from the surgery video [Figure 4]. The team has also developed a vision-based multi-stage model to evaluate the effectualness of the micro-suturing and micro-drilling based on the effectual image only. On the simulation side, the team is developing virtual models of brain, skull, ventricular region, and vasculature, as well as of tools including microscopic and endoscopic neurosurgery instruments, for use in a virtual neurosurgical simulation. In addition, they are creating a software simulation framework to integrate all models and provide realistic rendering and haptic feedback, with in-house software including newly developed algorithms for vasculature simulation, surface collision, parallel FEM computation and position/path estimation.

Simulation of Virtual Garments

Simulation of virtual garments is an essential task in computer graphics applications, and is also growing in importance as a pre-visualization tool in apparel design and e-commerce. Fabric, being a composed of numerous yarn threads woven or knitted together, can exhibit a wide array of behaviours such as highly variable stretchiness, anisotropy, area-preservation effects, etc. Simulating woven and knitted materials as a collection of interacting threads can accurately reproduce highly complex behaviours, but this direct strategy tends to be extremely computationally expensive. On the other hand, continuum-based cloth simulations are relatively computationally efficient, but, choosing a suitable material model is a nontrivial task, and little is known about the continuum behaviour of many woven and knitted fabrics in particular. The realism of the technique was further improved by adding yarn-level deformations to mesh-based cloth simulation. After precomputing the behaviours of a periodic yarn pattern based on the largescale deformation of the underlying cloth, these deformed yarn patterns are interpolated at runtime based on the deformation state of the cloth mesh, resulting in richly detailed yarn-level geometry, which rearranges in accordance with yarn-level mechanics in real-time. The method is lightweight and GPU-parallelizable, and can animate millions of yarn vertices at real-time rates. An underlying cloth mesh is used to animate yarn-level cloth in real-time by approximating the yarn-level response in a data-driven fashion based on the deformation of the mesh [Figure 5]. In collaboration with the Institute of Science and Technology Austria a technique to determine material properties directly from yarn-level geometry using numerical homogenization has been developed. The effective material response is precomputed from periodic yarn level simulations after which, an approximate material model is learned from the resulting data and can

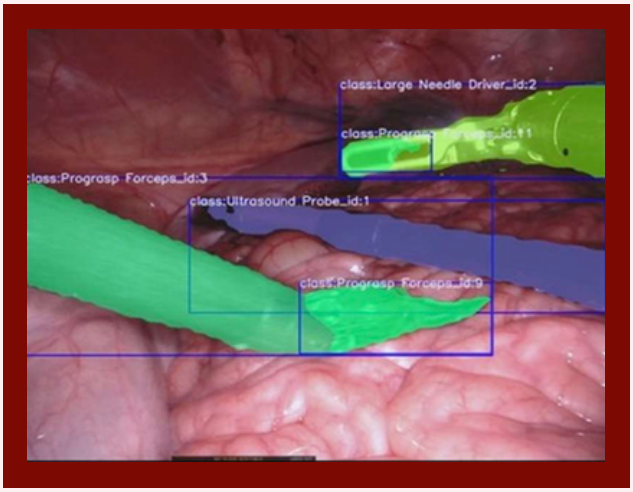


Figure 4

Simulation of Virtual Garments (Contd...)

be incorporated into an off-the-shelf cloth simulator. This work provides the first use of numerical homogenization for animating woven and knitted fabrics, and introduces novel co-rotated periodic boundary conditions for the non-linear homogenization of thin shells, as well as a procedure for fitting a material model capable of reproducing common textile phenomena such as anisotropy, area preservation, and curling.

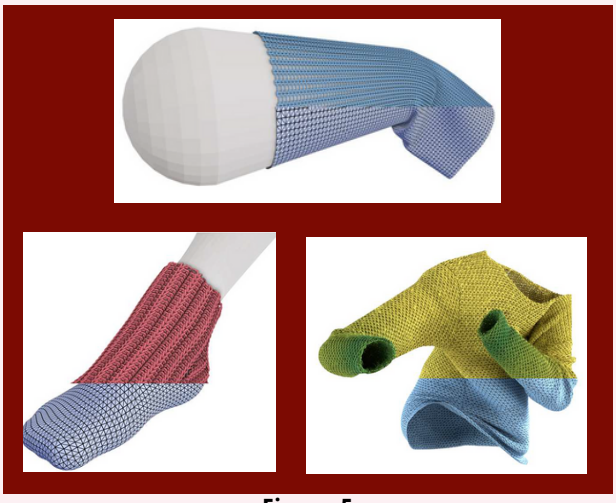


Figure 5

Deep Learning for Cancer Detection

Breast cancer is the most common cancer in women, and the second most common cancer overall in the world. Early detection is a crucial factor that aids in reducing mortality rates due to breast cancer. Screening mammography is the only modality that has conclusively been shown to reduce mortality. However, finding a cancer in a mammogram is a needle in a haystack problem: only about 5 out of 1000 scans would harbor a cancer. The cancer may only occupy less than 1% of the image, making the detection extremely tedious. Automatic detection of malignancies has received a boost with the use of convolutional neural networks (CNNs), but the detection of cancers of very small size still remains a challenge. This is however clinically significant as the purpose of mammography is early detection of cancer,

Deep Learning for Cancer Detection (Contd...)

thus making it imperative to pick them up when they are still very small. They showed that resolution, scale and image-context are all important independent factors in detection of small masses. They thereby designed a fully convolutional network, with ability to take the entire mammogram as input in full-resolution. In addition, they incorporated a systematic multi-scale approach, and encoded image context, which they showed to be critical factors to detection of small masses. This dramatically improves cancer detection, particularly for small masses, and is at par with the current state-of-the-art technologies. Small sized cancers in mammograms are automatically detected by the new neural network [Figure 6]. False positive detections have been reduced, sensitivity of detection has improved. The results are also made clinically relevant by incorporating information from clinical history and information from opposite mammographic view. In clinical practice, both these types of information are beneficial, and the team showed that incorporating them in the neural network to simulate the workflow of a radiologist makes its output more reliable and relevant as well. Finally, they found that state-of-the-art neural network models, which otherwise perform well in cancer detection on mammograms, often fail for patients with very dense breasts; this problem is particularly important given the higher risk of cancer in such patients. The team has design a network which takes traditional mammographic teaching into network design, and demonstrated a significant improvement in performance in cancer detection in comparison to the state of the art using these principles.

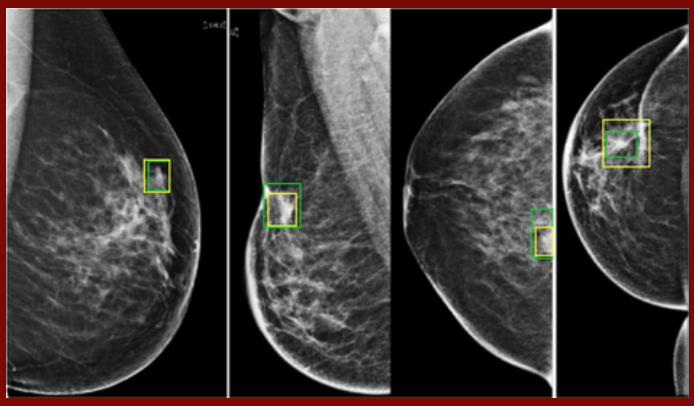


Figure 6

Certified Compiler and Deep Semantic Code Analyzer

It is hard to ascertain the correctness, performance, and security properties of mission-critical, safety critical and security-critical software. It is also difficult to test and verify a third-party software that is only available in binary executable form. Moreover, even if the developers have verified that the source code is free of defects and security vulnerabilities, there is a potential that the executable code has defects and security vulnerabilities, because the compiler may introduce incorrect behaviours. A deep symbolic analysis of software with high precision and scale has been done. When coupled with our translation validator, this allows for proving the properties of the binary executable code. When the tool is unable to complete the proofs, it generates counter examples that serve as test inputs, which trigger a safety bug or a security vulnerability. Thus, the tool also has applications in fuzzing and penetration testing of software, at both the source code level and the binary executable level [Figure 7]. This work is now being commercialized as a startup, called CompilerAI Labs (https://compiler.ai). The Indian Air Force (IAF) is among the early startup customers.

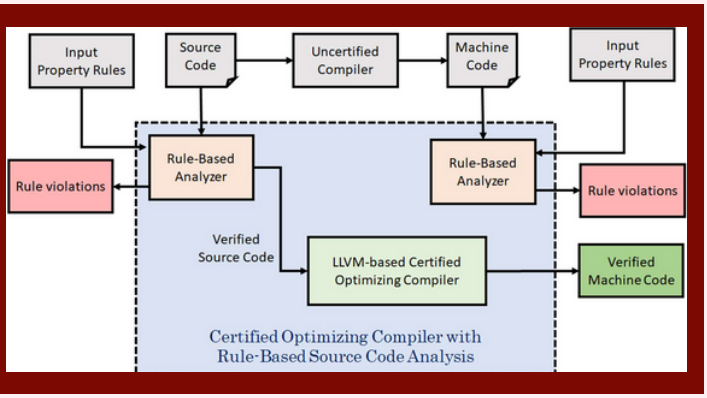


Figure 7

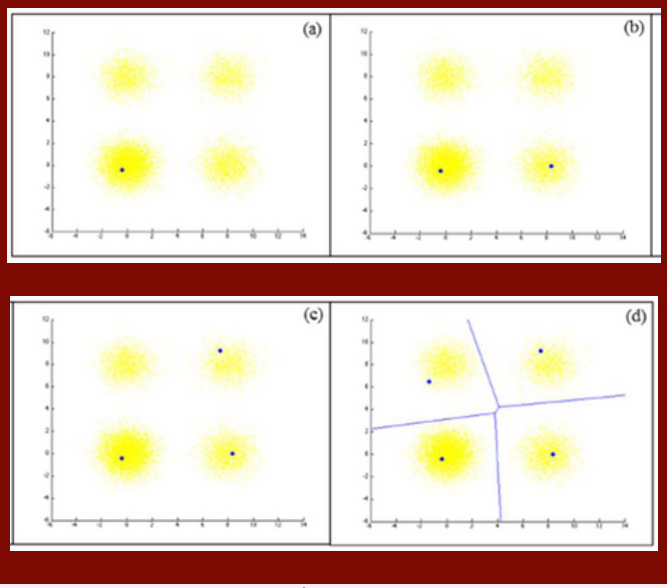


Figure 8

Clustering Algorithms

Clustering is one of the most basic data analysis tasks and is typically the first step when doing big data analysis. It is used extensively in computer science in areas such as data mining, machine learning, computer vision and many more. Understanding the powers and limitations of novel sampling based approaches for important clustering problems and advancing the state-of-art in clustering theory in general is a key research focus. Clustering is the problem of grouping objects into separate classes such that similar objects are in the same class [Figure 8]. For instance, given some news articles, clustering enables us to group these articles into various classes like sports articles, political articles etc. One of the most popular clustering problems is the k-means problem where we are given n points in a d-dimensional space and the goal is to output k points, called centres, such that all the n points are close to at least one of the centres. The sum of squared distances of all points to their closest center is a measure of the quality of the solution. Even though immensely useful computationally it is a challenging one. That is, it is unlikely that there is a fast algorithm that works for all instances of the k-means problem. There are fast and simple heuristics that work well for many real datasets but come with no quality guarantees. Simple and fast sampling based algorithms were explored for the k-means and other allied problems that also come with quality guarantees. Significant results on sampling approaches ranging from designing algorithms that provide arbitrary accuracy to refuting a popular conjecture on a well-known sampling based algorithm have been achieved. The algorithm samples the centres in four simple steps. The first centre is chosen randomly. For the second center, points that are further away from the first center are given more priority and so on.

Thermal Simulation of Chips

Thermal simulation of computer chips is a very important problem because as of today, temperature is a first-order design constraint [Figure 9]. Research was focused on fast Green's function-based thermal estimation techniques that are several orders of magnitude faster than existing methods. However, these methods were not fully developed for chip-level temperature estimation problems. Over the last five years, efforts have been directed towards making them effective and practical for such scenarios. From simple 2D chip layouts, to 3D chips with micro-channels, then Secure information flow followed by process variation and finally compact modeling was created for this method for large electronic components such as laptops and phones. A key challenge foreseen in this area is the need for even faster temperature estimation techniques in the future. Hence, much of the recent work is ML-based technique such as CNNs. Such networks are naturally suited to solving temperature estimation problems because the convolution operation is the key operation in Green's function-based methods. GANs and fast approaches that are hybrid of traditional compact modeling and CNN-based estimation are also being considered to increase the portfolio of techniques.

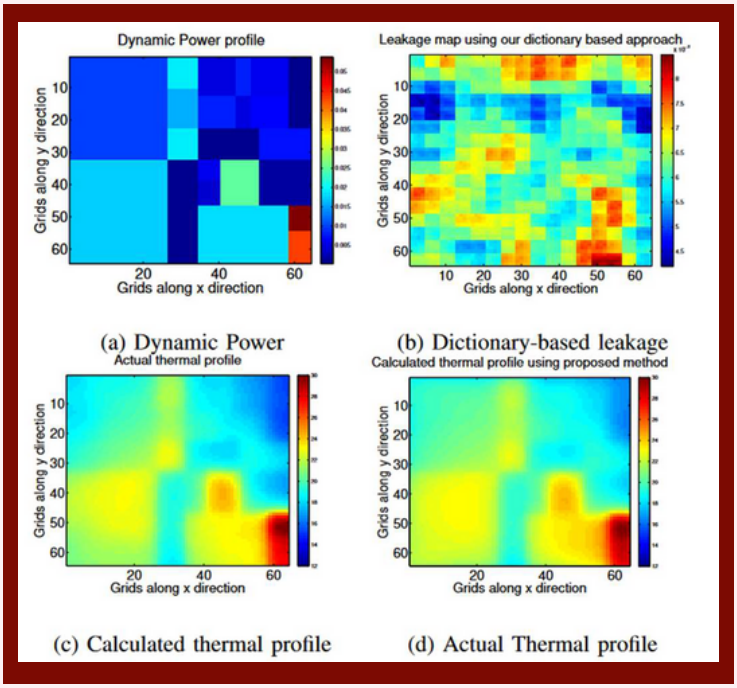


Figure 9

Partial-Order Based Verification Framework

Concurrency manifests in many mission- and safety-critical computational systems of today such as in health and medicine, environment modelling, autonomous vehicles, material discovery and many others. It is also well-known that verification of concurrent systems for safety property violations is a notoriously hard problem. Many safety problems (such as state reachability, deadlock detection, data race freedom, etc.) are undecidable in general. When such problems do become decidable under specific constraints, they incur unreasonably high complexity. The primary goal of our research is to design and implement efficient techniques to verify concurrent systems against a set of safety properties. Our contributions lie in either augmenting existing symbolic and abstraction-based techniques such as symbolic analysis, stateless model checking, and unfolding, or in designing novel concurrency-specific abstractions that allow for scalable and sound analysis. The work is primarily funded from the DST's Early Career Research Award and DENSO Inc. A Partial-order-based verification framework has been shown in Figure 10.

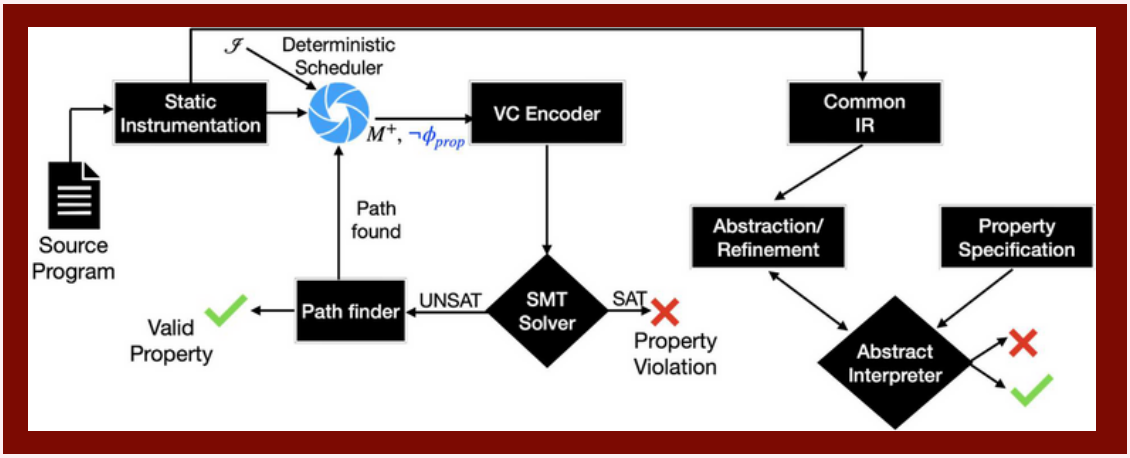


Figure 10

Secure Execution Environments

Software-only solutions that aim to ensure the integrity of a binary's execution are susceptible to attacks. We demonstrated this by developing an efficient form of control flow bending or CFB attacks. In a CFB attack, the control flow is hijacked by forcefully diverting the execution to a path that would have been skipped in the normal execution. AI-based methods were used to efficiently sift through billions of instructions and find the correct point of diversion that can break the security present in the binary --typically a license or key check. It has been demonstrated that a simple branch flip is enough to break the strongest of the encryption. In the subsequent work, on similar lines, we alleviated a key limitation of Intel SGX by providing the application running with SGX secure access to the file system. The operating system is not a part of the trusted computing base of Intel SGX, and hence, applications in SGX cannot directly make system calls. Hence, to store files on the filesystem, the applications must exit the enclave and store the files on the untrusted file system. This violates the confidentiality property of the data as the OS can see it in a plaintext format. The application can encrypt the data before sending it to the OS. However, doing so is a non-trivial task. It requires an application code change, the security burden falls on the application, and the encrypted data is also susceptible to replay attacks. In a replay attack, the attacker replays an old version of data to the application, accepting it as the most recent version. SecureFS, a secure and fast file system immune to replay attacks has also been developed for Intel SGX. The design of SecureFS is based on the characterization of popular workloads for Intel SGX. How these workloads interact with the file system. Based on the insights obtained, we modify the existing FAT-based filesystem to incorporate security while maintaining efficient file system operations. To thwart replay attacks, an efficient splitting of the data and the metadata was proposed, to create a small root of trust. The root of trust always remains in the processor's secure region while the secure volume is mounted and sent to a secure remote server when the volume is unmounted. Any attempt by an attacker to replay old blocks of the volume will fail the integrity check when mounting the volume.

Secure Information Flow

Secure information flow control aims at ensuring that security policies such as secrecy (and dually, integrity) are maintained during system operation. Our work on secure information flow control has embraced both a novel algebra-based extension of the fundamental framework to deal with autonomous systems, as well a correct-and-secure-by-construction programming model for environments like IoT systems.

SAPIEn: Systems & Algorithms Protecting Indian Environment

The SAPIEn (Systems & Algorithms Protecting Indian Environment) research group is working on problems of environmental sustainability in India. The group has deployed vehicle sensors (camera and radar) at the Delhi and Noida traffic intersections in collaboration with smart city companies like Aabmatica and Vehant. Camera data has been manually labeled and released as a computer vision dataset. Reinforcement Learning based traffic signal controller(s) have been designed and implemented, which are efficient enough to run on low-cost embedded platforms deployed on the road. To support vehicular sensing and management, state of the art Deep Neural Network (DNN) models need to run on embedded platforms. DNN software frameworks for embedded platforms are being characterized and optimized, on heterogeneous embedded processor cores like CPU-FPGA and CPU-GPU-DLA. Better thermal control is being examined, as temperatures in Delhi shoot to 45+ degrees, which is risky for road deployed platforms running DNN. This research has been published at the following venues: ICTD, NeurIPS, FPT, ESL, FPL, and IISWC.

The SAPIEn group has also deployed PM sensors in public buses in collaboration with Aerogram (manufactures custom platforms with 4G connectivity) and DIMTS (fleet partner) [Figure 11-13]. Pilot deployment ran successfully in 15 buses between Oct 2020 - Mar 2021, collecting PM 2.5, PM 10, GPS (to know bus location), accelerometer-gyrsocope-compass data (to measure bus speed and jerks), temperature and humidity. The dataset has been carefully cleaned with anomaly detection algorithms (e.g. intrasensor and inter-sensor variances) and is being used for interesting data-mining questions (spatiotemporal interpolation method comparison, picking the best locations for expensive static PM sensors). Security of the embedded software at minimal impact to the sensing and data processing have been explored. An interesting question of fleet location privacy, where more fleet companies will take part in vehicular sensing, but not reveal fleet location or fleet size to competitors (e.g. Uber vs. Ola or Swiggy vs. Zomato) has been examined in depth. This has been published at ACSAC and NDSS. The SAPIEn project is supported by the SERB Power Grant, Imprint-II Research Grant, Max Planck India Mobility Grant, FITT project with Aabmatica, Google India AI/ML Research Award, and the Pankaj Gupta Young Faculty fellowship.

Delhi-Noida intersection monitoring

Figure 11

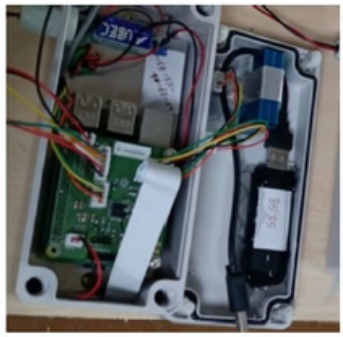

Platform for bus deployment

Figure 12


Pilot bus routes with PM heatmap

Figure 13

Graph Data Management

In one of the long-term research directions pursued by a research group, it has been working on an array of problems related to scalable graph data management and mining. The work can broadly be categorized into three focus areas: (i) Efficient reachability query processing on evolving graphs; (ii) Modeling information flow over dynamic graphs (e.g., Twitter) and spatio-temporal networks (e.g., Foursquare); and (iii) Traffic networks with dynamically changing constraints [Figure 14 &15].

Figure 14

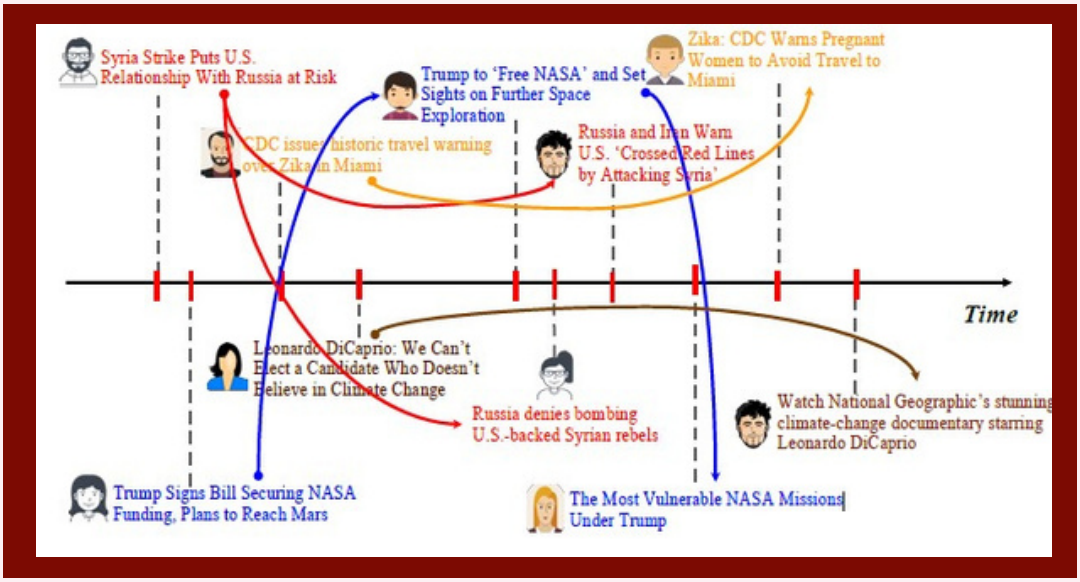


Figure 15

Reachability on Evolving Graphs

Answering reachability queries in submillisecond speeds on large-scale graphs is a critical requirement in many settings such as knowledge graphs, influence maximization on social networks etc. While much work has focused on static graphs where one can precompute a specialized index, in almost every real-world setting these graphs are rapidly evolving. A unique suite of algorithms based on conducting random-walks on graphs have been developed directly to answer not only simple reachability queries but also queries that can entail additional constraints such as timestamp or label restrictions on the paths allowed in the reachability answers.

Modeling Information Flow

Social networks offer a rich source of complex information (such as location/product recommendations, opinion, news, rumour etc.) cascades, and clearly understanding their behavior can help in many scenarios. However, disentangling various factors that drive the formation and growth of these cascades is extremely challenging. Modeling these cascades using spatio-temporal and topical point processes and deep temporal point processes to not only predict their growth, and the identification of latent communities of actors along with their influence patterns is a primary research focus.

Knowledge-Base (KB) Construction

Both structured and unstructured (text) data have been organized into "knowledge-bases" (KBs). These are basically tables consisting of entities and the relationships among them. Constructing these KBs as well as using these KBs in different kinds of applications is the focus of work.

Construction of KBs

Automatically constructing such rich, accurate and large KBs is itself a challenge, but a bigger challenge is to construct KBs for different "verticals", such as Computer Science and Bio-chemical Engineering. Constructing KBs for different kinds of information, such as procedures. Procedures are semi-structured text that outline a sequence of steps. Examples of procedures include cooking recipes, technical How-To's etc.

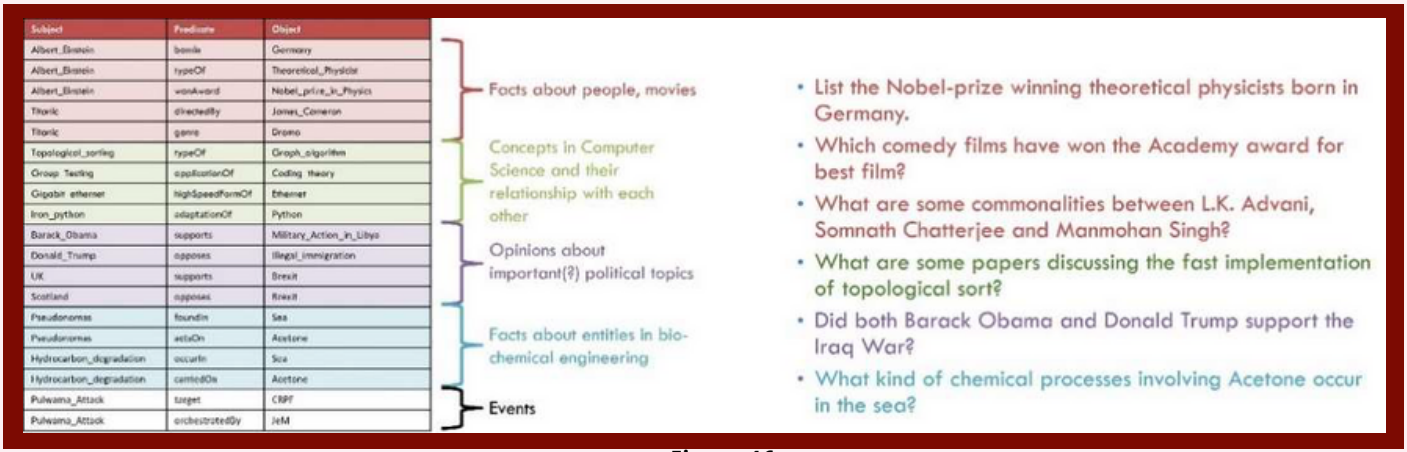


Figure 16

Querying and Reasoning Over KBs

Queries could be as simple as a fact lookup such as a List of Nobel-prize winning physicists born in Germany", but the query itself could be expressed as text or keywords [Figure 16]. One of the goals is to automatically take in natural language questions and automatically "translate" them into a structured query language that would be suitable for querying the KB. Researchers are also interested in queries that require additional reasoning over the facts in the KB. Of special interest are those that may involve the application of domain-specific inference rules. For example, "Which are all the anaerobic microbes that can found near the sea?" is a question that requires reasoning over facts about the environment in which certain chemical reactions may take place.

Figure 17

Other Applications of KBs

KBs have been used in other applications such as research paper retrieval ("Search for research papers that discuss efficient implementation of topological sort") and pre-requisite generation ("What topics should be understood before studying HMMs?").

Teaching Robots Common-sense for Semantic Tasks

Recent advances in robotics and AI are enabling robots to enter environments such as homes and factories. In such environments, an intelligent robot is expected to understand high-level instructions from a human partner and synthesize a plan of actions to realize the intended goal. For example, a robot assisting a worker in a factory may be asked to "transfer the machine parts on table to the assembly area". In recent years, robots have become increasingly capable in being able to recognize entities in the environment and controlling their motion to physically interact with the environment. However, present-day robots lack background common sense knowledge crucial for performing a high-level instruction. For example, consider the task of transporting objects referred to above. It is common for humans to use tools such as a "tray" or a "box" to collect and move objects efficiently between locations.

Teaching Robots Common Sense for Semantic Tasks (Contd...)

Robots lack such physical common sense knowledge of using objects as tools to perform tasks and hence either fail to perform a task altogether or often are inefficient in completing a task. Robotic platforms require common sense knowledge to complete tasks. The present work developed an imitation learning model to learn common sense knowledge (e.g, use of containers for transporting items) from human teachers [Figure 17 & 18]. The problem of imparting robots with common sense knowledge required for synthesizing task plans was addressed. The project involved collecting a novel data set that captured how humans performed tasks in a physics simulation environment. The data set implicitly captured how humans make creative use of objects as tools to achieve intended goals.

The data set was used to train a "neural imitation learner" for predicting which objects can be used as tools and how their use can be sequenced to accomplish a multi-step task. Contemporary approaches restrict the robot to operate in environments with the same object types as seen in training. The ability to learn dense representations of the environment and making use of knowledge corpora allows the researchers model to generalize to novel scenes with unseen objects that may not have been seen in training. For example, where the robot having seen use of trays to transport objects can generalize its knowledge to predicting use of a box for the same purpose in a new environment. The research provides the robot greater flexibility to adapt online and use objects that it may not have seen during the training.

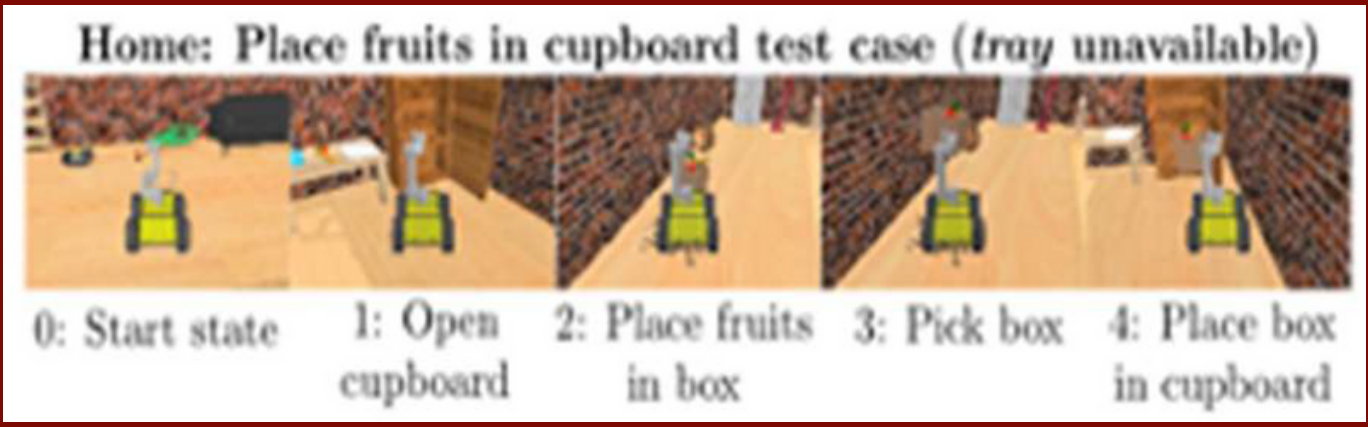


Figure 18

Neuro-Symbolic Artificial Intelligence

One of the long standing goals of AI has been to achieve the same level of reasoning that humans are capable of doing. As humans we find it very easy to look at objects, and infer about properties of objects such as their color or shape, or how they interact with each other. Similarly, we can process sequence of characters as words, and sequence of words as sentences, and then, for example, given a set of sentences, figure out that these sentences encode an instruction to move block A on top of block B in a robotics domain. One of the specific challenges in these tasks is a combination of low level reasoning (i.e., recognizing pixels in an image, or words in text), and high level reasoning which deals with properties of recognized objects or sentences. In literature, these two different kinds of reasoning have been referred to as System A and System B. The upcoming area of neuro-symbolic artificial intelligence tries to combine both these aspects: can neural models be trained in an end-to-end fashion, to not only deal with perceptual data, but also perform complex reasoning, in a manner which is interpretable to humans, i.e., via recognizing objects and reasoning over their properties. Another related line of research looks at explicitly using a symbolic solver along with a neural module to integrate both low and high level reasoning. In this direction, three different problems were addressed.

Robot Manipulation Programs

The problem of learning a model for neuro-symbolic robotic manipulation has been addressed. Given the data in the form of triplets, with each triplet representing (a) a natural language instruction (b) an input scene, (c) an output scene, the researchers' goal was to train a model which when presented with a natural language instruction, and an input scene, can output a program, explaining how the input scene can be manipulated by the robot to result in the output scene.

One-of-Many Solutions in Structured CSPs

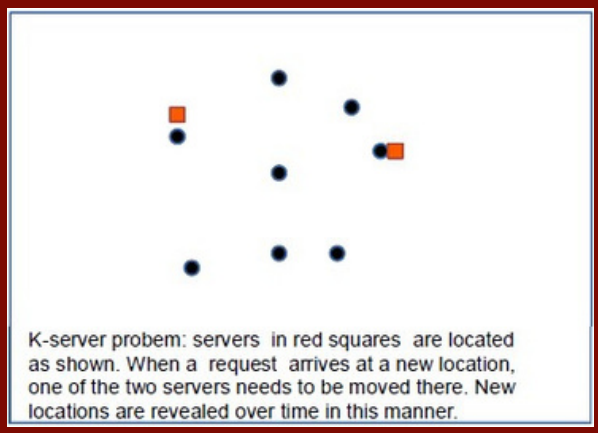
The task of learning one-of-many solutions for combinatorial problems in structured output spaces is formally defined, which is applicable for solving several problems of interest such as N-Queens, and Sudoku. A generic learning framework that adapts an existing prediction network for a combinatorial problem to handle solution multiplicity is also presented.

Incorporating Symbolic Algorithms

A perceptuo-reasoning tasks that require both perception over physical objects and downstream reasoning (e.g., Visual Sudoku) is solved by combining an image encoder with symbolic algorithms such as SAT solver. The main challenge is end-to-end backpropagation since symbolic algorithms cannot be differentiated. To address this, REINFORCE style RL algorithms are used.

Online Algorithms with Service Delays

Traditional theory of online algorithms deals with input sequences which are revealed over time. Classical examples are online caching, k-server, load balancing etc. In each of these settings, we need to service the input request as soon as it arrives. For example, in the online caching problem, there is a limited memory for storing pages, and whenever a new page request arrives, we need to ensure that the requested page is in the cache. Traditionally, online algorithms for such problems are evaluated using the notion of competitive analysis: one compares such algorithms with an "offline" algorithm which knows the entire input sequence in advance and behaves accordingly. Recently, there has been much work in studying online algorithms where delay in service of an input request is allowed, but with an increasing penalty function. In the caching example referred above, this would mean ensuring that the requested page is brought in the cache within a deadline (instead of bringing it in the cache immediately). The goal is to minimize the overall cache eviction cost. Such a problem arises naturally in on-line network streaming, and similar applications. The researchers give first non-trivial online algorithms for this problem and study it using the framework of competitive analysis. Their techniques involve making new connections of this problem with the so-called online covering problems using linear programming relaxations. A more challenging problem is the so-called k-server problem. In this problem, there are k servers placed in a metric space. At each time, a new request arrives at one of the locations in the metric space, and one of the server needs to be moved to the requested location. The overall objective is to mininimze the total distance travelled by the servers. This problem has been one of the most fundamental problems in the theory of online algorithms, and has been the test-bed of almost every technique known in this area. The researchers considered this problem in the service with delays setting – whenever a new request arrives, we allow it to be serviced within a deadline. They give the first nontrivial online algorithm for this problem. Their current work extends the results and introduces new tools in the study of the k-server problem, and promises to make progress on similar open problems in this area.



K-server probem: servers in red squares are located as shown. When a request arrives at a new location, one of the two servers needs to be moved there. New locations are revealed over time in this manner.

Figure 19

Multiflow and Multicuts in Planar Graphs

The classical problem of multicommodity flow and cuts are being studied. In multicommodity flow problems, there usually is an edge capacitated graph (called the supply graph) and several source-sink pairs. The graph formed by joining the respective source-sink pair is called the demand graph. The objective is to route flow between the source-sink pairs without violating the edge capacities. A flow is integral (resp. half-integral) if each flow path carries an integer (resp. half-integer) flow. Multicommodity flows can be used to model a variety of routing applications in communication and transportation networks.

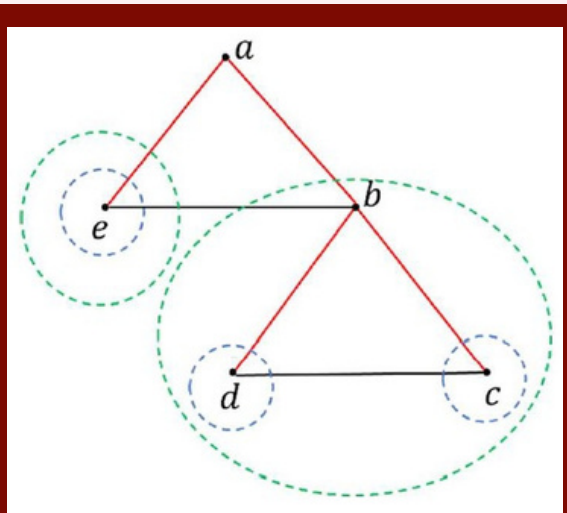


Figure 20

In sum multicommodity flow, the researchers seek to find a flow that maximizes the total flow routed between the source-sink pairs. A set of edges whose removal disconnects all the source-sink pairs is called a multicut. The value of a multicut is at least the value of the sum multicommodity flow, and the ratio of the minimum multicut to the maximum (integral /halfintegral) sum multicommodity flow is called the (integral/half-integral) multiflow-multicut gap.

Multiflow and Multicuts in Planar Graphs (Contd...)

it was proved that a half-integral multiflow-multicut gap of 2 when the union of the supply and the demand graph is planar. A sequence of instances is also provided by them, where-in the multiflow-multicut gap approaches 2, showing that the results are right. To prove this result, they make an interesting connection of multicut in such instances to a connectivity augmentation problem. Given an edge-weighted graph and a forest F, the 2-edge connectivity augmentation problem is to pick a minimum weighted set of edges, E', such that every connected component of $E' \cup F$ is 2-edge connected. Williamson et al. gave a 2-approximation algorithm (WGMV) for this problem using the primal-dual schema. The researchers show that when edge weights are integral, the WGMV procedure can be modified to obtain a half-integral dual. Further, an algorithm is given for computing an integral flow of value at least half the integer flow and this implies an integral multiflow-multicut gap of 4. The arguments lead to polynomial-time algorithms for a 2-approximation to minimum multicut, a 1/2 - approximation for maximum half-integral flow and a ¼-approximation algorithm for maximum integral low in such instances.

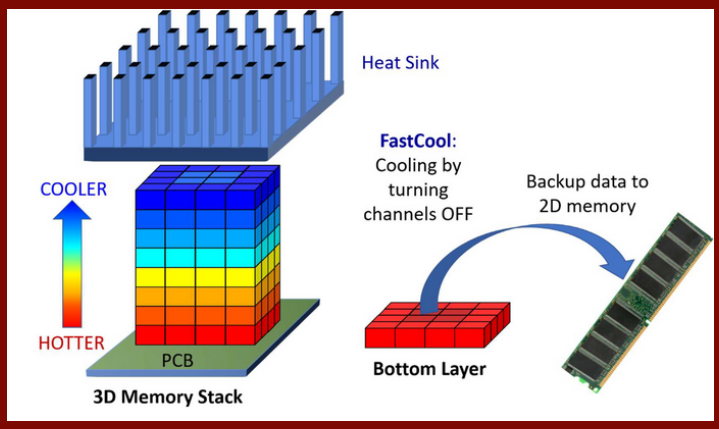


Figure 22

Performance and Thermal Model and Optimisations for 3D Memory Systems

Stacked 3D memory systems constitute a new memory technology that is witnessing commercial adoption due to several advantages it offers in area, bandwidth, and energy efficiency. However, thermal issues arising out of higher power densities have limited its widespread use. An important research question that arises is, how to maximise performance while operating under thermal constraints? The solution involves abstracting out low-level physical effects into system-level actions such as data migration and voltage scaling of memory banks. In this work a comprehensive modelling of 3D memory energy and temperature was performed, along with an integration with performance simulations so that the thermal impact of various CPU-3D Memory optimisations was jointly studied [Figure 22]. The research activity involved close collaboration with research groups at University of Amsterdam and Karlsruhe Institute of Technology. The open-source integrated model (CoMeT) is available at: https://github.com/marg-tools/CoMeT.

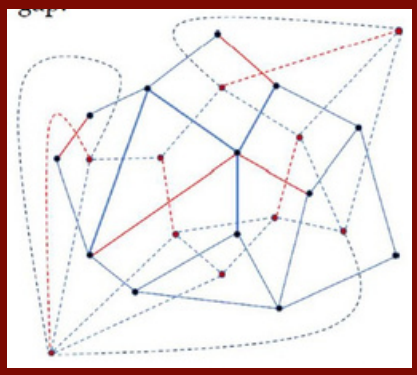
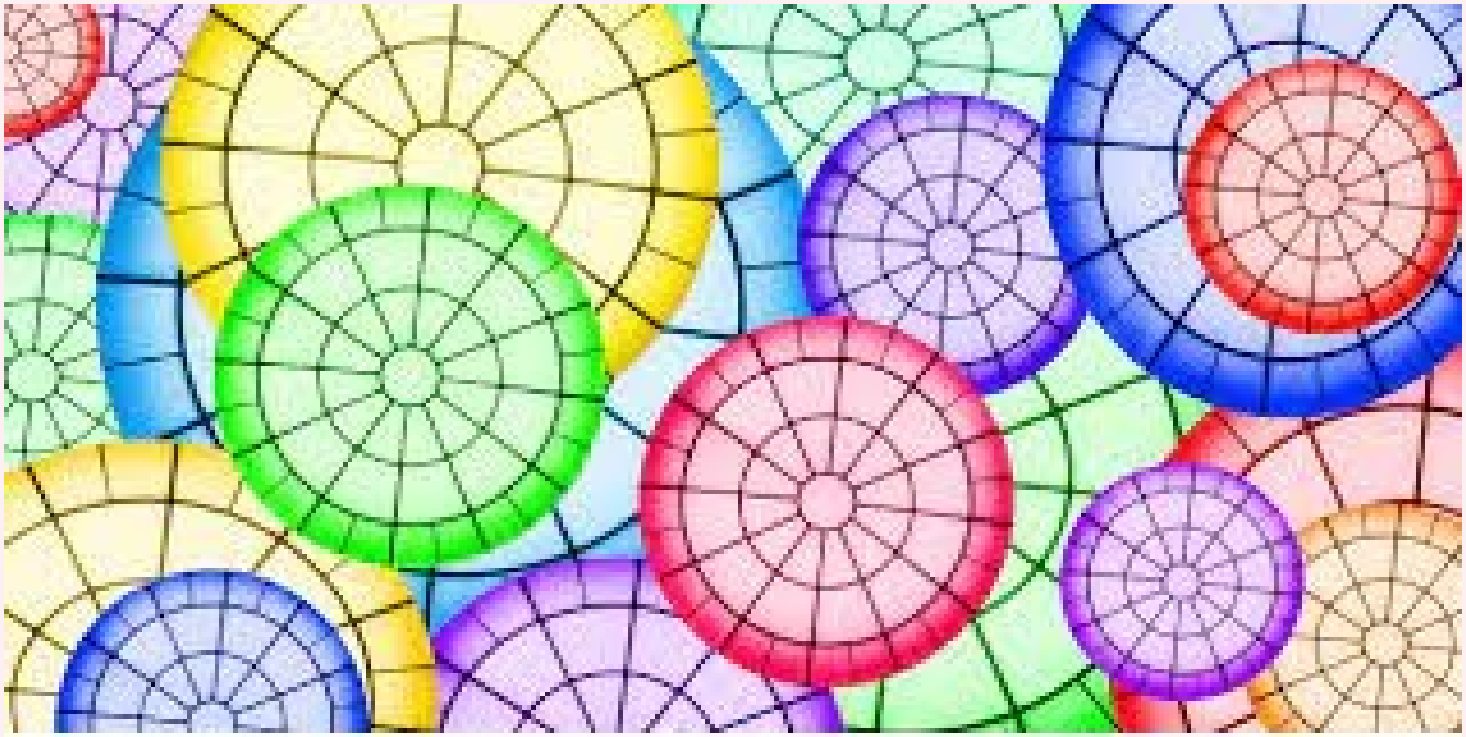


Figure 21

Question Answering over Tourism Domain

Travellers often post questions online to seek personalized travel recommendations by describing their preferences and constraints with respect to locations, points of interests, budget, etc. Answering such recommendation questions (questions that seek specific entity recommendations) is challenging because the questions themselves are very long, the answer space (possible candidate answer entities) rather large, and even the information document for each entity (user reviews) quite long. This creates significant challenges of reasoning at scale. In contrast to the first setting, in the second approach a collection of reviews to directly answer questions is used, without explicitly parsing questions. A cluster-retrieve-re-rank architecture that helps address some of these challenges, is developed. It first cluster reviews text for each entity to identify exemplar sentences describing an entity. It then uses a scalable neural information retrieval (IR) module to select a set of potential entities from the large candidate set. A re-ranker uses a deeper attention-based architecture to pick the best answers from the selected entities. The entity-seeking recommendation questions are answered in two settings: (i) QA with intermediate annotations (ii) QA without intermediate annotations. In each setting a new problem is formulated and new datasets created, which the researchers hope will help further research in QA. In the first setting, they developed a pipelined model which breaks down the task of question-answering into a question-parsing task followed by knowledge-base querying. Learning a question-parser requires large amounts of training data and they overcome this challenge by employing a constraint driven learning framework that uses a small set of expert-annotated questions, along with a larger set of crowd-sourced partially-annotated questions. Additionally, in order to accommodate reasoning over physical locations of entities, they extend this work by developing a joint spatio-textual model. They develop a modular spatial reasoning network that uses geo-coordinates of location names mentioned in a question, and, of candidate answer entities, to reason over only spatial constraints. They combine the spatial reasoner with the textual QA system to develop a joint spatio-textual QA model. They demonstrated that their joint spatio-textual model performs significantly better than models employing only spatial or textual reasoning.



DESIGN

RESEARCH AREAS

DESIGN

- INDUSTRIAL DESIGN
- PRODUCT DESIGN
- ENGINEERING DESIGN
- CREATIVITY AND INNOVATION,
- DESIGN THEORY & METHODOLOGY
- APPLIED ERGONOMICS AND HUMAN FACTORS IN DESIGN
- UNIVERSAL AND INCLUSIVE DESIGN
- DESIGN FOR UX/UI, HCI
- GRAPHIC DESIGN
- COMMUNICATION DESIGN
- COMPUTER AIDED DESIGN AND MANUFACTURING
- DESIGN AUTOMATION AND DESIGN OPTIMIZATION
- DESIGN COMPUTING AND DESIGN INFORMATICS, MATERIALS & DESIGN
- DESIGN FOR PRODUCT LIFE-CYCLE,
- ART & DESIGN
- PRODUCT AESTHETICS
- DIGITAL MEDIA & DESIGN
- SOCIAL AND CULTURAL ASPECTS OF DESIGN
- DESIGN POLICY
- DESIGN STRATEGY
- DESIGN MANAGEMENT

The Department of Design was established in the year 2017 and traces its roots to the Instrument Design and Development Centre (IDDC), which has been pioneering design education at IIT Delhi since 1994. Presently the Department has expertise in three main design domains of Industrial Design, Communication Design, and Interaction Design.

Diversity of Research in Design

The department faculty are actively involved in various aspects of design which include design thinking, user experience design, healthcare design, information design, media design, game design, inclusive/universal design, graphics design, IOT driven design, social and cultural factors in design, user experience design, design for usability, design for emotion and persuasion, design cognition, transportation design, publication design, and design for sustainability.

Research Mission

The mission of the department is to excel in all three aspects of design namely knowledge dissemination, knowledge creation and knowledge application.

Figure 1

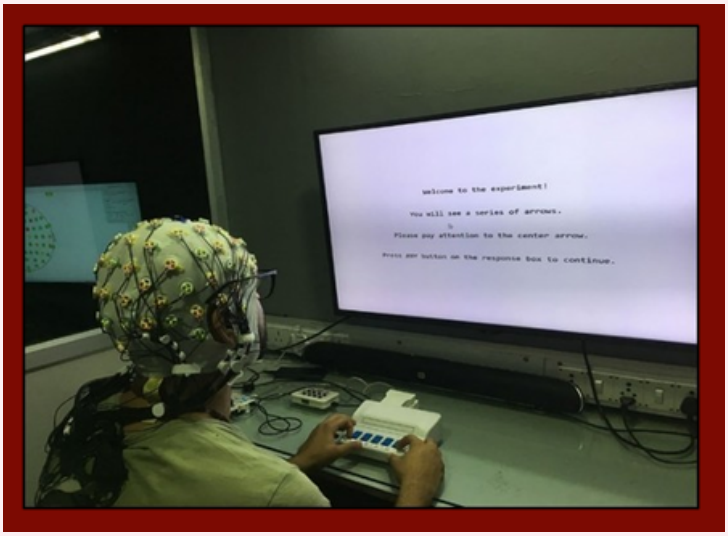


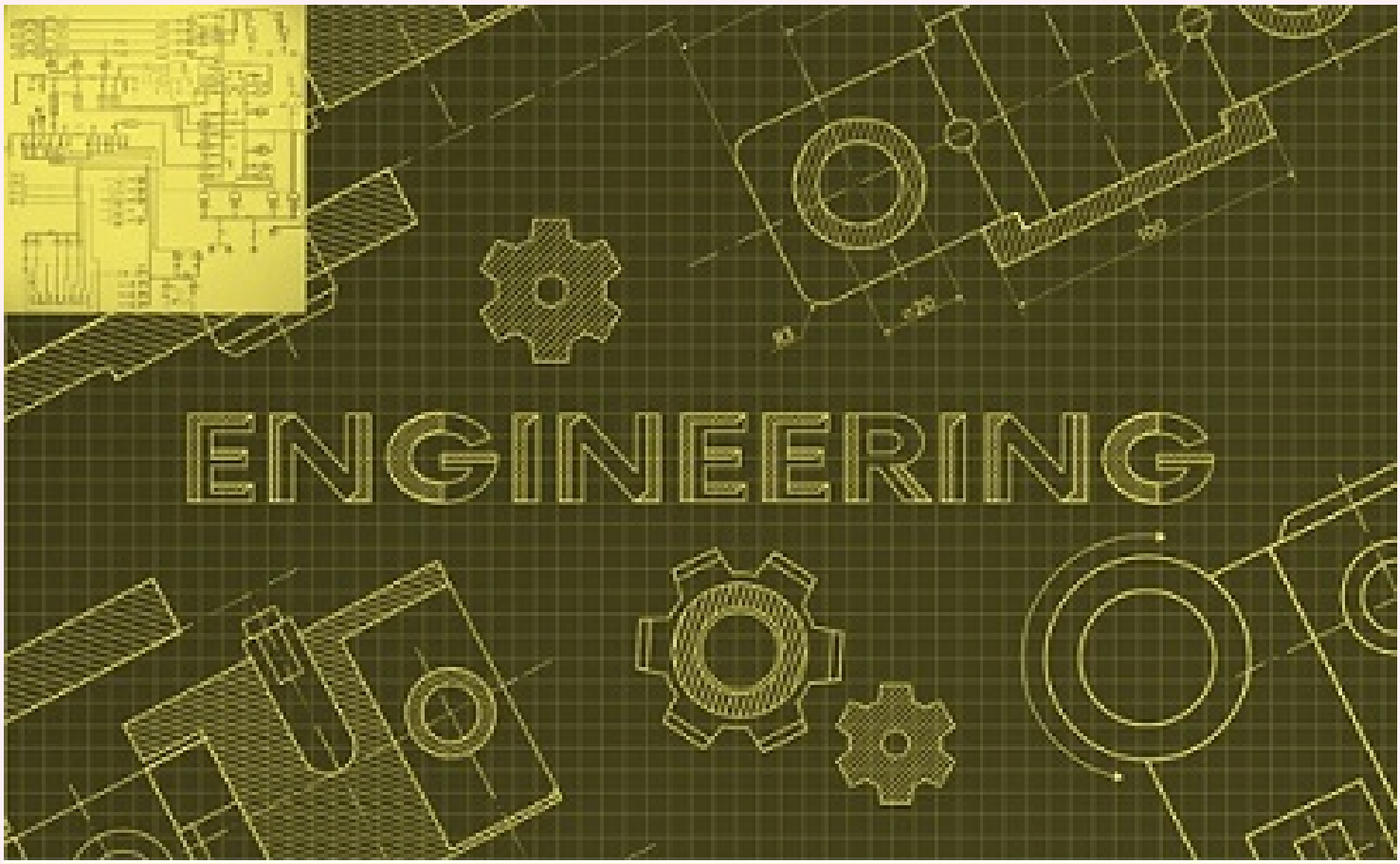
Figure 2

Commerialised Patents and Designs

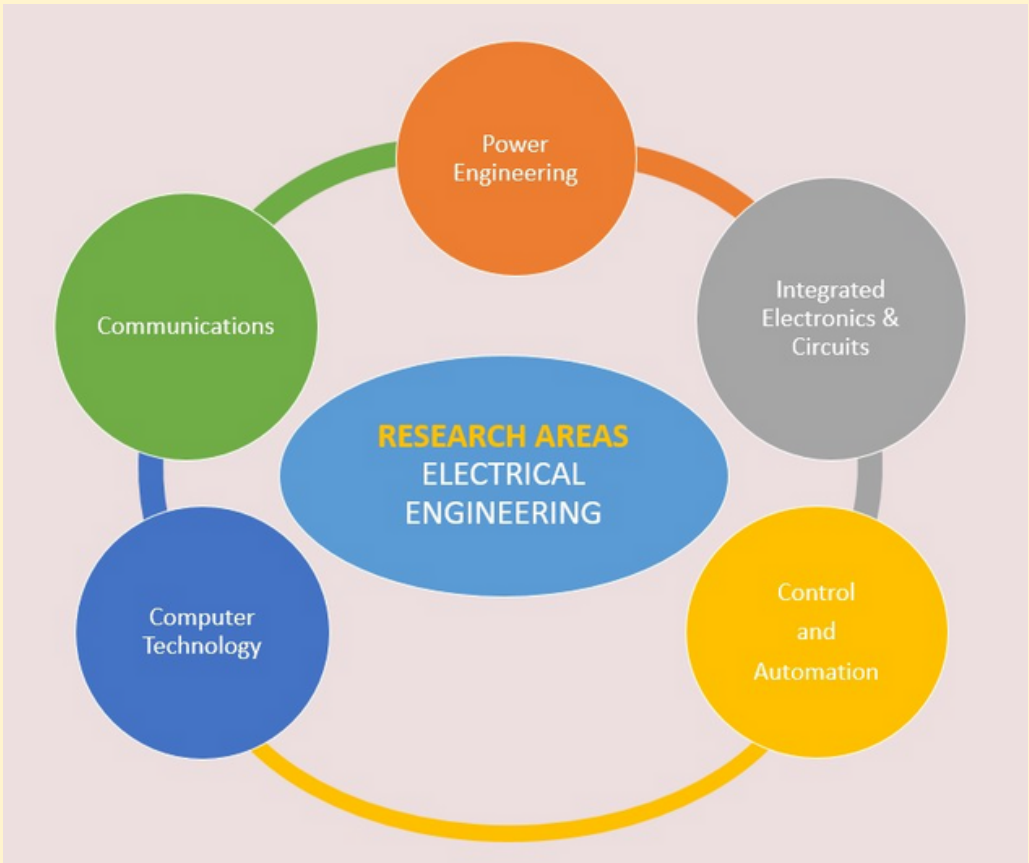
Department faculty have number of patents and designs to their credit many of which have been commercialized. Faculty have also founded and mentored a large number of startups. The department has close collaboration with industry in the form of joint research and innovation projects, joint guidance of student projects, industry participation in teaching courses and curricula development and summer internships for students in industry.

Impact of Design

Design has had enormous impact on human lives and has been a vehicle for social and economic progress of any country. It has come to play an important role in the strategic planning of corporations, plans for innovation, and development of new products, services, spaces, communications and experiences. The Department of Design at IIT Delhi is involved in addressing multiple needs of the industry and society through design-led innovations and has adopted design to deliver value in multiple ways namely: aesthetic, business, technological and sociological. IIT Delhi has design programme starting in 1994 and since then it has produced many outstanding design professionals, design leaders, design researchers and design educators.



ELECTRICAL ENGINEERING



The Department of Electrical Engineering has been playing a vital role in producing scientists and technologists of highest caliber ever since it was established in the year 1961. It caters to the ever challenging needs of technical excellence in all areas of electrical engineering such as Integrated electronics and circuits, Tele-communications, Computer technology, Control & Automation, Power systems & Power electronics through innovative research.

Power Engineering

Research in this area is under two broad sub-groups, namely Power Systems and Power Electronics, Electrical Machines and Drives (PEEMD) covering Power Systems Analysis and Control, Power Generation, HVDC, FACTS, Distribution Automation, Power Quality, Energy Systems, Energy Audit and Energy Conservation, Renewable Energy (Wind, Small Hydro, and PV), Electrical Machines and Drives, Power Electronics, Special Electric Machines, Adjustable Speed Drives and Intelligent Motor Control. The group has research collaboration with several industries, power utilities and R&D organizations in India and abroad [Figure 1].

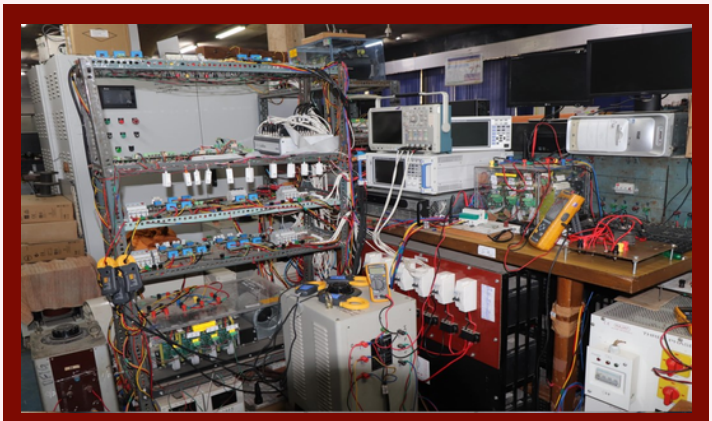


Figure 1

Integrated Electronics and Circuits

Research in this area includes Digital Signal Processing, VLSI Design, Photonics, Mixed-Signal, RF Circuits, Memory Technologies, Spintronics and MEMS, Analog Circuit Design, Artificial Neural Networks, Circuit Testing, Fault-Tolerance, Fail-Safe Design, Microelectronics and Power Devices [Figure 2].

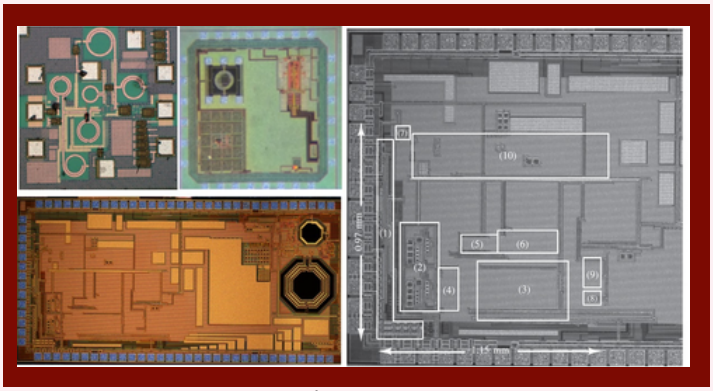


Figure 2

Figure 3

Control and Automation

Research is carried out in all aspects of Control Engineering including Identification and Adaptive Systems, Robust Filtering and Control, Distributed Systems, Optimal and Stochastic Control, Robot Dynamics and Control, Intelligent Control, Automation, Neural Networks and Fuzzy Logic, Applied Systems Analysis, Modeling of Computer Communication Networks and Image Processing. Besides, following thrust areas have been defined for future work: Robust Control, Reinforcement Learning Control, Simulation and Control, Guidance and Control, Robotics, Nonlinear Control, Discrete Time Systems, Distributed Parameter Systems, Biological Systems, Electromagnetic NDT, Model Order Reduction, Dynamical Systems, Electromagnetic and Coupled Systems, Computational Methods for Modeling, Flexible Structures, Adaptive Control of Uncertain Nonlinear Systems, Finite Element Method, Approximate Dynamic Programming, Cyber Physical Systems, Intelligent Control, Sliding Mode Control, Mechatronics, Differential Games, and System Identification [Figure 3].

Computer Technology

Research is focused in the broad areas of Computer Networking, Parallel and Distributed Processing, CAD for VLSI, Computer Vision, Artificial Intelligence, Pattern Recognition, Graph Theory, Neural Networks and Multimedia Systems [Figure 4].

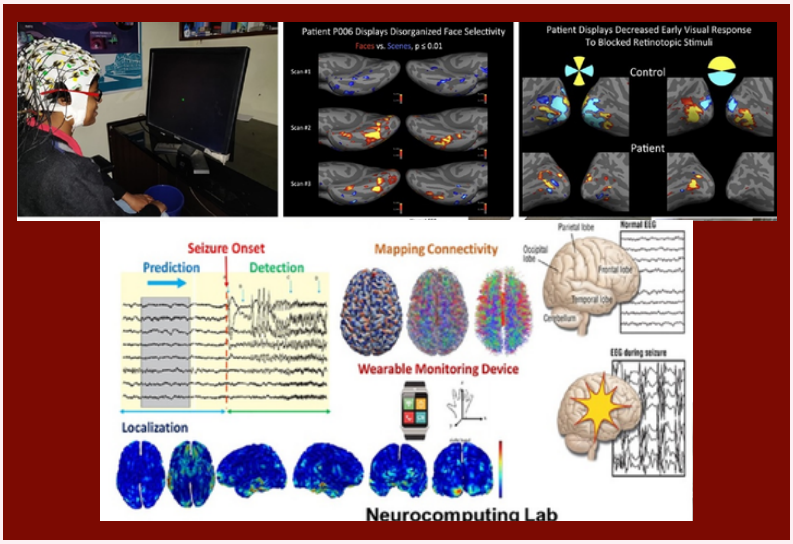


Figure 4

Communications

Research is pursued in Communication Systems, Computer Communication, Signal Processing, Coding Theory, Microwave Integrated Circuits, Optical Communications, Quasi-Optical Techniques and Integrated Optics. The faculty members of the group are engaged in both fundamental and applied research, leading to important publications and the execution of several sponsored projects. The group has well-equipped laboratories in the areas of Communication Engineering, Telematics, Microwave Engineering, Signal and Information Processing, Optical Communication and Photonic Systems. The group has undertaken a major thrust area project in Telematics and two mission projects in Photonics [Figure 5].

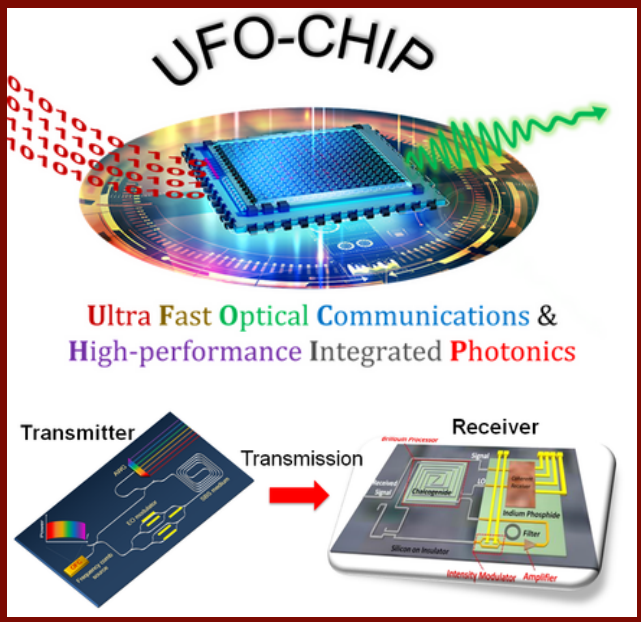
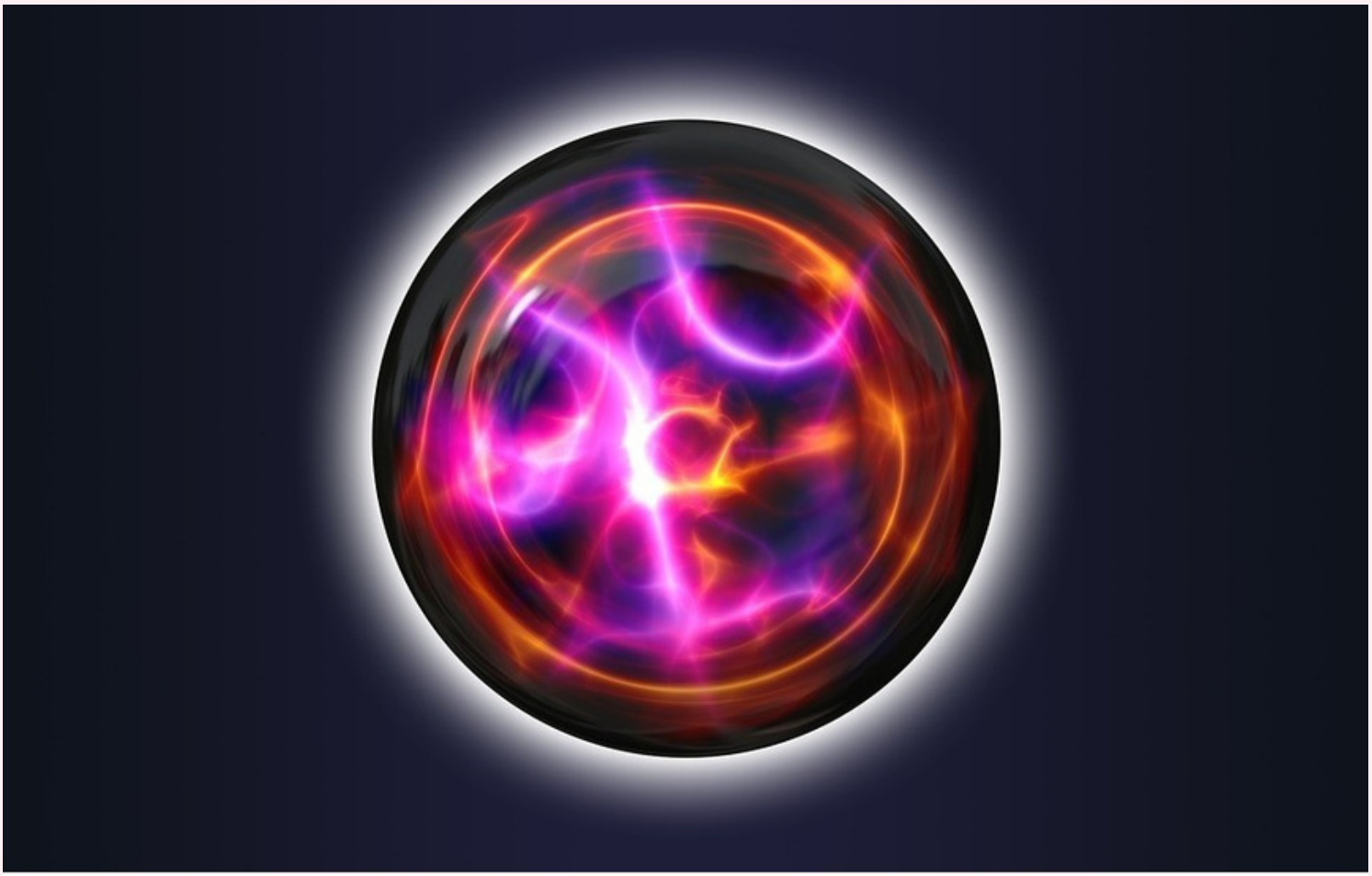
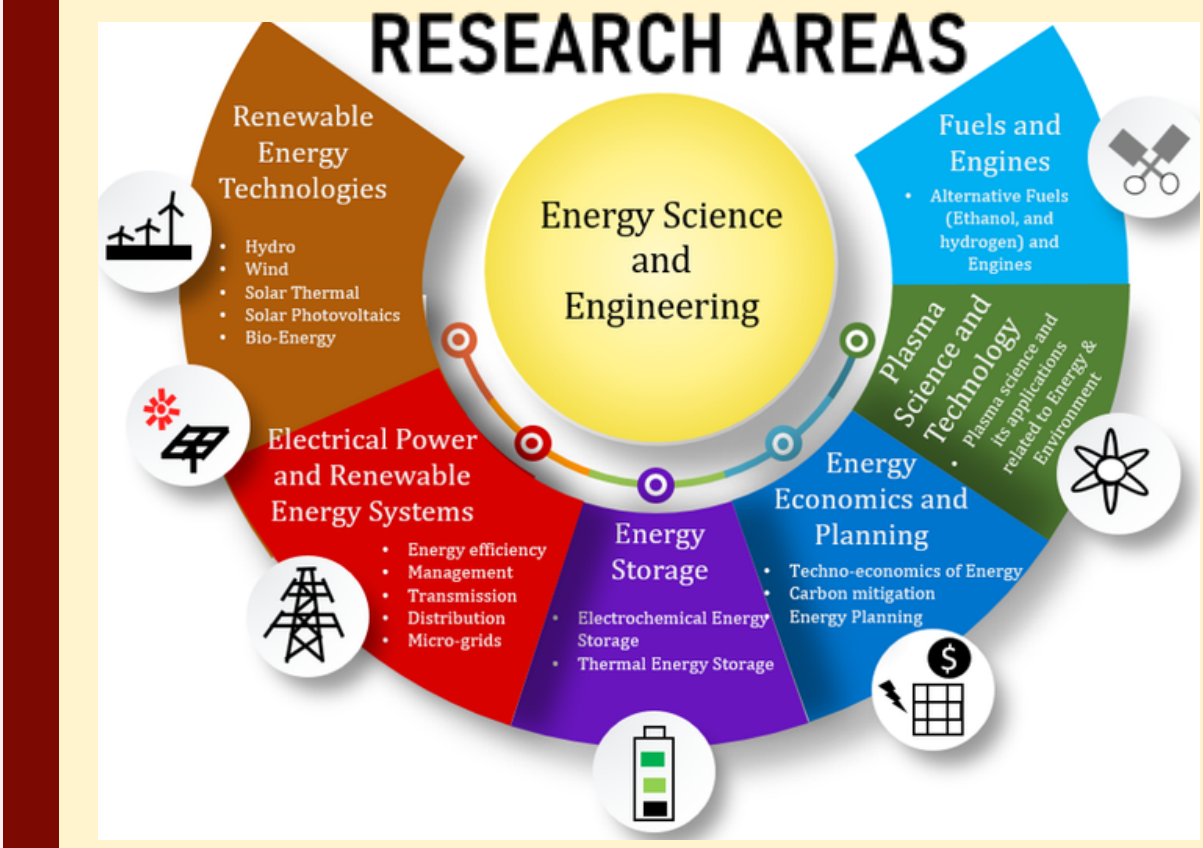


Figure 5



ENERGY SCIENCE AND ENGINEERING



Realizing the need for education and research in the field of energy, the Government of India established a national Centre for Energy Studies (CES) at IIT Delhi in the year 1976. Research and development activities on various relevant aspects of conventional as well as non-conventional energy sources were initiated and suitable infrastructure established in its formative years. In the year 2021, the centre became the Department of Energy Science and Engineering.

Silicon Heterojunction

The present aspiration for Photovoltaic (PV) technology is to meet sustainable development goals and being responsible for the planet and its inhabitants by focusing on an inexpensive way to convert solar energy into electrical energy. To make the energy from PV is more affordable than before. With this aim, the group has generated know- how with a few critical publications and some patents. a. Next-generation Silicon Hetero-junction (SHJ) technology development: according to the PV technology roadmap, SHJ technology is going to have a significant share in the PV market due to: (1) the Highest Cell Efficiency, (2) Superior Temp. Coefficient., (3) Low-temperature process, (4) Solar cells can be bifacial, and (5) on thin wafers for flexible cells fabrication for various mobile applications. Figure 1 shows the 1" x 1" SHJ cell fabricated at IIT Delhi and the cell schematic.

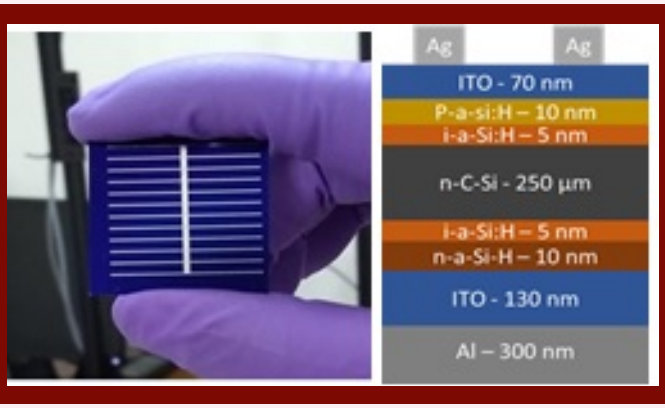


Figure 1

Plasmonic Colored Solar Cells

Colored and flexible solar cells have been developed for Building Integrated Photovoltaic (BIPV) application using nanoscience concepts. Figure 2 shows colored silicon solar cells and the flexible silicon wafer for fabricating solar cells. The solar concentrator laboratory is dedicated to the development of cost-effective solar thermal technologies, thermal energy storage, and their utilization in industrial as well as household applications.

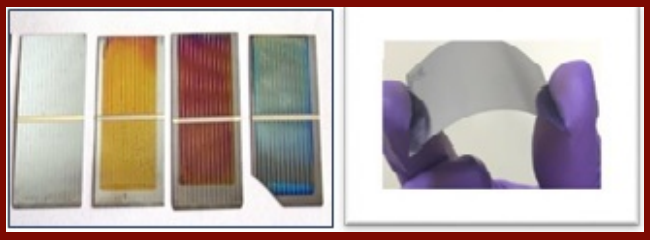


Figure 2

Direct Steam Generation

Large aperture parabolic trough collectors is an area of research. A model has been developed for optical analysis of large aperture parabolic trough collectors (PTC). The influence of various conventional heat transfer fluids and nano-fluids on the thermal performance of PTC has been investigated. Direct steam generation (DSG) in the solar field is the next-generation advancement in PTC. Extensive numerical investigation of multiphase flow in the absorber tube is performed using the Eulerian two-fluid modeling technique. The researcher group has developed an experimental test facility to design an absorber tube for DSG [Figure 3]. The group is also working on the development of thermal energy storage systems based on phase change material (PCM) and metal-hydrides and is in the process of developing an experimental test facility for the characterization of metal hydrides. Further, the group is also working towards the utilization of solar energy for various applications such as cooking, desalination, and process heating applications.

Figure 3

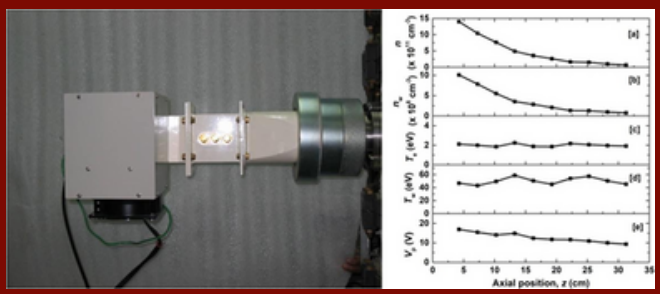


Figure 4

Light Weight, Compact ECR Plasma Source (CEPS)

The CEPS was conceived and developed (1995) as an ECR based compact source for high-density plasma, which can be attached to any suitable port of a chamber for filling it with plasma. Its total weight including the ring magnets is @ 14 kg and its length is about 60 cm.

Light Weight, Compact ECR Plasma Source (CEPS) (Contd...)

Compact ECR Plasma Source (CEPS)60 cm long and weighing only 14 kgs can be easily mounted to any system at any orientation [Figure 4]. (RHS) Typical Argon plasma results from a CEPS source attached to an expansion chamber of 50 cm diameter and 75 cm long (a) bulk electron density (ne); (b) warm electron density (nw); (c) bulk electron temperature (Te); (d) warm lectron temperature (Tw); (e) plasma potential (Vp). A patent has been granted for this development. The highlight of this development has been in its utility for various research activities of the lab which are of national importance that include:

a) Developing a scalable, large volume plasma system (1000 - 1600 lts) for generating high density uniform plasma. It would be especially useful for plasma processing industry.

b) Developing a CEPS based electrodeless ECR plasma thruster that could be used for deep-space propulsion. Discussion with ISRO for direct thrust measurements.

c) Developing a large area (0.5 m dia), high current (few Amperes), hydrogen plasma source for fusion devices in the country. This is being developed under an MoU with IPR Gandhinagar.

d) Initiating studies for developing high pressure discharges using CEPS for the environment and biomedical applications beneficial to society.

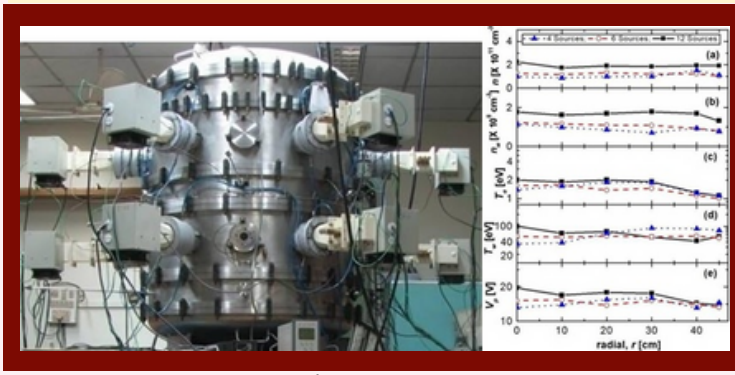


Figure 5

Large Volume Plasma Source (LVPS)

By combining multiple CEPS in a suitable manner it is possible to produce high density, uniform plasma over a very large volume and large area, for industrial-scale applications like nitriding, carburizing, PIII, semiconductor processing for shallow junctions, ion beam source for ion implantation, etc. Typical LVPS specifications: Chamber dia.: @1m, Height: @2.1 m, Volume: @1.6 m3, Number of CEPS: 18. These specifications are the maximum scalable height tested in the lab. A typical configuration with 12 such sources mounted onto the LVPS is shown in Fig. 2 with typical radial plasma parameters. Figure 5 shows an LVPS using 12 compact ECR Plasma Sources for producing uniform, large volume, high density plasma (~ 1000 to 1500 lts) (RHS) Typical radial plasma parameters with an input power of 400 W per source, 1 mTorr pressure using the LVPS configuration of 4 (blue, dotted line, filled up-triangle),

Large Volume Plasma Source (LVPS) (Contd...)

(red, dashed line, open circle) and 12 (black, solid line, filled square) CEPS Sources. respectively (a) Bulk plasma density n, (b) warm electron density nw, (c) bulk electron temperature Te, (d) warm electron temperature Tw, and (e) plasma potential Vp. Apart from its potential being used in the plasma processing industry, the LVPS has been modified to be developed into a large area hydrogenion beam sourcefor using as an auxiliary heatingor diagnostic sourcefor the National Fusion Programme under an MoU with Institute for Plasma Research, Gandhinagar.

CEPS based Electrodeless Plasma Thruster

Using a CompactECR Plasma Source(CEPS) connected to a large expansion chamber, it was shown that the CEPS has very good thruster properties. In argon gas it can produce a thrust of @50 mN at a pressure of @ 0.5 mTorr and @ 600 W of microwave power. These values are highly encouraging and have been vetted by theoretical calculations. A typical experimental setup for testing the efficacy of the CEPS as a plasma thruster. As shown in Figure 5 The CEPS is mounted to a larger expansion chamber (50 cm dia., 75 cm long) with the plasma expanding from the source into the expansion chamber along the diverging magnetic field lines. The ion energy distribution function f (E) with respect to ion energy, E derived from a typical RFEA characteristics [Figure 6]. Simulated plots of (a) bulk plasma density n; (b) bulk electron temperature Te; (c) plasma potential Vp; (d) thrust Fth [mN] as a function of pressures for Argon [black solid line, open circle] and Xenon [red dashed-dotted line, open square] [Figure 7]. The highlight of this work has been that the plasma thruster developed uses an electrodeless scheme, enhancing the longevity of the source. Further, these results have paved the way for initiating discussion with the LPSC, ISRO Team for the possibility of making direct thrust measurements at their facility. The modifications required for undertaking such measurements are in process.

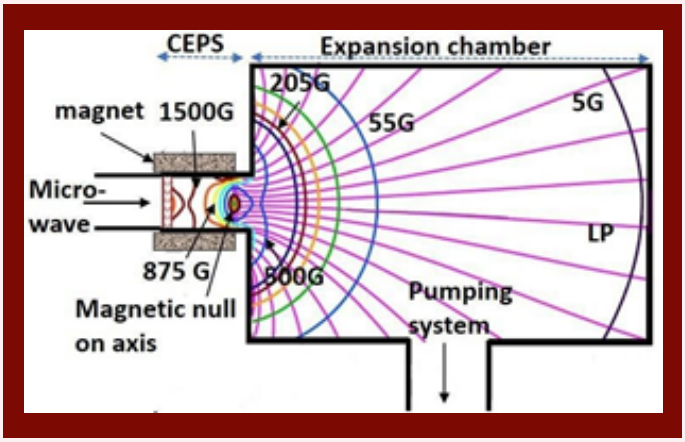


Figure 6

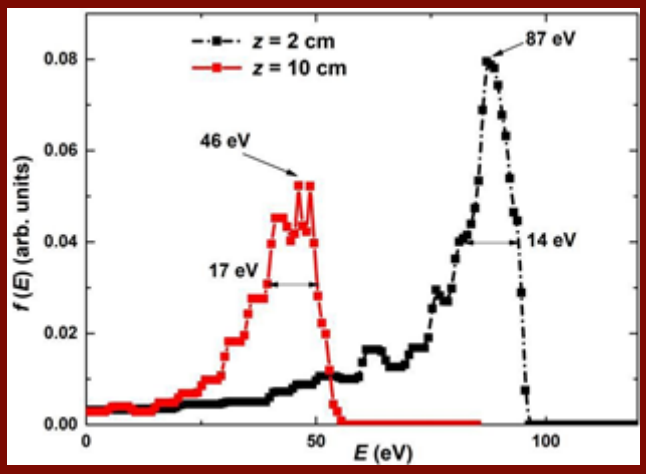


Figure 7

CEPS Studies on Hydrogen Plasma

Detailed studies have been conducted on hydrogen plasma produced by CEPS and allowing it to flow into an expansion. The studies have relevance for semiconductor surface modification, negative hydrogen ion beam production, etc. The highlight of these studies recently has been the development of a large area hydrogen ion source for ion beam extraction. This source is under development under a MoU with the Institute for Plasma Research Gandhinagar that could be further developed into neutral beams to be used as a heating source / diagnostic beam source in their fusion devices. Several configurations have been evaluated to date. Some salient configurations are shown in Figures 8 & 9. Multiple CEPS-ELNIBS configuration using 6 CEPS sources; Simulated magnetic field profiles of the upper configuration with the polarity for all CEPS aligned in (a) same direction (unipolar); (b) opposite direction (cusped). Plasma columns in (a) unipolar and (b) cusped configurations are shown in Figure 8. Single CEPS-ELNIBS configuration; Simulated magnetic field profiles of the single source-ELNIBS configuration. Photographs of plasma columns formed in this configuration have been shown in Figure 9.

Figure 8

Power Absorption in Capacitively Coupled Discharges (CCDs)

New and novel diagnostics have been developed for measuring accurately the harmonic power spectrum both inside and outside the CCD. Measurements have yielded new results on the harmonic spectrum and tuning theoretical models to reproduce these results would result in stronger and more accurate predictions from such models leading to better system design. The highlight of these studies has the development of a novel measurement scheme and a plasma diagnostic. A novel method of harmonic detection using RF Dual-Directional Couplers using a dual directional coupler between the plasma load and the matching network, it is possible to measure the entire harmonic spectrum produced in RF discharges like capacitatively coupled plasmas, for gaining insight into the nonlinear mechanisms generating the harmonics. A scheme for transformation of plasma impedance from the powered electrode (in contact with the rf plasma) of a capacitively-coupled rf discharge to the dual directional coupler (DDC2) plane Ã2 is shown in Figure 10. The estimation of the harmonic power using this scheme (a) Plasma density measured using a compensated Langmuir probe and (b) RF harmonic power content (second, third and sixth harmonic) using DDC2 versus Argon gas pressure at fixed 10 W RF power. The novelty of this scheme is that in spite of the DDC2 being placed in the region of the rf transmission line having multiple reflections between the nonlinear plasma load and the matching network, the forward and reflected powers in the line can be estimated separately and can be transformed to the desired plane. This non- invasive scheme is thus able to provide a host of rf electrical parameters which define the electrical characteristics of the nonlinear plasma load. b. J.E probe for power density measurement in RF discharges A novel J.E probe was developed for measuring absorbed power density in RF discharges at the fundamental and its harmonics. The highlight of this work is that it has provided key insights into the nature of RF power absorption in rf-driven capacitively coupled rf discharge (CCD). As CCD discharges are widely used in the industry, these studies will not only enable one to improve the models of the CCD discharge behavior but also identify methodologies to improve the efficiency of these systems for industrial purposes [Figure 11 & 12].

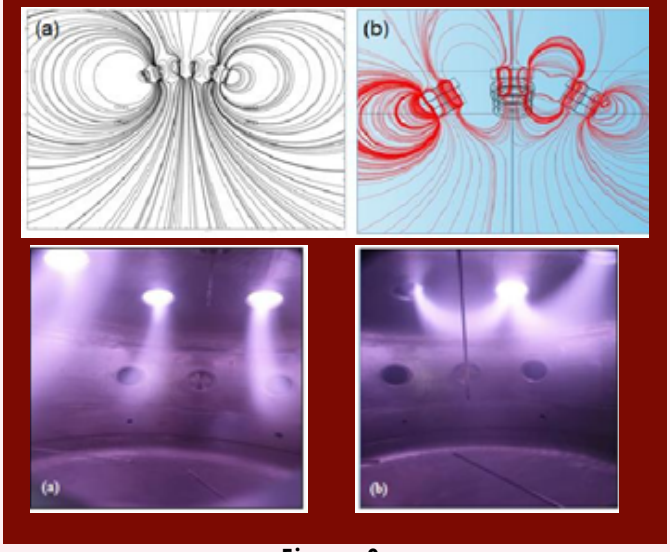
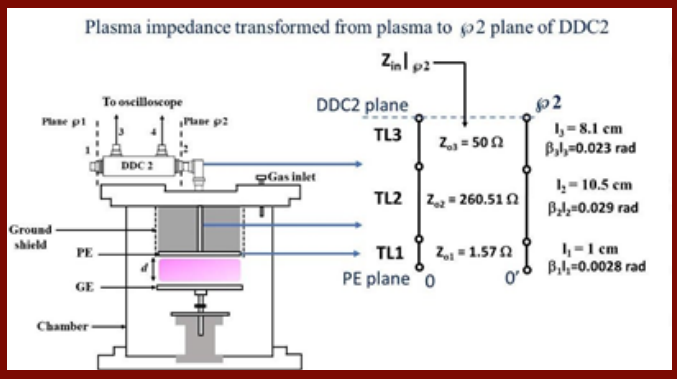


Figure 9

Plasma Theory and Simulation

Broadly three areas of theory and simulations on space plasmas, fusion and neutral fluids have been focused. Further, the objective has been to develop simulation related to turbulence, reconnection and nonlinear waves. The group has worked extensively on how turbulence and reconnection affect plasma confinement and heating. Since the experiments using high power lasers are in laboratory astrophysics, interpretation of these experiments by simulation codes through observed universal scaling laws related to turbulence is the focus. Also, various space missions like MMS are sending observational data related to scaling, break points, spectra and generated current sheets by reconnection at ion and electron scales. It has been of interest to estimate the energy of the energetic particles generated due to turbulence and magnetic islands in space as well as fusion plasmas. The methodology used is based on finite difference (with predictor corrector method) and pseudo spectral method for code development at serial and parallel machines. The goals are to carry out simulations on laboratory astrophysics experiments conducted in TIFR and Rutherford lab and to estimate the energy of the energetic particles generated due to turbulence and magnetic islands in space plasmas as well as fusion plasmas. The future plan is in heating and confinement problems in fusion device where plasma turbulence and reconnection play a vital role. Inputs are from: Experiments done by high power lasers (TIFR, Rutherford Appleton Lab etc), Space missions like CLUSTER, MMS, solar PARKER probe etc.



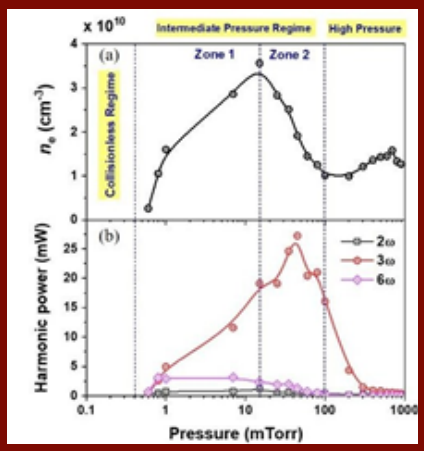
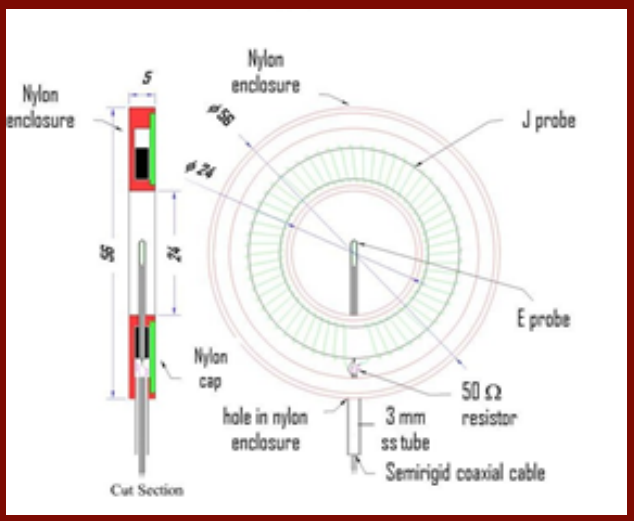


Figure 10



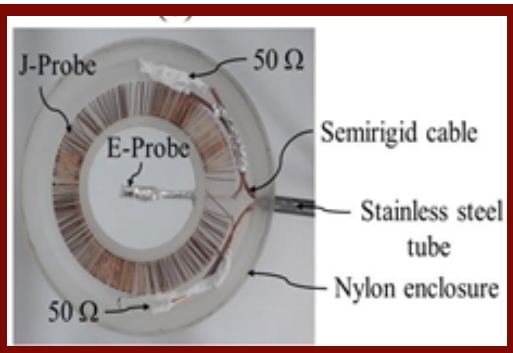


Figure 11

Hydrogen as Fuel

Technology for Hydrogen Utilization in Spark-Ignition Engine Generator for Electricity Generation with Zero-Emission ·developed in collaboration with Kirloskar Oil Engines Limited and Indian Oil R&D Centre. Diesel-fuelled internal combustion engine generator for electrical power generation mainly emits carbon monoxide (CO), Hydrocarbon (HC), Smoke, Particulate Matter (PM), Oxides of Nitrogen (NO_x), and Carbon dioxide (CO_2) emissions resulting in a contribution to air pollution. To tackle this, researchers at the Engines and Unconventional Fuels Laboratory, IIT Delhi developed a new technology and built "Hydrogen fuelled Spark-Ignition Engine Generator" in collaboration with Kirloskar Oil Engines Limited (KOEL), and the Indian Oil R&D Centre for the utilization of hydrogen in internal combustion engines for zero- emission with higher thermal efficiency. A dedicated lubricating oil for the engine was also developed by the IOCL. The project was mainly funded by the Ministry of New and Renewable Energy (MNRE), Government of India, and supplementary funded by KOEL and IOCL R&D Centre. IIT Delhi and KOEL have jointly filed a patent application for the technology. As Hydrogen does not contain carbon, the hydrogen-fuelled engine does not emit any carbonaceous emissions. The emission 'oxides of nitrogen' can be controlled to ultra-low levels using the appropriate technologies. Hydrogen is available as a tangible product from industries including chloro-Alkali, ammonia, and refineries. Hydrogen can also be produced from the splitting of water using electrolyzers coupled with renewable energy sources (solar, wind, biomass, etc.). The surplus electricity can be converted into hydrogen using the electrolyzer and then, the electricity can be produced using this engine whenever needed such as meeting peak load demand, no short-term grid power available, emergency, etc. The hydrogen fuel at up to 4 bar from the gaseous cylinder (150 bar / 350 bar / 700 bar) or the pipeline stored at low pressure (10 bar and above) in the industries will be injected into the intake manifold of the engine. The technology will be useful to the industries (chloro-Alkali, Ammonia, etc.), those are producing hydrogen as tangible or main products, to generate electrical power to meet their inhouse-power requirement in the industry". The developed hydrogen engine can also be used in decentralized power generation for industries, buildings, etc. Thus, the green power with hydrogen can be generated using the multi-cylinder spark-ignition engine generator with the developed technology for strengthening the sustainable energy and environment." If hydrogen infrastructure can be developed and made available in the future, diesel generators can be replaced with hydrogen generators for electrical power generation. It will help to control air pollution, especially in urban areas. A view of Hydrogen Fuelled Spark-ignition Engine Generator for Electrical Power Generation is shown in Figure 13 & 14.

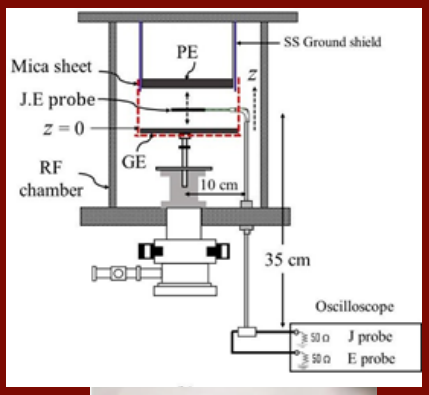


Figure 12

Figure 13

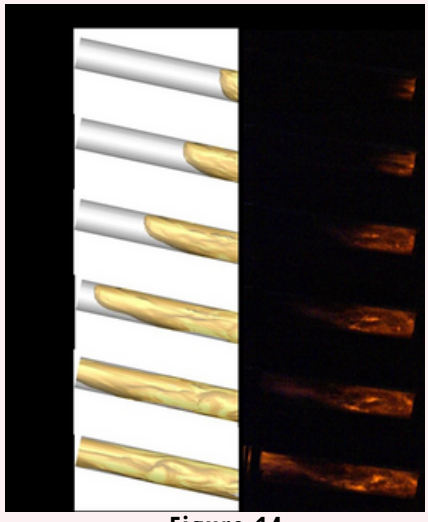


Figure 14

DME as a Fuel

Development of Methanol / Ethanol fuelled spark ignition engine with Oxy-Combustion is also under development. Dimethyl Ether (DME) is one of the alternative fuels to compression ignition engines/vehicles as it has a higher cetane number (~58) than that of conventional diesel, which has a cetane number of 51. DME can be produced from Biomass, Coal, Industrial Wastes, Municipal Solid wastes, Black liquor (a by-product of pulp) through gasification and the Fisher-Tropsch synthesis process. It can also be produced via catalytic dehydration of methanol. DME is generally stored in liquid and phase change from liquid to vapor/gas could easily occur at the ambient temperature and pressure. DME fuel is injected into the intake manifold of the engine, and diesel is directly injected into the engine cylinder. The CRDI system controls both diesel and DME fuel injection with respect to the load. The engine/vehicle operates with the optimum DME energy share without a knock. DME fuel being filled in Dost Vehicle by Portable dispensing system at IOC (R&D). Key highlights of the technology include the ability to run in Flex Fuel mode i.e. either 100% diesel or DME-Diesel mode, lesser particulate emission, lower noise with smoother engine/vehicle operation, improvement in transient engine performance, all resulting in enhancement of energy security, accomplished through a sustainable approach.

Unconventional Fuels

The production of the new generation fuel including ethanol, methanol, biodiesel, Fisher-Tropsch Diesel, Dimethyl ether, etc. with the desired fuel quality and its utilization in combustion engines with higher efficiency and ultra-low emissions is a major research challenge. The research work in the area of the utilization of alternative fuels/biofuels in spark ignition/compression ignition engines with an aim of higher torque /power output, higher thermal efficiency, and ultra-low emissions is being carried out. In this line, one of the current research is towards utilization of Dimethyl Ether fuel (lower carbon to hydrogen ratio and high ignition quality/Cetane number) in a Light Commercial Vehicle with the collaboration of reputed oil and automotive industries and the development of the technology has almost been completed and it will soon be flagged-off on the ground. The developed research test set-up at the Department has been shown in Figure 15.

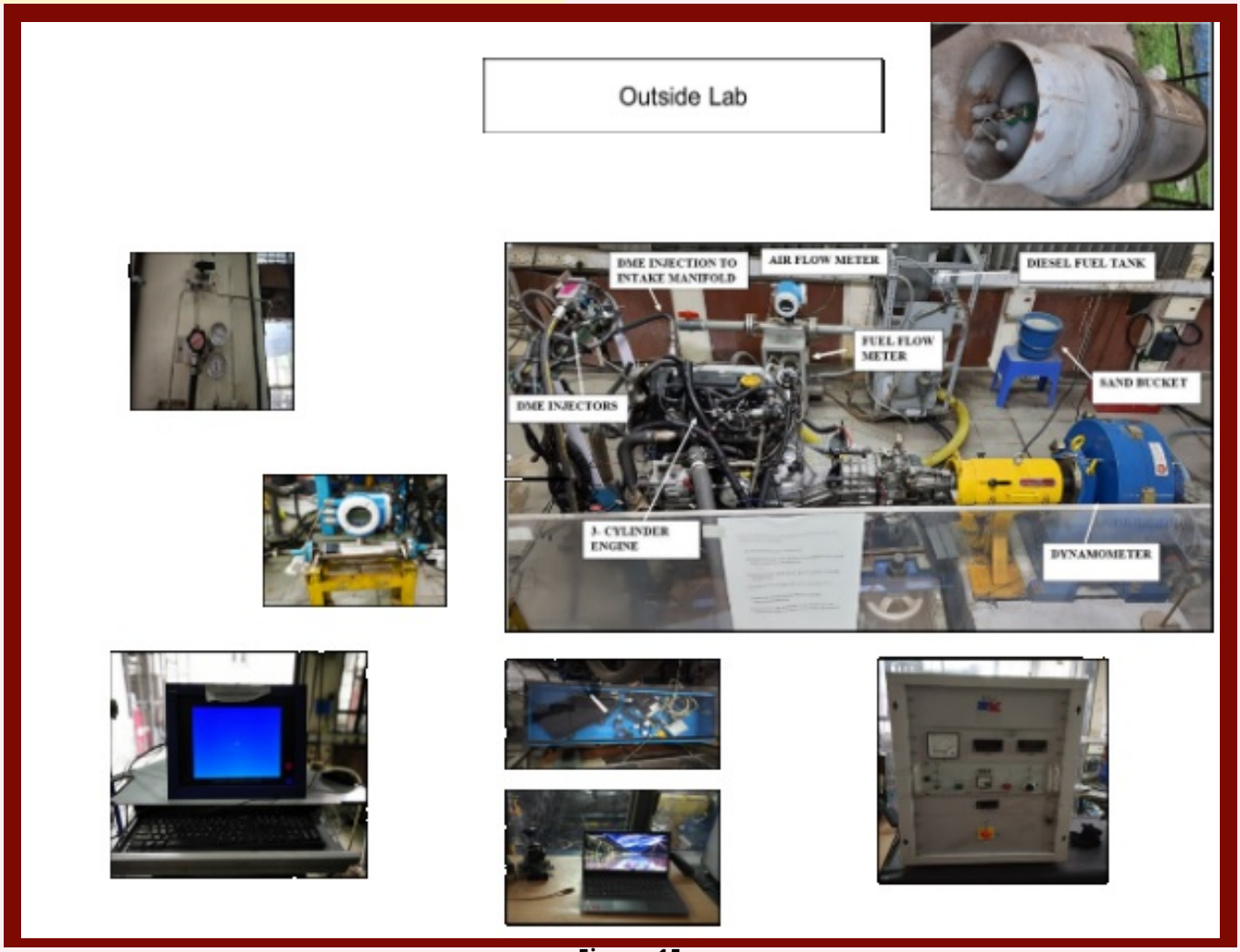
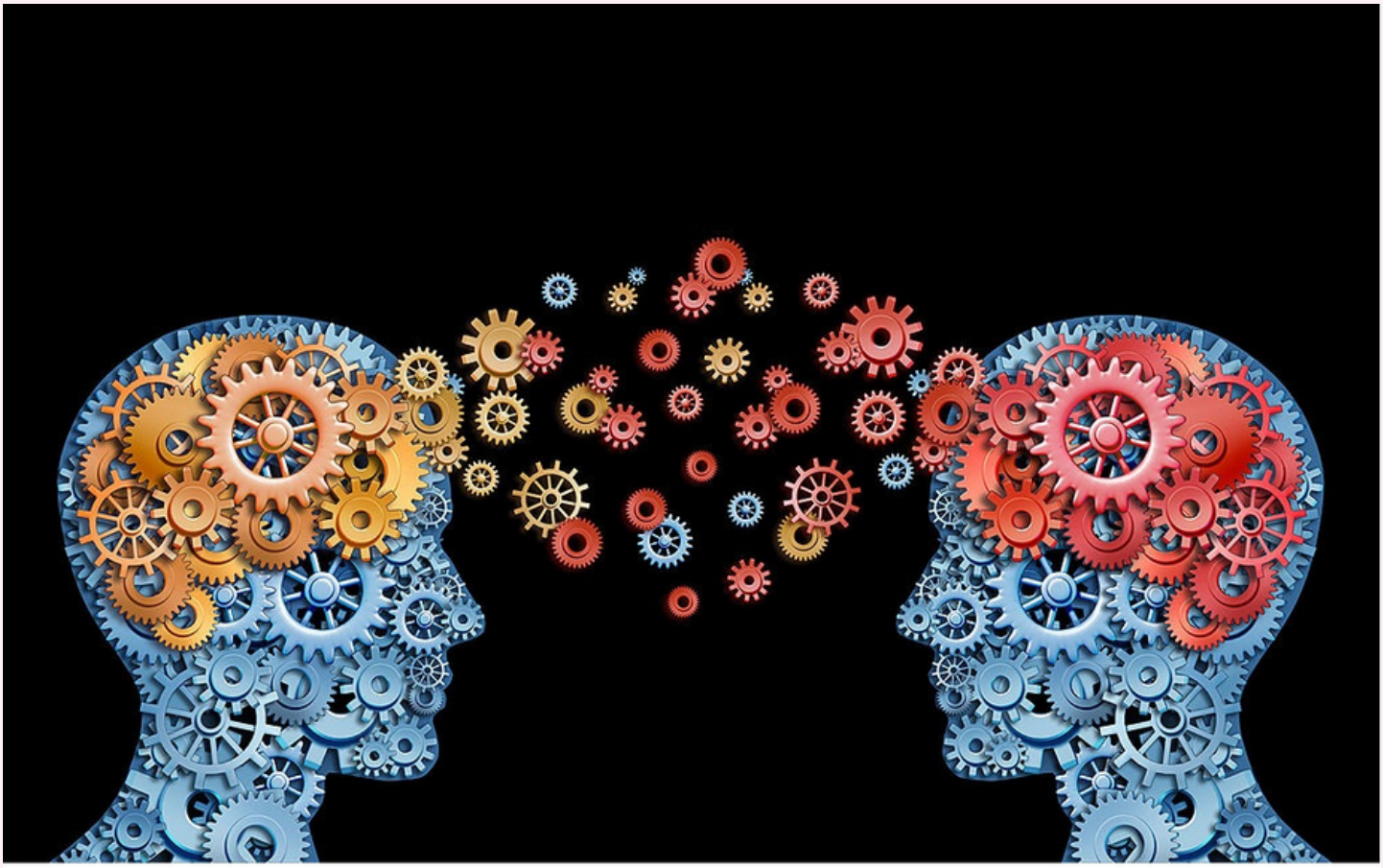
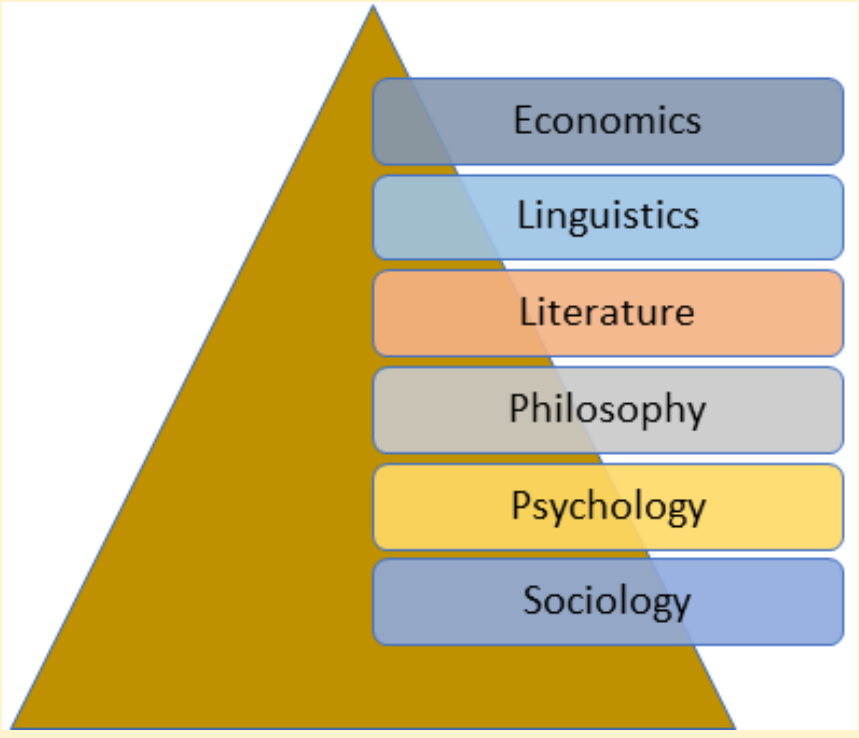


Figure 15



HUMANITIES AND SOCIAL SCIENCES

RESEARCH AREAS



The Department of Humanities and Social Sciences, with its excellent faculty in Economics, Literature, Linguistics, Philosophy, Psychology, Sociology and Policy Studies, contributes to this excellence. IITs are mandated to pursue teaching and research in science, technology and arts. IIT Delhi regards knowledge of Humanities and Social Sciences as a core value.

Sex-differences in Cognitive Functions

Whether the frontal asymmetry in brain activation potentially contributes to sex-differences in cognitive and emotion processing? Through a research collaboration with University of Queensland, the group seeks to explore hormones contribute to cognitive sex differences. Next step was to understand whether cognitive sex-differences are observed in countries with higher socioeconomic and gender equity compared to India (Germany and the United States of America). A three-country comparison found sex-differences to be stable, suggesting that male-advantage remained unaffected by the socio-economic variability of the three countries. Recently, the group observed that regulation of sex and stress hormone (testosterone and cortisol) contributes to male-advantage in a cognitive task, specifically when decisions involve risk-taking. More work is needed to understand somatic and neural basis of variability in cognitive functions. For instance, in a separate study on Mind-Body-Cognition with Computer Science Engineering, and Mechanical Engineering, the group observed that motor control, the ability to carrying out planned movements involved to achieve specific postures were associated with cognitive control. Also, how does injury to the spinal cord influence cognitive and affective processing, whether motor disability is associated with depression and early cognitive decline?

Loss Aversion

Despite the fact that behavioral economics, design, public policy, education, investment decisions, environmental action and multiple other domains have assumed loss aversion for last four decades and also the fact that two Nobel Prizes in the past have been awarded to the economists who upheld the theory of Loss Aversion, empirical evidence for the classic strong version of loss aversion is turning out to be weak. A research group in the department has shown that a magnitude-dependent version about loss aversion shows that unlike the classic idea, possible monetary gains loom equal to or larger than losses for low stakes (25 Rs), while losses loom larger than gains for high stakes (250 Rs.). It has been further argued that this needs a rethink on the very definition of loss aversion and associated less-discussed but fuzzy aspects that was not looked at in detail by previous researchers. These experimental findings have been replicated across other countries spanning Germany, Switzerland, China and others highlighting the robustness of the idea. Moreover, the research has found for the first time that beyond money, even time is valued in a similar way such that small gains of time (5 mins or 10 mins) loom almost equal to or larger

Loss Aversion (Contd...)

than losses of time. These studies were done in the context of daily travel suggestions using apps. It goes against the common saying that it is better to be one minute early than the hour late causing time scarcity and anxiety. In ongoing research, loss aversion is being tested in the domain of education where the stakes are about marks scored by students. Early evidence suggests a similar effect - gaining marks seem to loom larger than losing marks for low magnitudes (say 2 or 5 marks). Taken together, the idea that loss aversion is magnitude-dependent implies a deviation from the classic theorization and findings. The significance lies at realizing the implications across multiple domains and verticals spanning education, finance, mobility, healthcare, etc. A more nuanced understanding of how we value gains versus losses is critical for development of technological, social or policy interventions.

Brain and Cognitive Functions

How does the brain contribute to cognitive function, specifically making decisions that are rewarding in a long term? What happens to cognitive functions when specific areas of the brain are surgically resected, and reorganized? Understanding the complex relationship between brain and cognitive functions requires a multi-disciplinary approach. An inter-disciplinary, cross-institution collaboration with the All India Institute of Medical Sciences (AIIMS), New Delhi, examined a neurological case of a young lady with drug refractory epilepsy (NV, name not revealed) undergoing surgical procedure (hemispherotomy) for a cure of her epilepsy. Decision-making was compared pre and post-surgery (after 3 and 11 months) to understand how left-hemispheric atrophy and post-surgery re-organization might contribute to changes in female decision-making in the task. It was observed that left hemispheric atrophy and brain re-section showed the most prominent alteration in frequency-based processing of gains and losses in decision making. Further, this alteration was most prominent when dealing with uncertainty about decision outcomes, rather than in a phase that involves risk related to outcomes. Although based on a clinical case study, these insights align with other studies where female preference for frequency-based processing is observed, but more questions still remain unanswered. For instance, the way males and females deal with uncertainty and risk in decision-making remains poorly understood.

MANAGEMENT STUDIES

RESEARCH AREAS

- System Approach and Innovation Management
- Consumer Research and Business Analytics
- Sustainability and Business Ethics
- International Management
- Management of Education

The Department of Management Studies came into existence in 1993 by an amendment to the IIT Delhi statutes. The department has been adding value to both public and private sectors by virtue of various projects undertaken in both research and consulting domains. The interests are wide and varied ranging from social development to application of AI/ML techniques in finance, tourism and telecommunications.

Assessing Tourist Concerns From Social Media Posts

Indian tourism and heritage has seen immense growth in the past few years. Foreign tourists as well as citizens are enjoying Indian heritage, culture and art and there are constant updates on social media platforms. The social media has been a major platform throughout for people who post images, videos, blogs, check-ins and review heritage sites visited by them. This makes it essential for us in analyzing this unstructured micro blog text which may give us useful insights to identify the main user concerns surrounding heritage and tourism sites.

Impact Assessment of Migrations

Identifying patterns for understanding of the major trends in play, push and pull factors and patterns of migration, etc. using a variety of data. What are the economic impacts of such migrations? Does it create additional values for receiving economies? What gaps does it leave from where people are leaving or is it beneficial for those economies as well?

Impact Assessment of Migrations in India

In a study to carry out an impact assessment of various initiatives and schemes run by the Government of India, appropriate recommendations were made to improve the quality of the scheme and its ground-level implementation.

Management of Oxygen During Covid-19 Crisis

An IIT Delhi Review and Recommendations for Management of Oxygen during Covid-19 Crisis for GNCTD" was presented to the Hon'ble High Court (HC) in 2021 during the second wave of Covid-19.

Optimization of AI-based Chatbots

A study conducted to list out factors that play a key role in improving experience of customers who use AI-based chatbots in their day-to-day life for various purposes like registering complaint/ feedback found that the customer experience is built from the chatbot's ability to predict the suitable recommendation in minimal time [Figure 1]. Predictability is a crucial feature of an AI-based chatbot. It mimics the customer's interaction to offer them a feeling of judgment (or ambiance). The primary driving factor for a customer to use a chatbot is finding accurate information, which the chatbot designing team should consider as the most crucial factor.

Assessing Issues Associated With Electronic Payments in India

In the current scenario, with the government's digital India and cashless payments initiative, there has been an exponential growth in the use of digital payments and the underlying necessity of telecommunications network for the increased internet use for the same. There have been huge discussions surrounding the concerns of the masses and this is how the fact that the citizens of India have been facing major issues since the last few months have been visualized. This makes it critically essential to analyze unstructured micro blog text to get useful insights to the main user pain points surrounding digital payments and telecommunications.

Indian Technical Textile industry and Recommendations for Accelerated Growth

Analysis of the Technical textile industry in India and given recommendations for its accelerated growth; study how Covid-19 has impacted the MSME firms and understand the impact on various business dimensions

Covid-19 Vaccine Roll Out

IIT Delhi was the Institutional Management Partner for Covid-19 Vaccine Roll Out, an effort that was sponsored by Bill and Melinda Gates Foundation (BMGF), 2021.

Medical Waste Disposal Firm Selection

A study has thrown light on how hospitals can select a sustainable medical waste disposal firm. Hospitals, which often encounter difficulty in disposing their medical waste in a hygienic and sustainable way, can utilize a decision support framework. The study proposes a hybrid multi criteria decision support framework integrated with mathematical model to tackle the issue of safe disposal of hazardous and infectious healthcare waste

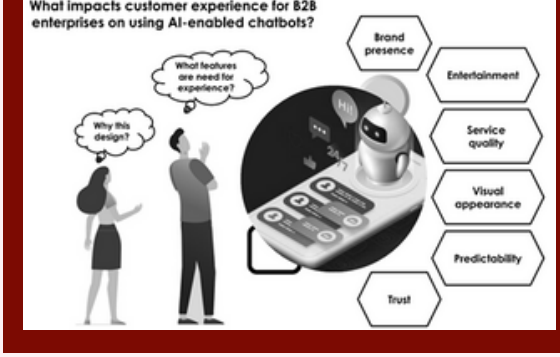
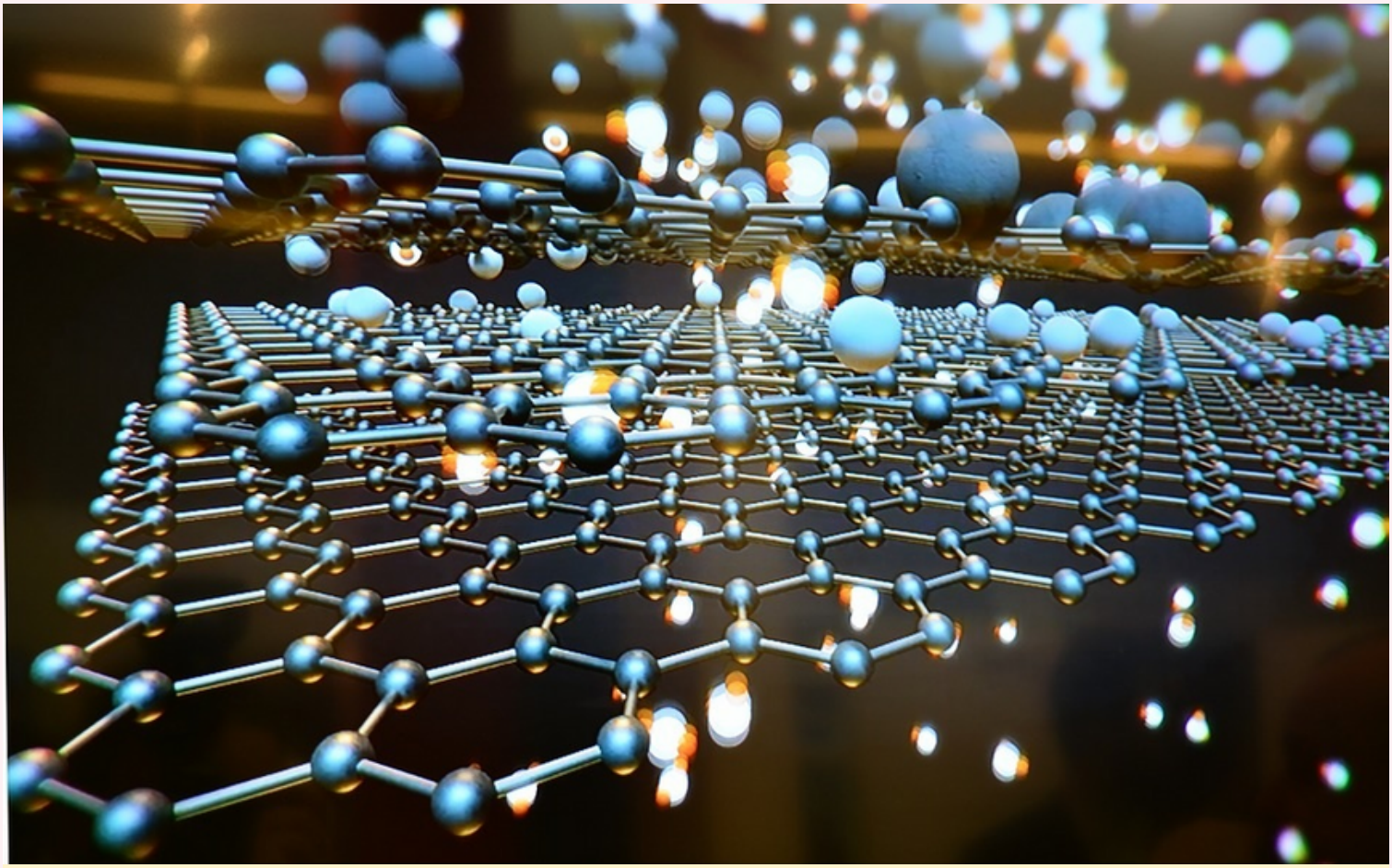
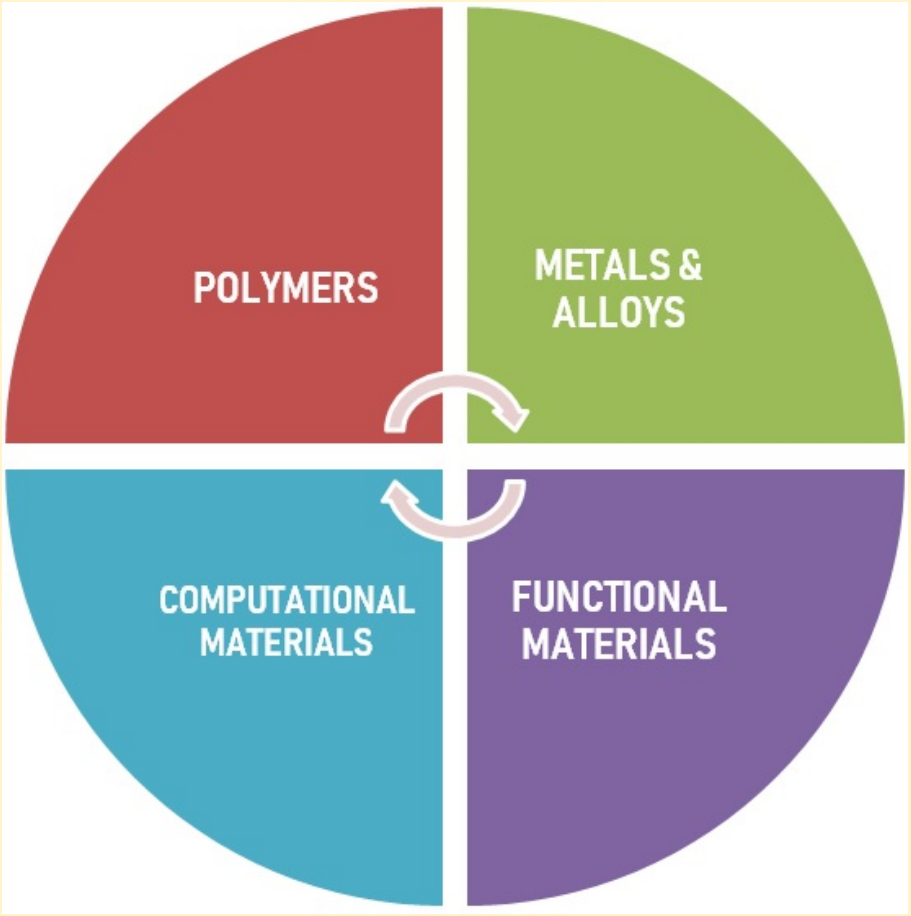


Figure 1



MATERIAL SCIENCE AND ENGINEERING



The Department of Materials Science and Engineering (DMSE) was established in 2018 for developing and undertaking research on materials for specific end uses. It holds the privilege of being the only materials research and engineering department in Delhi-NCR region. The department's research is inherently an interdisciplinary drawing from all application areas, and the fundamentals of materials science.

Perylene Diimide

Perylene diimide based polymers were successfully developed. These are used for Perovskite solar cell devices, truxene derived pure blue-emitting chromophore, water-soluble chelating polymeric materials for heavy metal ion sequestration from aqueous waste, D-galactose-based organogelator for phase-selective solvent removal, and sequestration of cationic dyes, pentaerythritol derived phosphorous based bicyclic compounds as promising flame retardants for thermoplastic polyurethane films, tunable macroporous D-galactose based hydrogels for controlled release of a hydrophilic drug, and macroporous polyzwitterionic gels as versatile intermediates for the fixation and release of anions [Figure 1].

Delignified Micro-Fibrillated Fibres

An eco-friendly method for obtaining micro-fibrils from natural fibres was developed. The process delignifies lignocellulosic fibres with supercritical carbon dioxide and water as precursors. Subsequent to delignification, the ultra-sonication performed on the delignified fibres results in the formation of delignified micro-fibrillated fibres. The work promises higher reinforcing efficiency with lower energy requirement leading to sustainable and efficient process [Figure 2].

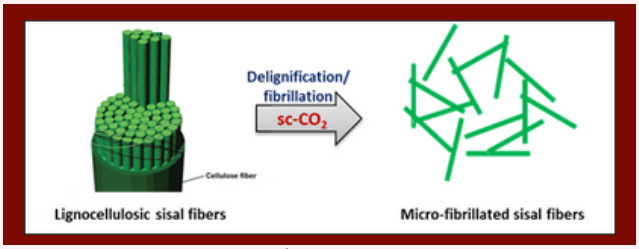


Figure 2

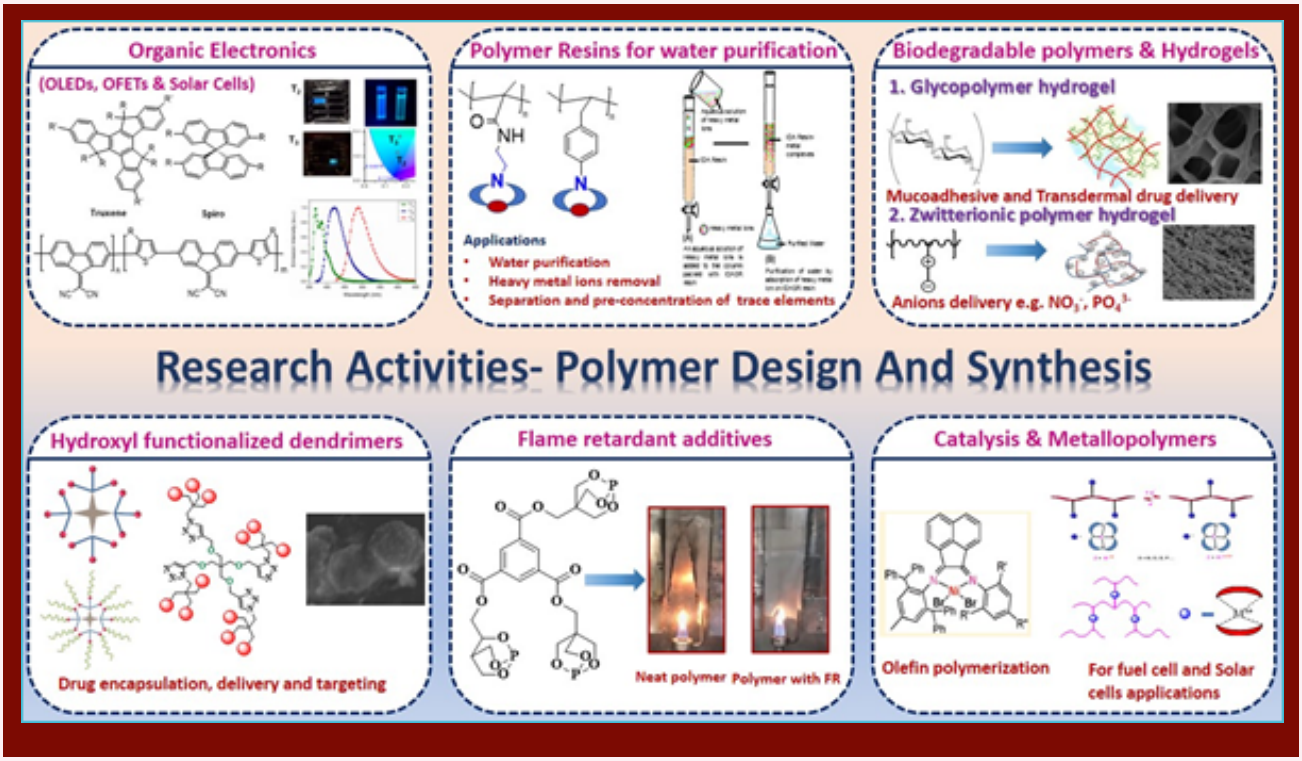


Figure 1

Grafted Nano-Cellulosic Fibre

The present disclosure relates to the process for preparing grafted nano-cellulosic fibre, the process comprising obtaining at least one alpha-cellulosic micro-fibre; and sonicating the acid hydrolyzed mixture to obtain the grafted nano-cellulosic fibre, wherein the grafted nano-cellulosic fibre is nano-lignin grafted nano-cellulosic fibre [Figure 3].

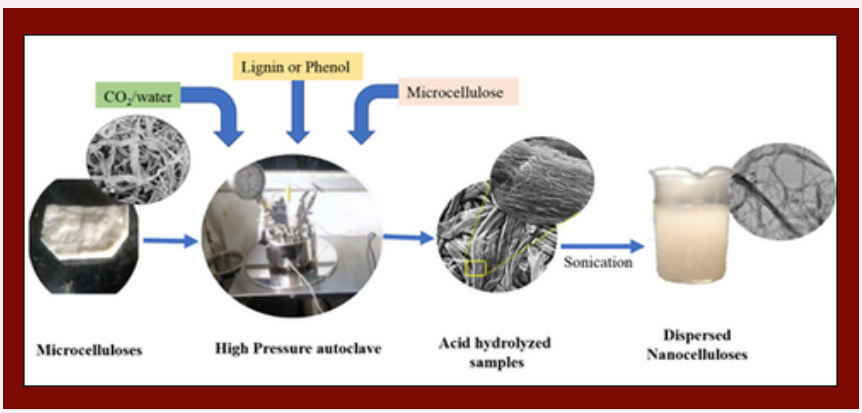


Figure 3

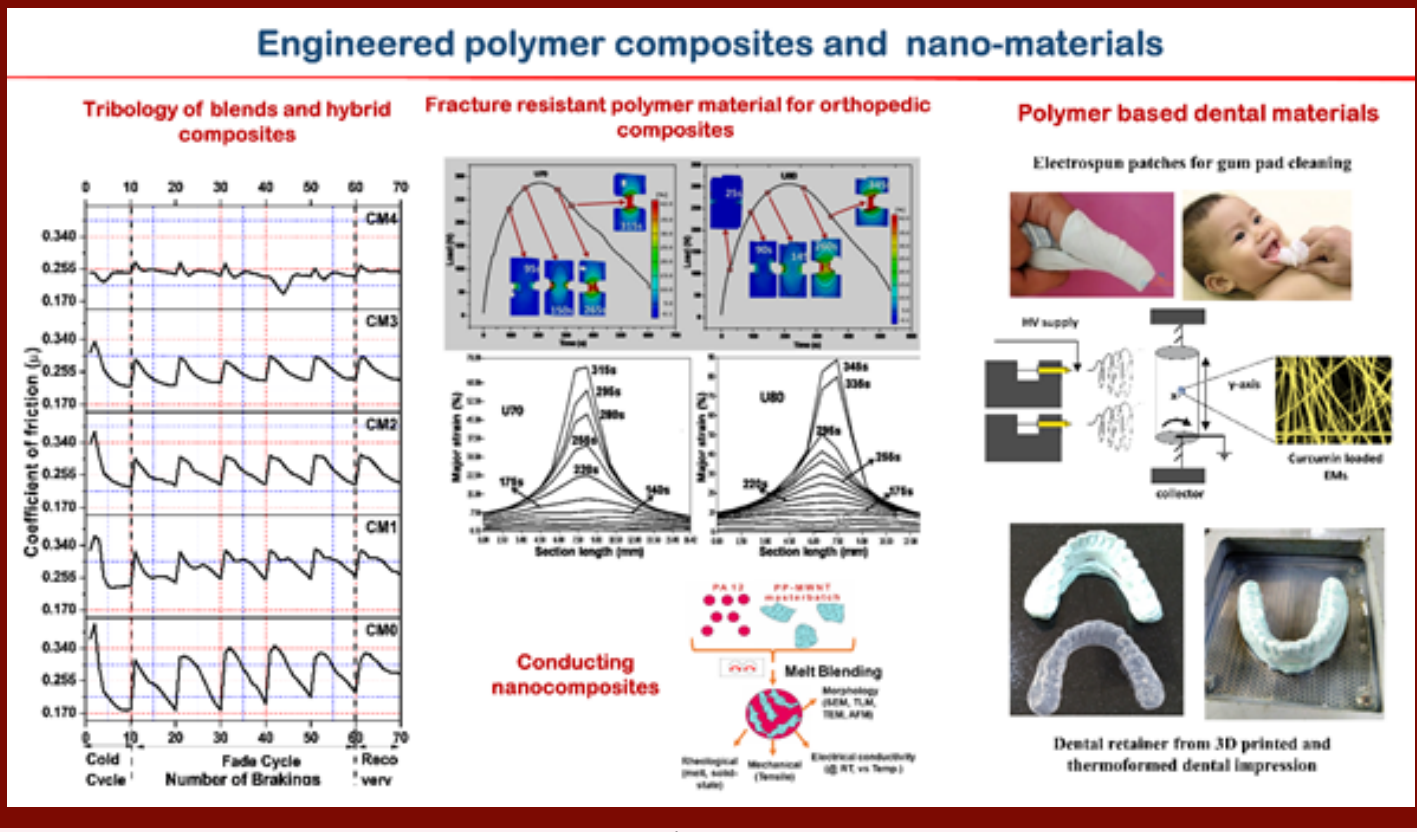


Figure 4

Novel Magnesium Alloys

The current demand of the automobile and aerospace sector is to improve the fuel economy to reduce CO_2 emission for minimizing the environmental impact. This can be achieved by reducing the weight of the components and as such lightweight materials are gaining significant interest. Owing to their low density and high specific strength, magnesium (Mg) alloys are potential candidates in light-weighting. However, application of Mg alloys is constrained due to their poor formability at ambient temperature and poor corrosion properties. In nearly one decade, our research group has made significant contributions towards designing novel Mg alloys with enhanced mechanical, tribological and corrosion properties. Several new alloys have been designed and prepared in-house at IIT Delhi. These alloys were subsequently processed and tested for the range of different properties. Among several approaches that include creation of ultrafine grain microstructures, enhanced solid solution strengthening, favourable distribution of nanostructured precipitates and manipulating the crystallographic textures are key. Some of the research group's recently developed alloys have demonstrated significantly enhanced mechanical and corrosion properties as compared to the conventional Mg alloys, opening up wider applications of Mg alloys, where weight-saving is critical. Representative images illustrate the enhancement of corrosion and mechanical properties in a newly developed Mg alloy [Figure 5].

Hybrid Functionalized Materials

Establishing highly innovative protocols for macromolecular surface engineering via combination of orthogonal and controlled radical polymerization techniques. The key research areas include (a) hybrid functionalized materials based on silica. A focus area of research is the development unique methodologies for the preparation of hybrid and functionalized silica for diverse applications, for example, nanoconfinement of hydrides, shear thickening material, controlled drug delivery, etc. (b) hybrid materials based on polybenzoxazines. Polybenzoxazine - a new class of phenolic thermoset, have emerged as potential precursor for preparing engineered and sustainable materials, in view of its inherent features such as high char yield, high cross-link density, and impressive thermal performance [Figure 6].

Surface and Particle Engineering

Different aspects of surface and particle engineering such as multi-compartmental biodegradable polymeric particles for drug delivery, biodegradable multi-layered polymeric particles for food packaging applications, infection resistant surface acquired by developing polymer brushes, nano fibrillated cellulose are being studied for biomedical and food packaging applications, biodegradable Janus particles for water remediation, catalysis and drug delivery [Figure 7]

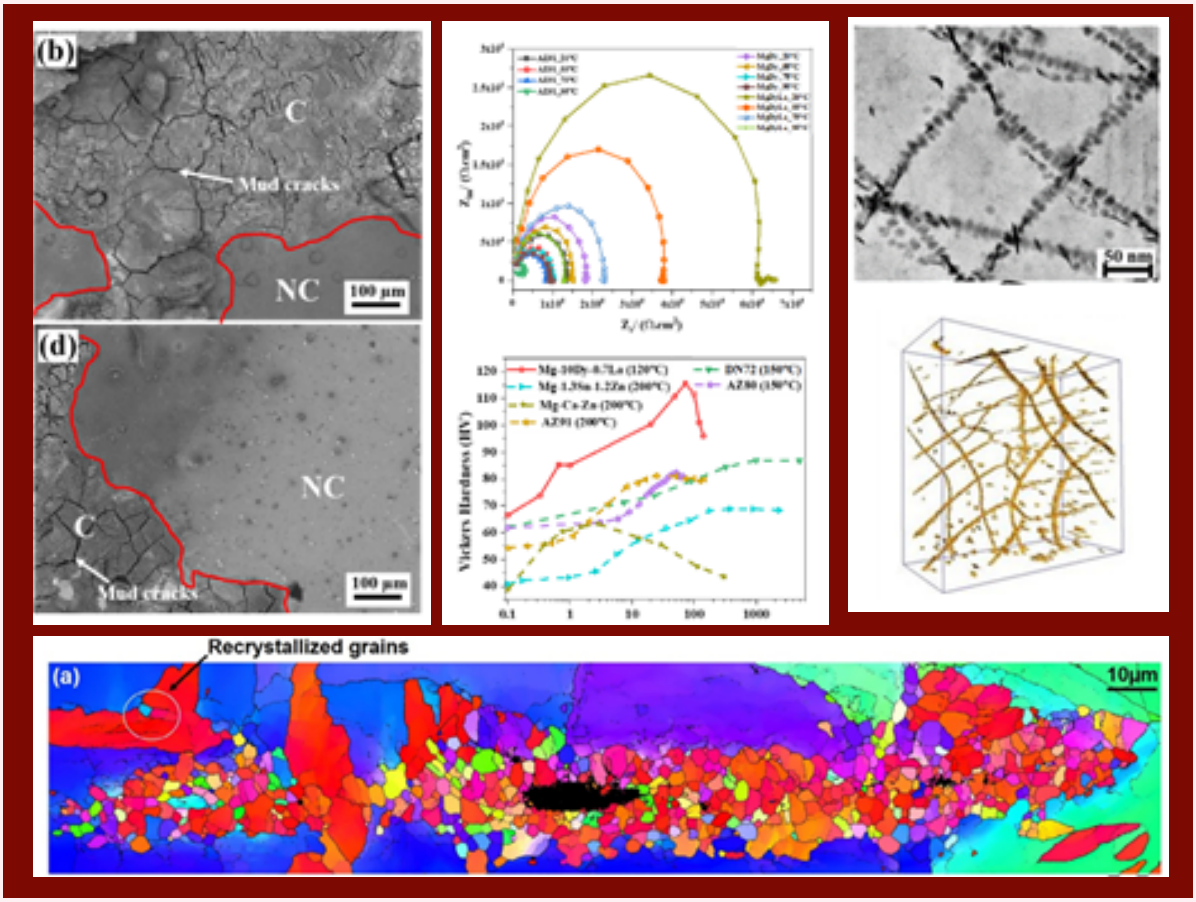


Figure 5

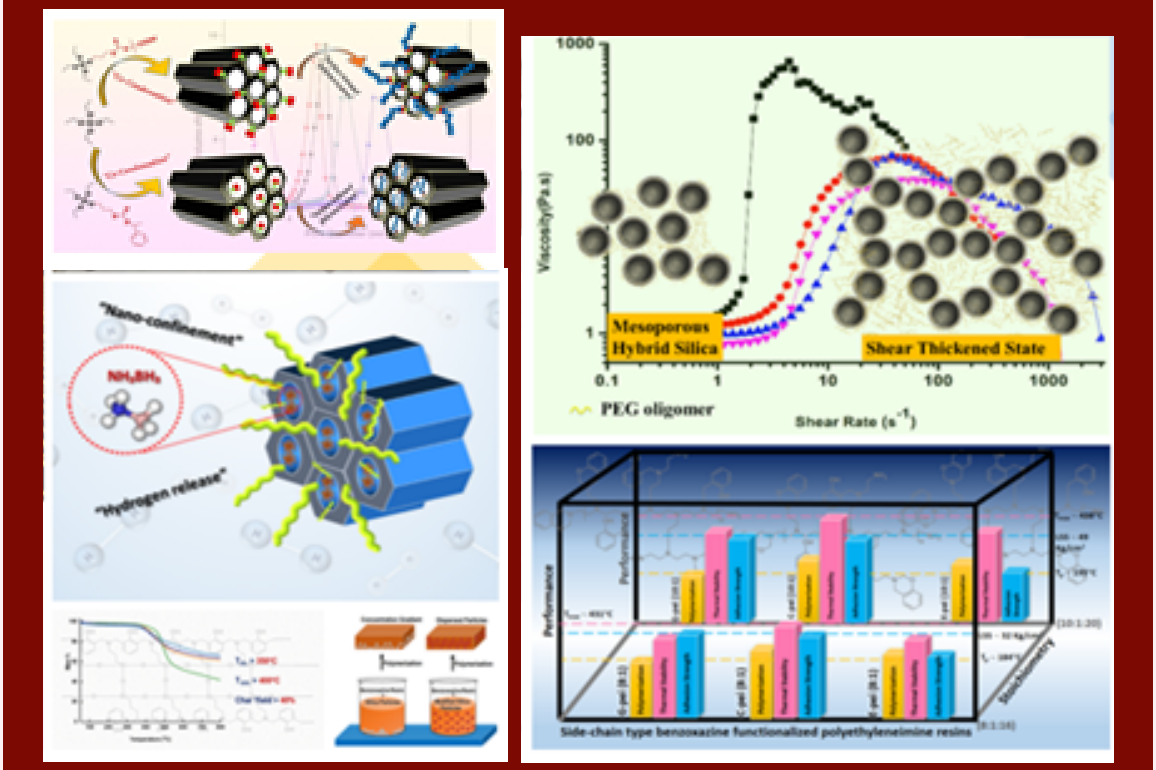


Figure 6

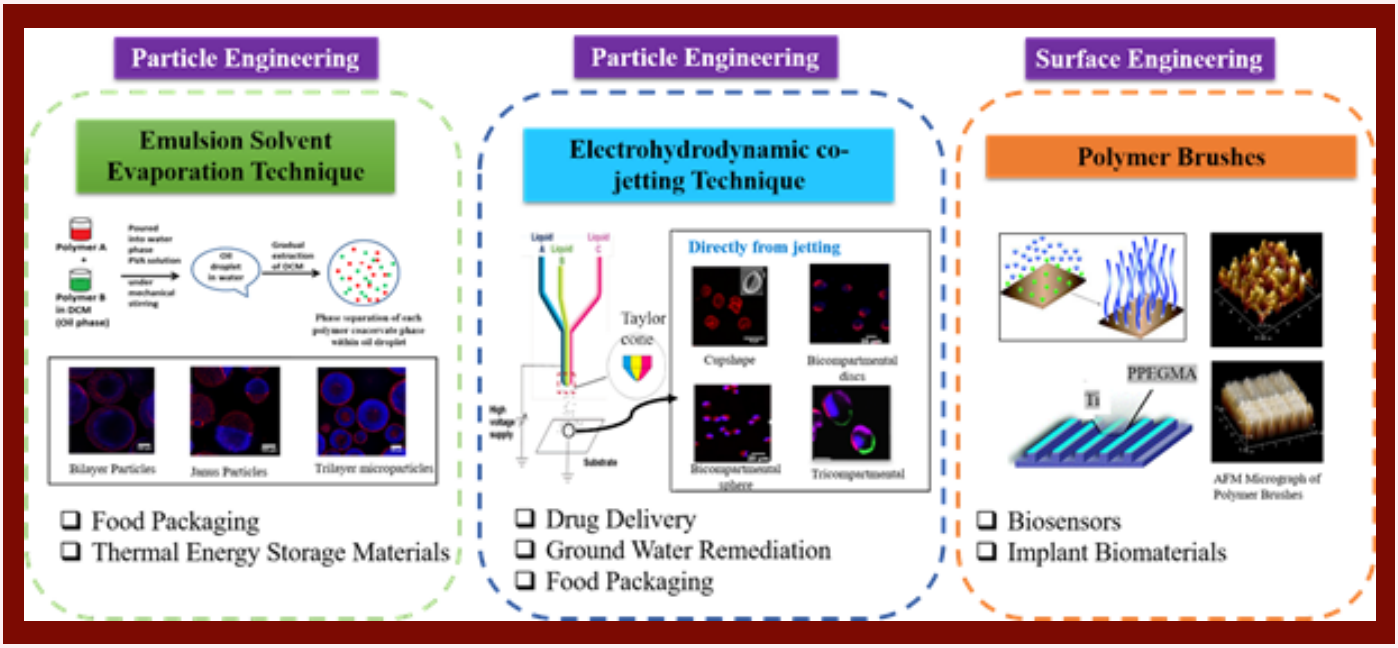


Figure 7

Non-Leachable Antimicrobial Coating

Prolonged use of body Implants such as pacemakers, intra-ocular lens, heart valves, hip and knee implants, and medical catheters etc. often lead to infections that arise from the microbial biofilms that are formed on the implant's surface. The most common strategy to counter the problem of Implant-associated infections (IAI) is the use of high dose antibiotics. But with the evolution of antibiotic-resistant microbes, this has proved ineffective in infection management. Another disadvantage of this strategy is the exhaustion of the antibiotic dose over a period of time due to leaching out. A non-leachable antimicrobial coating as a measure to deal with the danger of infections related to implants. Using the polyester as a scaffold, infection resistant polymer brushes are chemically bonded to its surface. The surface tethered brushes, fabricated from poly[(2-methacryloyloxyethyl] trimethyl ammonium chloride) (PMETA), are of nanometre dimensions, which possess antibacterial activity. An evaluation of antibacterial activity and cytocompatibility revealed that the composition of the brush not only inhibits bacterial growth but also offers a stable, non-leaching, anti-infective, cytocompatible coating on the surface of the implant. Further, the brushes also offer a physical barrier to the microbial cells, discouraging their colonization on the surface of the medical implant for a prolonged period of time. Fabricated disc-shaped microparticles, merely 15 micrometres in size, made up of two compartments for carrying dual drugs levodopa and carbidopa used in the management of Parkinson's disease without having drug–drug interactions. The particles are made entirely of biodegradable and biocompatible polymers which are FDA-approved and are currently in use as drug carriers. These were fabricated as disc-shaped particles as they have a superior ability to attach to the intestinal lining, thereby increasing the bioavailability of the drug, crucial for oral drug delivery system

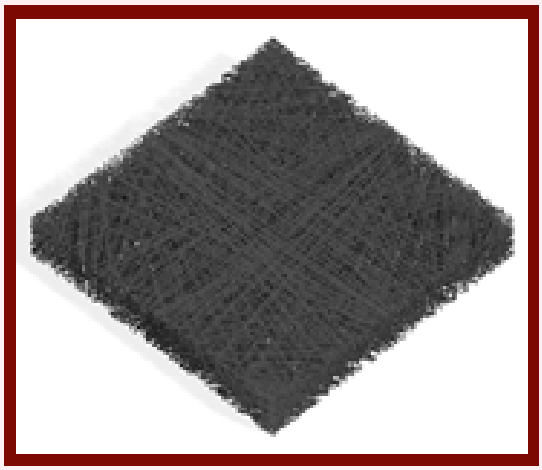


Figure 8

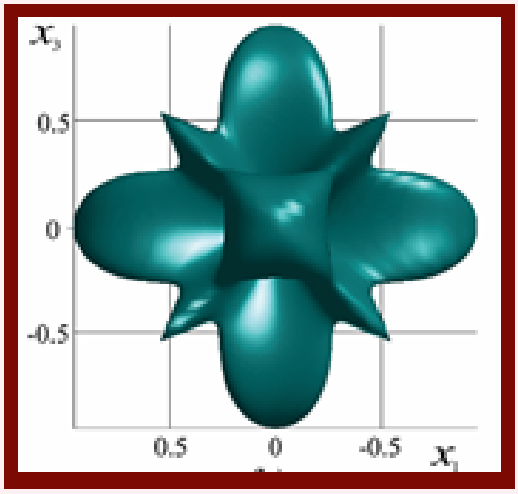


Figure 9

Figure 10

Advanced Materials Alloy Design

Research on mechanical behaviour of advanced metallic materials: bulk and porous forms aims to exploit in situ phase transformations, triggered by mechanical and/or thermal means and to achieve microstructure modifications, by precipitation, grain refinement, fibrous architecture etc., in order to optimize structure–property correlations in materials.

Currently, the group is working on High Entropy Alloys (HEAs) and β Titanium alloys; TRIP/Stainless steels & Ti-, Ni- and Fe-based: shape memory alloys, stochastic fibre networks, auxetic (i.e. negative Poisson's ratio) materials/composites for various structural and biological applications. Significant progress has been made in the following topics/areas within the purview of the theme. These include i) Design and development of porous materials which include,

a) Fibre networks made of shape memory alloy/smart material fibres, Design of 3D porous fibre networks [Figure 8]

b) Auxetic materials or structures [Figure 9]

c) Dental splints [Figure 10]

ii) Microstructure modification in Advanced materials (HEAs, power plant steels, Ti alloys etc.,)

a) Precipitation formation and control for enhancement in mechanical properties of HEAs. Extensive precipitation in Al0.2Co1.5CrFeNi1.5Ti0.3 HEA after aging, promoting strength and ductility is shown in Figure 11.

b) Optimum heat treatment conditions for stable microstructure in dissimilar welded power plant steels (T91 and SS304H grades). Post-weld heat treated microstructure of T91 grade steel showing martensite promoting strength is shown in Figure 12.

c) Grain refinement through thermo-mechanical processing in β Titanium Alloys. Grain refined beta Titanium alloy microstructure after cold-rolling and recrystallization annealing resulting with enhanced strength-ductility properties is shown in Figure 13. Among the facilities that were established are the Vacuum Hot Sintering Press Machine Vacuum hot sintering press unit of 1600 °C temperature capacity and 20 ton pressure [Figure 14].

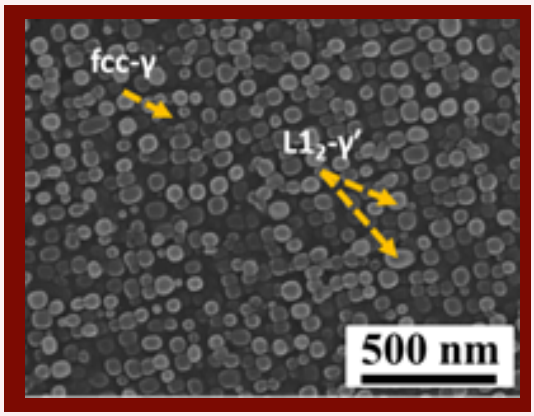


Figure 11

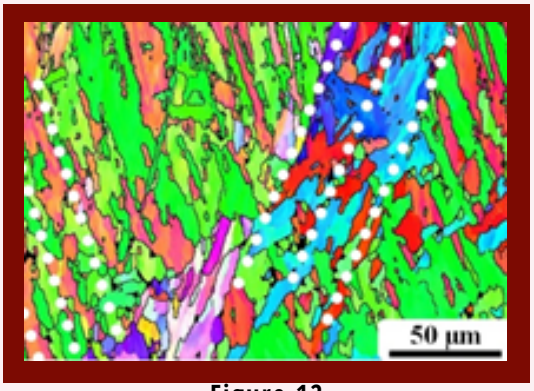


Figure 12

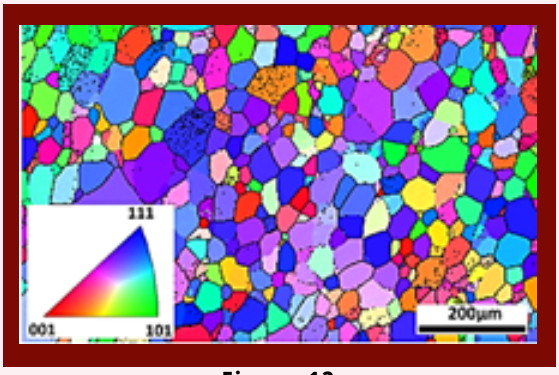


Figure 13

Figure 14

Micro and Nanoscale Tribology

Solving several fundamental but industry relevant issues such as energy inefficiency and material failure due to friction and wear in tribological components, which also results in harmful environmental emissions, is the focus of research. Currently about 25% of total energy produced worldwide is lost due to friction and wear related issues and results in burning of more than 100 billion gallons of fuel globally every year in transportation sector alone. The research group is working on understanding the fundamental mechanisms leading to such inefficiencies and failures to minimize these issues. Few of the ongoing projects are focused upon fundamental investigation of mechanisms of wear and friction behaviour of aluminium and magnesium based lightweight alloys; Microscopic investigation of sliding induced tribochemical reactions under automotive lubricants; Tribostress induced self-generated lubricious thin films; Fundamental investigation of lubrication and wear of 2D materials; Scratch induced wear and cracking of glasses and controlling scratch induced damage of glasses using 2D materials and nanotextured surfaces for controlling friction for MEMS devices.

Micro and Nanoscale Tribology (Contd...)

Highlights of research activities in Nanoscale Tribology, Mechanics and Microscopy of Materials (NTM3) Research Group at DMSE are shown in Figure 15.

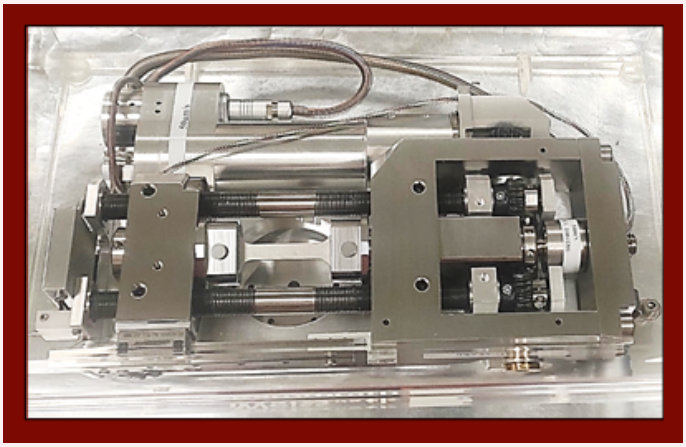


Figure 15

Nanostructured Materials & Nanoporous Membranes

Research in the group is focused on developing advanced functional materials and membranes for applications in water purification & separation, energy and electrochemical processes, environmental nanocatalysis, and biochemical applications. Unique combinations of nanomaterials are being developed with functional polymers to produce advanced hybrid materials and tuneable membranes for the above applications. As part of the development of superhydrophilic membranes, polyvinylidene fluoride (PVDF) and polysulfone (PSF) based nonsolvent phase inversion membranes have been prepared and molecularly grafted to induce in air superhydrophilic and underwater superoleophobic properties. The prepared membranes were used for oil-water emulsion separation. Almost complete rejection and recovery of the permeation properties showed that the prepared membranes could be used for wastewater treatment and water purification. Molecularly grafted antifouling PVDF membranes with in-air superamphiphilicity and underwater superoleophobicity are shown in Figure 17. In a second approach, the PSF membrane was modified with polydopamine followed by grafting of N, N-dimethylethylenediamine (DMEDA). In the final step, 1-Iodo-1H,1H,2H,2H-perfluorodecane molecules were grafted on the DMEDA functionalized PDA layer on the PSF membrane to obtain a hydrophilic-hydrophobic modification on the surface. The prepared membranes can be used for water purification, oil-water emulsion separation, and wastewater treatment. Amphiphilic antifouling membranes by polydopamine mediated molecular grafting [Figure 18 & 19].

Thermal Energy Storage

Phase change materials are essential candidates for thermal energy storage and management. In this work, a library of Phase Change Materials (PCMs) with a wide range of phase transition temperatures and latent heat storage capacities were synthesized using green and catalyst-free esterification reaction of stearic acid (SA) with different molecular weight poly(ethylene glycol) (PEG). In this process, the phase transition temperature and phase change enthalpies of synthesized PCMs were easily tuned by changing the molecular weight of PEG. The resultant PEG-distearate showed melting temperature in the range of 34.8-52.9 °C, with the latent heat storage capacities ranging from 121.5-145.1 J/g, depending on the molecular weight of PEG. These PCMs have a pleasant odor, do not undergo sublimation during their heating process, and are non-corrosive. Further to enhance its practical applicability, the PEG-distearate synthesized with PEG having 6000 MW (E6000) was nanoencapsulated into a thin silica shell using a miniemulsion assisted sol-gel method. The nanoencapsulated E6000@SiO2 showed excellent phase change performance with more than 48% encapsulation efficiency, 100% of heat storage capacity, and more than 98% retention of heat storage capacity after continuous 50 cycles of heating and cooling. Synthesis and nanoencapsulation of PEG-Distearates Phase Change Materials for Latent Heat Storage and Release [Figure 21].

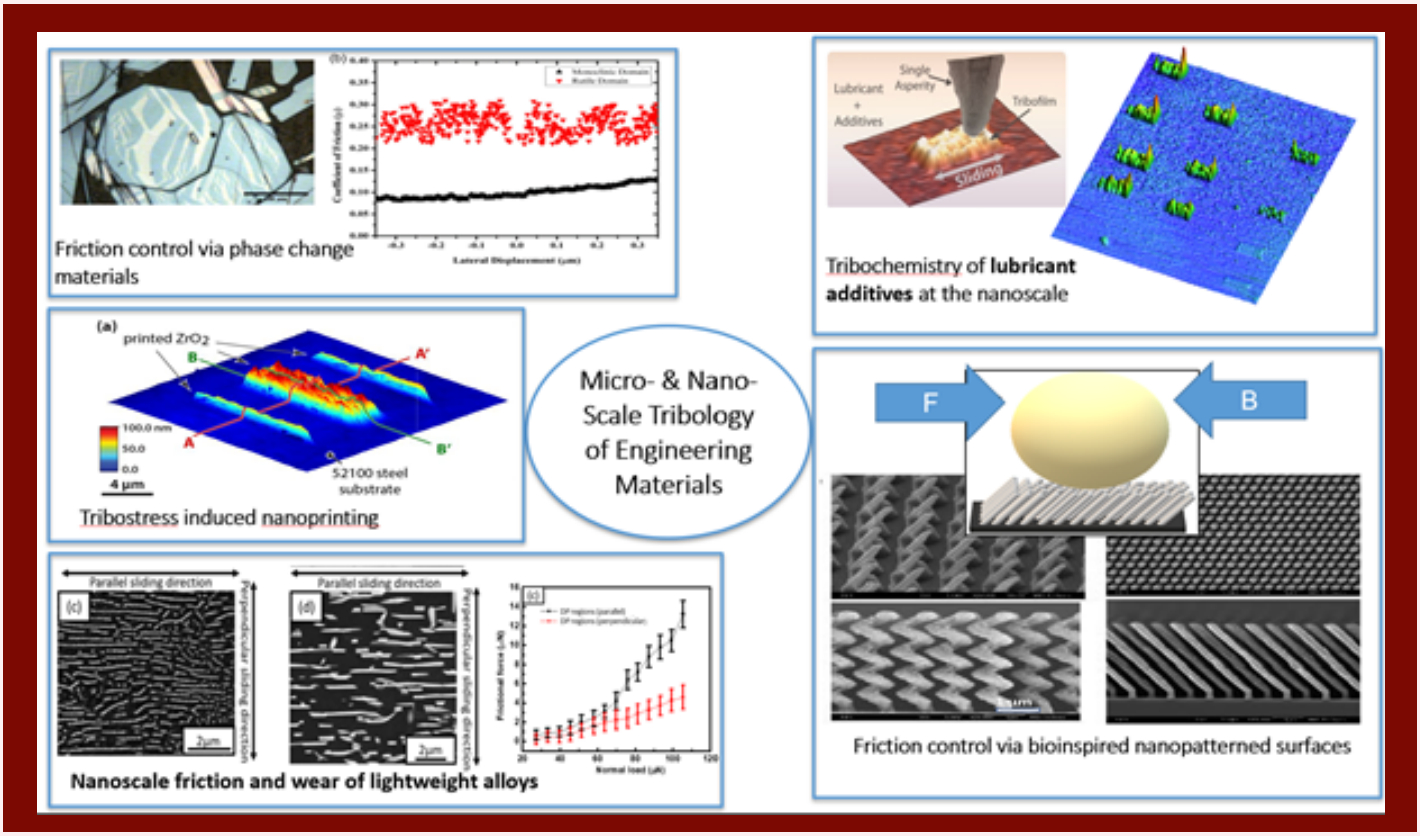


Figure 16

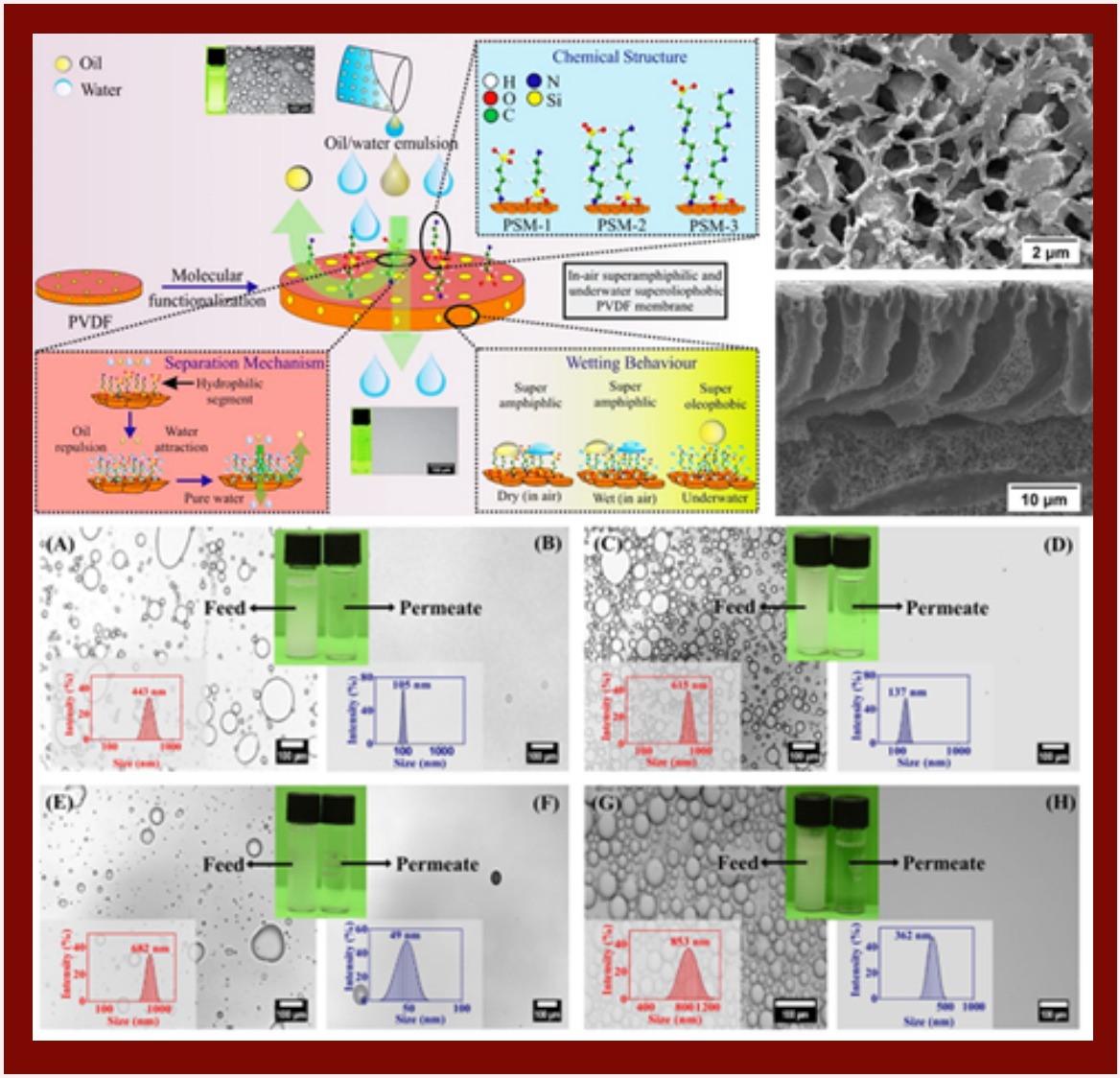


Figure 17

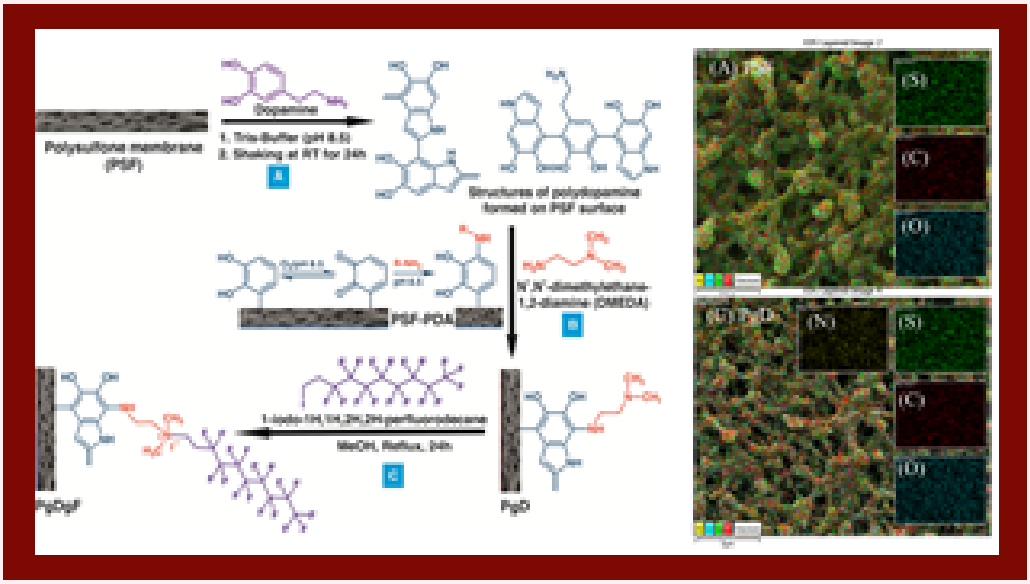


Figure 18

Aqueous Redox Flow Battery

A novel aqueous Organic Polymer-based Redox Flow Battery (ORFB) system based on Janus nanoporous and charged membranes and tailor-made electro/redox-active organic oligomers and polymers has been developed. The focus here was to synthesize water-soluble redox-active polymers based on monomers with redox-active moieties and Janus membranes to achieve high cell performance by limiting the crossover of materials and long-term application. Finally, a lab-scale prototype RFB consisting of Teflon support and flow chambers, current collectors, EPDM gaskets, graphite felt electrodes, and reservoirs for catholyte and anolyte connected to a peristaltic pump has been fabricated. The galvanostatic charging/discharging of the developed batteries and their life cycle assessment is underway [Figure 20].

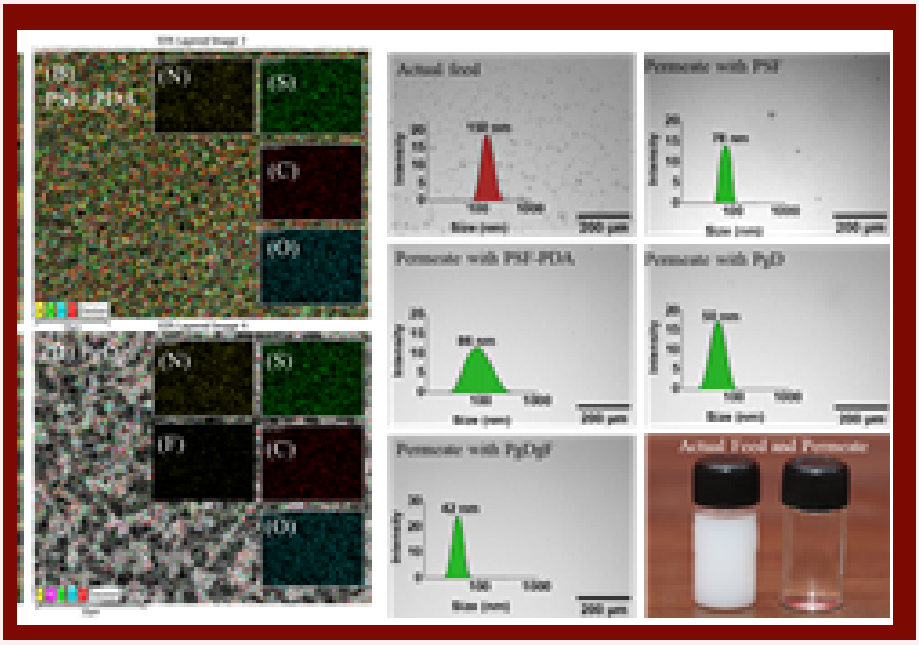


Figure 19

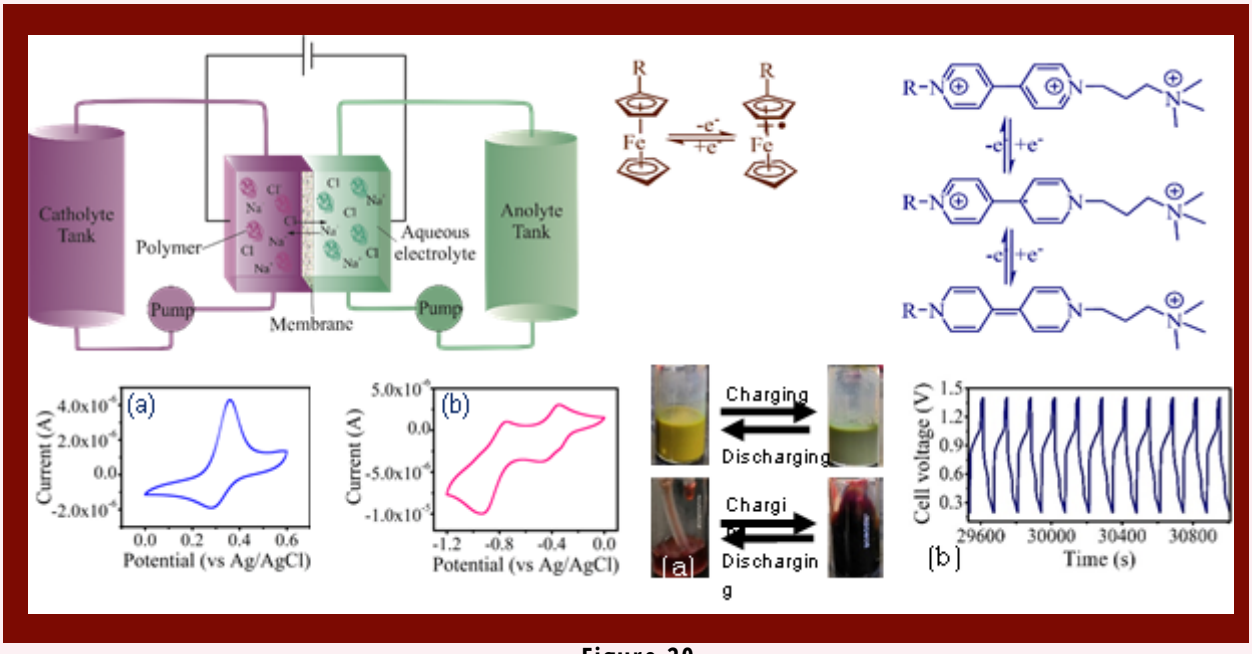


Figure 20

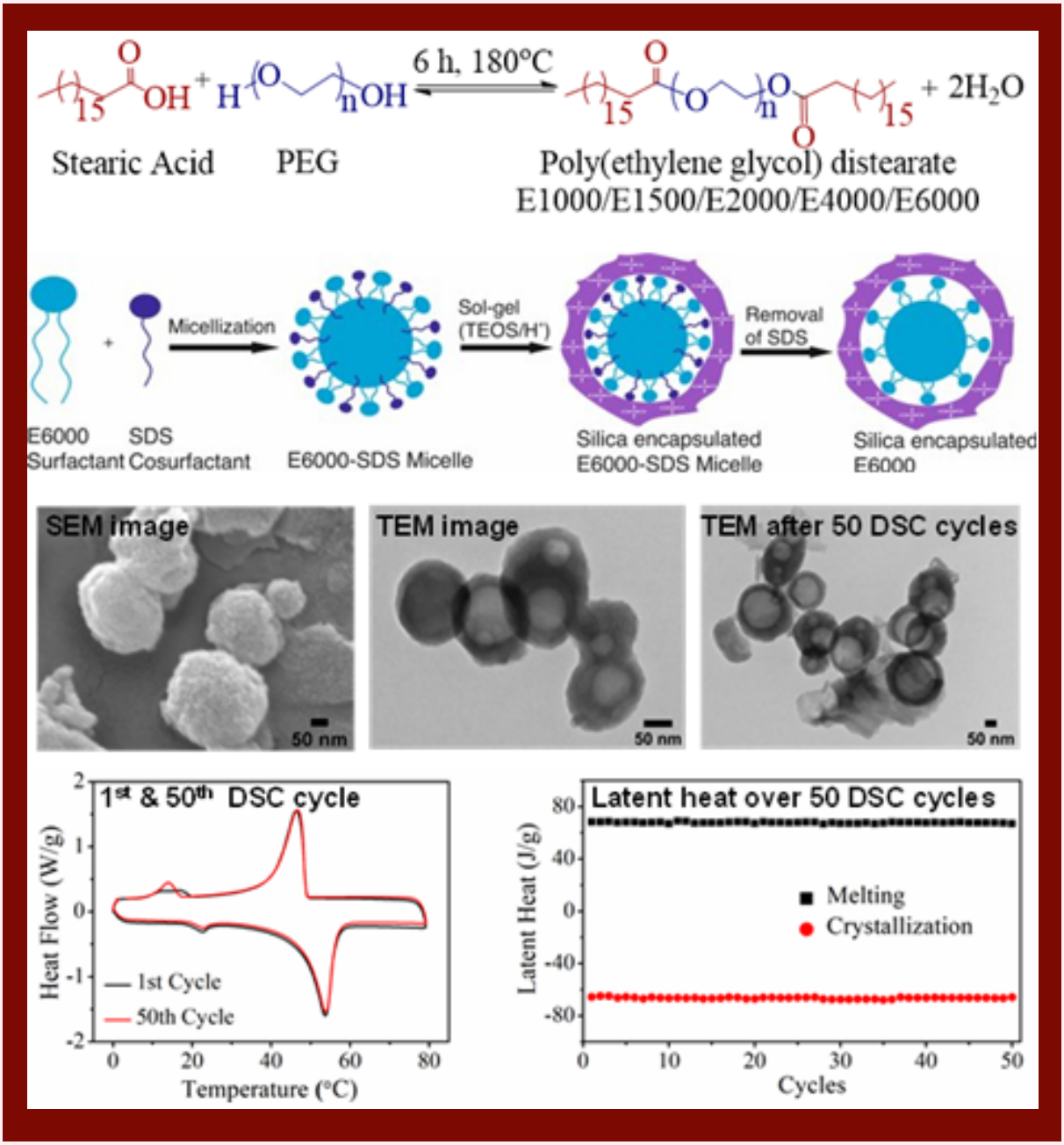
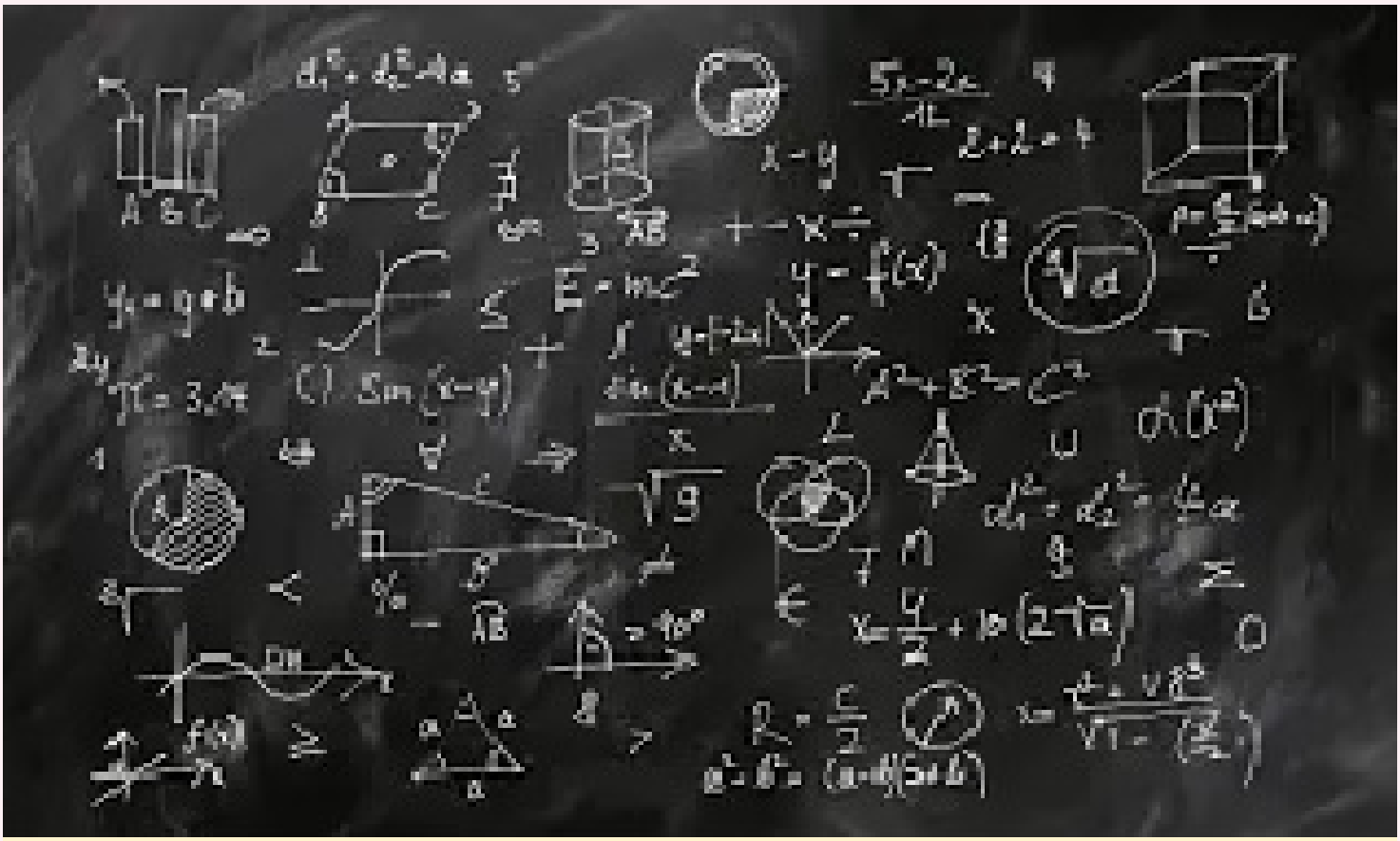

6 h, 180°C
+ 2H2O
Stearic Acid
PEG
Poly(ethylene glycol) distearate
E1000/E1500/E2000/E4000/E6000
Micellization
Sol-gel
(TEOS/H+)
Removal
of SDS
E6000
Surfactant
SDS
Cosurfactant
E6000-SDS Micelle
Silica encapsulated
E6000-SDS Micelle
Silica encapsulated
E6000
SEM image
TEM image
TEM after 50 DSC cycles
50 nm
1st & 50th DSC cycle
Heat Flow (W/g)
1st Cycle
50th Cycle
Temperature (°C)
Latent heat over 50 DSC cycles
Latent Heat (J/g)
Melting
Crystallization
Cycles

Figure 21



MATHEMATICS

The Department of Mathematics at IIT Delhi strives to be recognized for excellence among academic institutions in India and abroad. The department is conducting research in all the major areas of mathematics.

Energy Optimization

In the current wireless technology, although LTE-A (Long Term Evolution-Advanced) data transmission can be done at massive speeds, energy consumption by the User Equipment (UE) is the biggest concern. As part of a project titled 'Performance and Dependability Analysis and Development of Testbed of 5G Networks', a model for energy optimization has been designed through an energy saving scheme in the LTE-A networks using the Discontinuous Reception Scheme (DRX) mechanism,. In the LTE-A network, the DRX scheme is subscribed with evolved Node B (eNB), as a result the UE enters into a sleep mode when there are no packets to serve in the system, thus reducing power consumption as the system is in sleep mode.

Annuity Pricing

A discrete-time model for annuity pricing using generalized autoregressive conditional heteroscedastic (GARCH) model is proposed to address the pricing problem of a variable annuity (VA) contract embedded with a guaranteed lifelong withdrawal benefit (GLWB) and to overcome the limitations of the GBM model of constant variance. The US, Japanese and the World markets have been analysed. In the proposed framework, an analytical expression is obtained for the price of annual reset and point-to-point designs of equity-indexed annuities (EIA) by employing the measure change technique. The effects of the model parameters governing the jump risk and the clustering of jumps on the EIAs pricing are illustrated through numerical experiments.

Multi-penalty Regularization

Multi-penalty learning algorithms are quite popular in practical applications. However, a theoretical justification was not known for these algorithms. Research on the analysis of multi-penalty regularization and sampling theory addresses the convergence analysis and optimal rates for multi-penalty regularization in the learning theory framework.

Applications of Fractal Functions

Research is being pursued in exploring connections and consequences of fractal interpolation to other mathematical fields such as constrained approximation, functional analysis, operator theory, harmonic analysis, fractional calculus and differential equations. Currently, the research projects include multivariate approximation using fractal functions. Fractal interpolation is a relatively new methodology that supplements and subsumes the traditional interpolation techniques.

Network Resource Optimization

Technology transfer of reinforcement learning-based auto configuration of CM parameters, optimization of Inter layer traffic ratio and automatic detection of anomaly in transmission through monitoring of graphs in the field of network resource optimization has been achieved. Technology transfer has also been done in 'Working towards developing automatic Q/A system for robot attendant' for setting up a Centre of Excellence (CoE) on Artificial Intelligence (AI) under an industrial alliance with Nokia Systems and Solutions.

Meshfree Spectral Graph Wavelet Method

An adaptive meshfree spectral graph wavelet method to solve partial differential equations on network–like structures has been developed. Moreover, a nonlinear Caputo fractional boundary value problem on a star graph has also been studied. Further, the adjoined state and the optimality system are derived for fractional optimal control problem (FOCP) by using the Lagrange multiplier method. The research focus is also on deriving a numerical method to find the approximate solution of the resulting optimality system.

GOEMS

The main focus of the project titled, 'Games and Optimization for Energy Management with Stochasticity-GOEMS' is on applied problems where it is necessary to take optimal decisions in the presence of risk and uncertainty together with dependence between the random events, where the source of uncertainty is twofold. One component of uncertainty is exogenous, and results from substantially incomplete knowledge of important dependent problem data, like demand for goods and services, weather conditions, prices for commodities, high impact technical failures and other disruptions occurring with low probability. If only this kind of uncertainty is present, then the adequate methodology for modelling and solution of such decision problems is stochastic programming and game theory. The main achievements of this project are the proposal of a primal-dual pair of second order cone programs whose optimal solutions give a saddle point equilibrium of a zero-sum chance constrained game. An n-player distributionally robust chance constrained game with joint chance constraints was also considered. For various uncertainty sets, we showed the existence of Nash equilibrium.

Cournot Competition Model in Electricity Production, Distribution

An n-player Cournot competition model in electricity market was proposed, where the problem of production and distribution of electricity has been considered. The Nash equilibrium of the game has been computed using the best response algorithm. An n-player game was considered with joint chance constraints under mixture distributions. For a list of selected distributions from elliptical family of distributions, it was shown that there exists a Nash equilibrium of the game. As an application a game theoretic situation was studied arising in financial market. Simulations were performed using the best response algorithm. The existence of a Nash equilibrium for an n-player stochastic Nash game with individual chance constraints was shown. An equivalent optimization problem was proposed to compute the Nash equilibrium. An equivalent primal-dual pair of second-order cone programs for a zero-sum distributionally robust game for various uncertainty sets was also proposed.

Pseudo-differential Type Calculus

A study of a global version of the pseudo-differential type calculus on different types of decompositions given in terms of representations of groups acting on the spaces, revealed the characterizations of Gevrey functions on compact Lie groups. But, later it was noticed that the group structure is actually not necessary! Many of the developed techniques can be extended to settings without group structure.

Modelling & Validation of Dinucleotides in Human Genome

In this research, the main objective was to assess the influence of methylation associated with the mutational bias of methylated CpG dinucleotides on the relative abundance of other dinucleotides in the whole genomes of humans. In this model, a change from any nucleotide to G or C occurs at rate Θ if it is a transversion and at rate Θ if it is a transition, while changes to A or T have rates of $1-\Theta$ or $\kappa(1-\Theta)$. Subsequently, Duret and Gartier et al., used a modified version of the Tamura model as it was evident that CpG doublet also evolve at an increased transition rate $\kappa 1$. Using this model, 100 randomly generated sequences of 10,000bp generated were simulated using Python. Five hundred random initial sequences of length 1,000,000 bp were generated using Python. The model that was used for the study is described below:

(A) d(u) = dij(u) is the 4 X 4 matrix of dinucleotide frequencies at time u

(B) t(u) = tijk(u) is the matrix of trinucleotide frequencies at time u

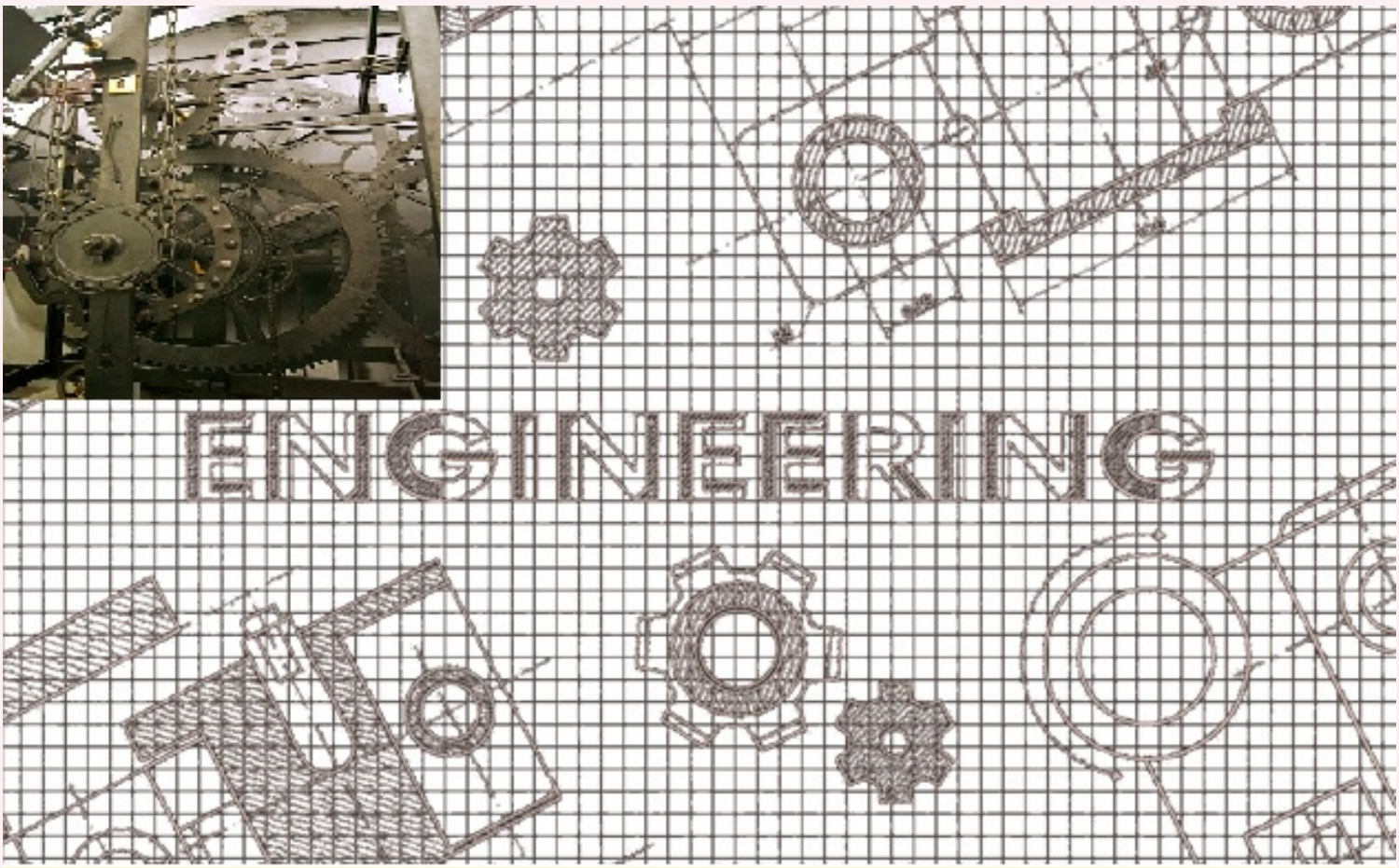
(C) r(i, j m, k) is the rate of change from trinucleotide (ijk) to trinucleotide (imk), deductible from the model

Modelling & Validation of Dinucleotides in Human Genome (Contd...)

(D) Factor b ((x, y), (i, j m, k)) in equation is the balance for dinucleotide (xy) when a (ijk) to (imk) change occurs, i.e., the difference between the number of (xy) dinucleotides included in trinucleotide (imk) and the number of (xy) dinucleotides included in (ijk). It has previously been shown that mutational bias (or excessive mutations in CpGs) may affect the relative abundance of CpG dinucletoides or the observed /expected ratios (O/E ratios). However, the effect of mutational bias for C to T mutations within the CpG dinucleotide may affect the O/E ratios of the remaining 15 dinucleotides; there is no literature on this aspect. The effect of mutational bias occurring within CpG dinucleotides on the O/E ratios of 15 other dinucleotides has been investigated.

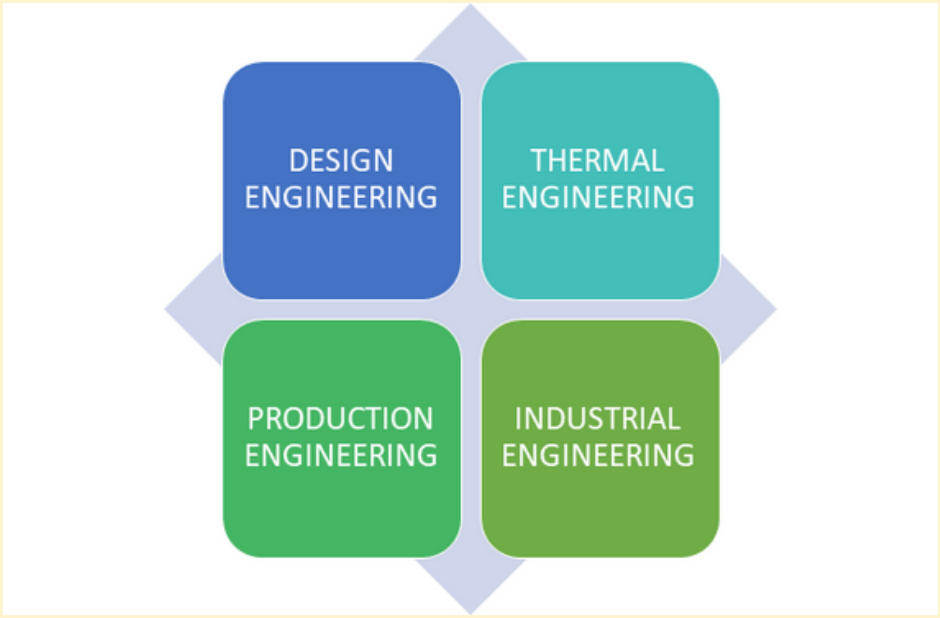
Pseudo-Differential Operators

In Michael. E. Taylor's words, "The basic method of noncommutative harmonic analysis, generalizing the use of the Fourier transform, is to synthesize operators on a space on which a Lie group has a unitary representation from operators on irreducible representation spaces. Thus, one is led to determine what the irreducible unitary representations of a given Lie group are, and how to decompose a given representation into irreducibles". Decomposing a function or operator in simple components, which can then be analysed efficiently is a powerful approach to various problems. This is the idea behind the Fourier analysis when functions are decomposed into simple waves, which leads to a notion of "symbol" – the representation of an operator with respect to these components. In the context of partial differential equations this is known as the theory of pseudo-differential operators, which proved to be very effective in the treatment of e.g. elliptic equations with variable coefficients. The important question is how to recapture properties of functions/operators from those of their symbols. The theory of pseudo-differential operators on spaces such as Lie groups, like compact Lie group, Heisenberg group, Affine groups and its various versions is the focus of this study. The simplest case is a compact commutative Lie and the Fourier analysis of operators there is already very interesting. Here a global theory of operators on such manifolds is of particular importance since it allows to capture many geometric and other underlying algebraic properties of the manifold (a Lie group), and to relate them to various properties of operators.



MECHANICAL ENGINEERING

RESEARCH AREAS



The Mechanical Engineering Department is one of the oldest departments of the Institute. It engages in research spanning a range of areas which are also highly interdisciplinary.

Lithium-Ion Cells

A Lithium-cell fabrication and testing facility has been established at the Institute that has been widely used by many academic institutions and industries for benchmarking and understanding thermal issues related to these battery systems [Figure 1 & 2]. Nanoengineering of Lithium-ion battery electrodes has also provided insights into the degradation and health of these batteries [Figure 3]. Mathematical models for simulating thermo-electrochemical behavior of Lithium-ion cells. have also been developed. Currently efforts are in progress towards developing accurate simulation framework for large-format Lithium-ion cells [Figure 4]. Efforts are also underway to develop efficient battery management systems capable of monitoring and estimating battery health for a variety of electrical loads and climatic conditions [Figure 5].

Figure 1

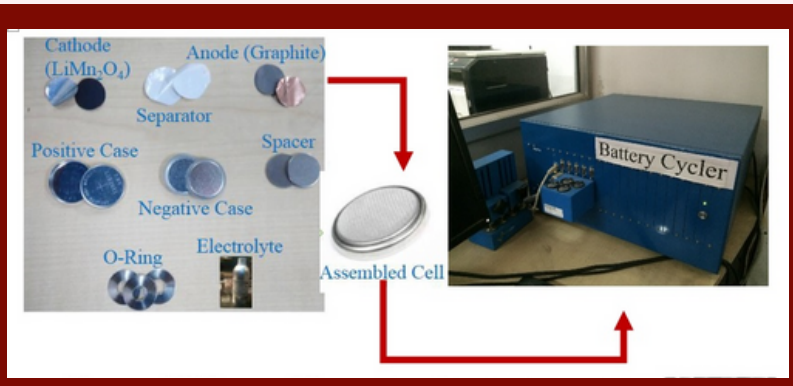


Figure 2

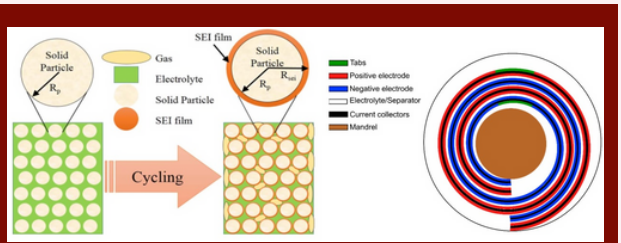


Figure 3

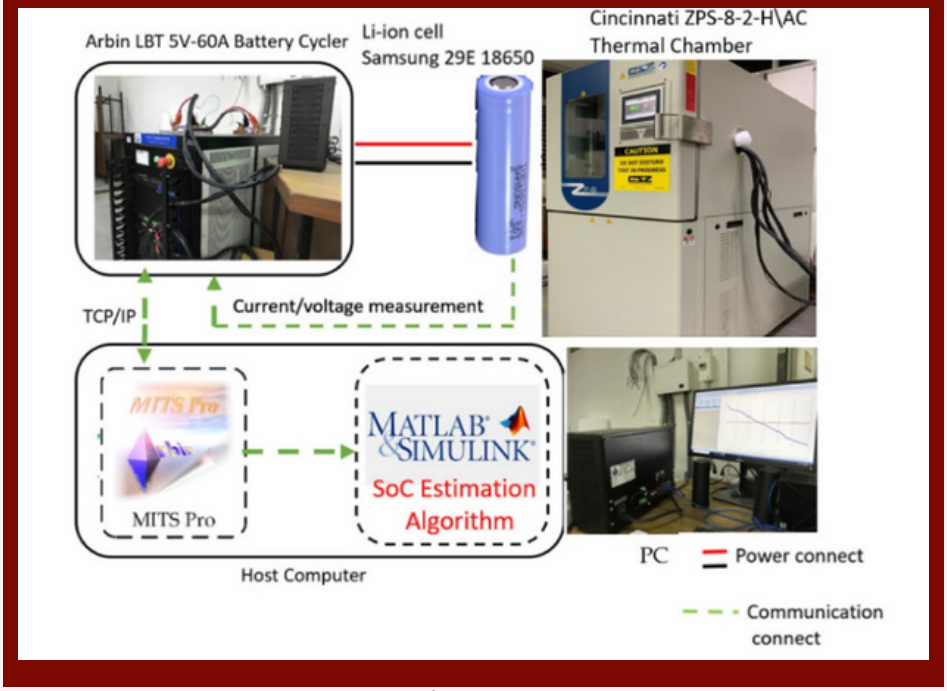


Figure 4

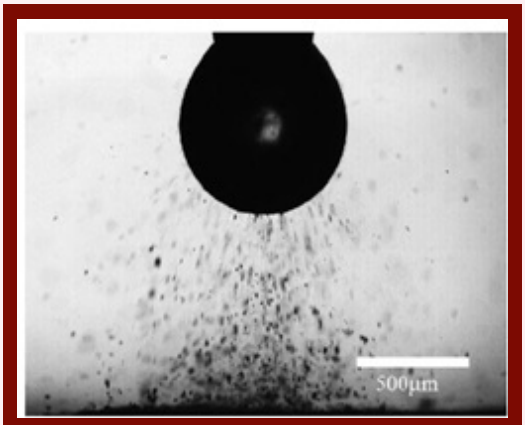


Figure 5

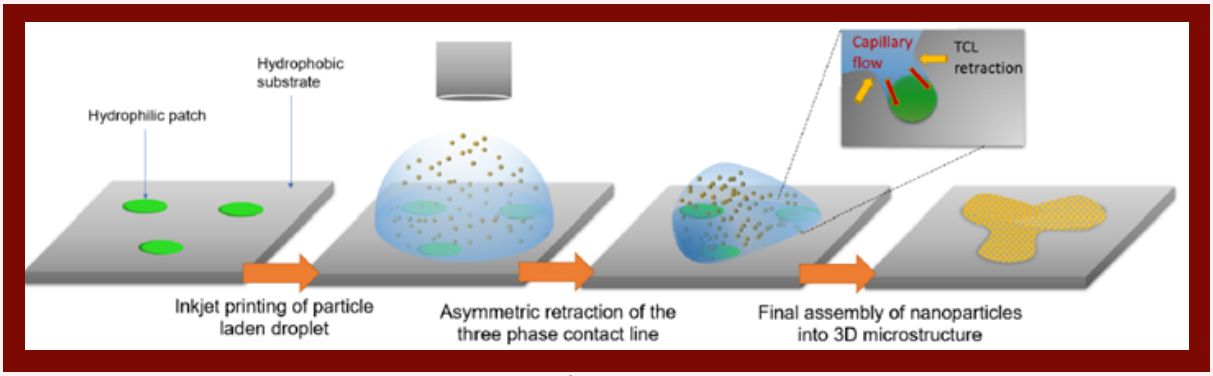


Figure 6

Mitigation Tools for Air Pollution

Development of mitigation tools for reducing air pollution in a by charged liquid droplets is an area of research. A multidimensional data-driven exhaustive and evolutionary solution to control-map-control the urban air pollution. This concept has been awarded in the Honda Y-E-S Forum. In addition, a numerical tool for understanding the physics involved in Multiphase problem has also been developed. Besides, research is underway to understand the process of 3D printing [Figure 6]. A numerical tool to simulate particle interaction of nano sized particle to millimeter sized particle [Figure 7] has been developed. Lastly, multiphase interfacial phenomena of drops and bubbles is also an area of interest [Figure 8].

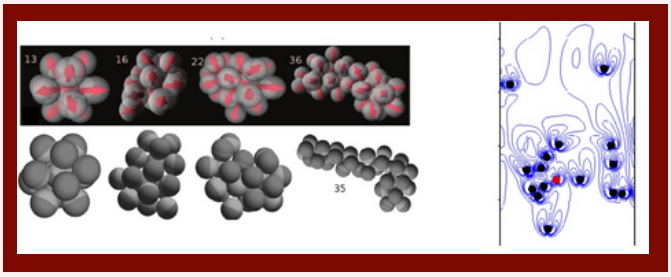


Figure 7

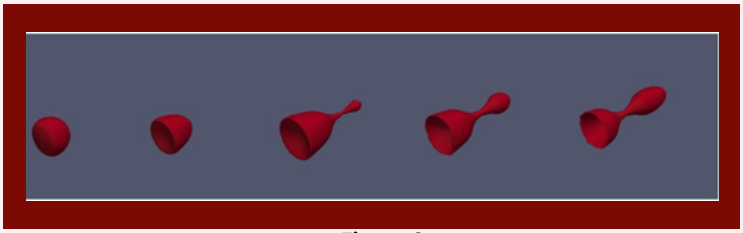


Figure 8

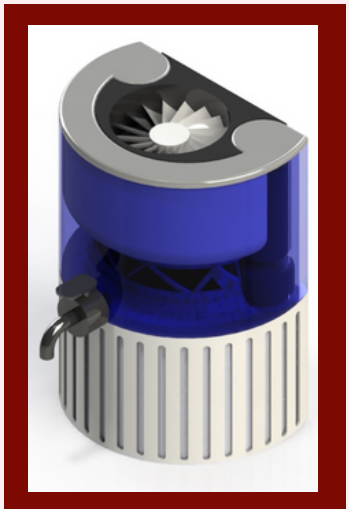


Figure 9

Integrated Air and Water Purification

Lately, mortality rates due to air pollution and water pollution have touched alarming highs. Public health problems caused by lack of access to potable water and clean air are the main cause of current research. While significant advancements have been made in air and water purification, the objective of the research is to address the factors of affordability and practicality, employing such technologies in a host of settings, spanning from indoor to outdoor environments. The work entails integrating and combining air and water purification within a single device with a host pragmatic. Both, polluted air and contaminated water are made to pass through multi-staged filtration processes which involve techniques such as, but not limited to, particulate pre-filtration for eliminating large impurities and increasing the life of subsequent layers, activated carbon filtration for removing volatile organic compounds (VOCs) and other harmful gaseous pollutants, polymer, synthetic, or HEPA-based filtration for tackling PM2.5 pollutants and photochemical oxidation for immobilizing Sulphur Dioxide and oxides of Nitrogen present in the air, and sediment filtration, reverse osmosis and activated filtration for purifying particulates, dissolved impurities and VOC impurities present in water. In addition, UV light has been used with a suitable transmitting arrangement for eliminating biological contaminants from both air and water at the same time without allowing for any form of contact between the two. A protective film fitted on to the front face of water storage tank prevents UV radiation from coming out into the environment. The invention features a novel air-handling and delivery system that is responsible for guiding the transport of air from suction to outlet. In addition to suitable flow regulating design bits within the path of air passage, multi-staged fans with a combination of different airfoil profiles facilitate efficient suction through the filter media and impart superior flow rates. The proposed invention not only poses the potential to serve the best health interest of lower-middle class to middle class households, but also establishes new grounds for dispensing great boon in the outdoor space as a meaningful public facility. An Isometric view of the integrated purification device is shown in Figure 9.

Real Time Source Apportionment of Fine Particulate Matter and Black Carbon Over Delhi

The impact of Covid-19 lockdown on Delhi-NCR's fine particulate matter (PM2.5) pollution was studied. It was found that contributions frome vehicular and domestic coal burning sources were the most affected. There was unprecedented rise in Ozone with $_{x}$ declining NO levels - also evident in other parts of the world, leading to significant rise in low volatility oxidized organic aerosols. The impact was, however less pronounced on secondary chloride, power plants, an d biomass burning, Black carbon reduced considerably. This was primarily attributed to fossil fuel burning and crop residue burning. A summary of this work was submitted to CPCB. Stubble burning activities in Punjab and Haryana significantly impact the black carbon (BC) concentrations over Delhi in November. Impact of Diwali firecrackers on Delhi's BC concentrations lasts only for a few hours.

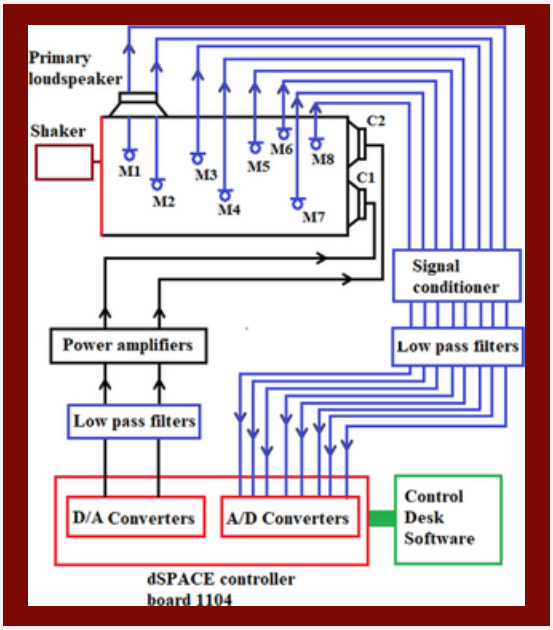


Figure 11

Noise Control in Vibro-Acoustic Cavities

A feedforward technique has been developed for active noise control in vibro-acoustic cavities without increasing structural vibrations [Figure 10]. A modal filtered-x LMS algorithm for global active noise control in a vibro-acoustic cavity was also developed in addition to a two-stage approach to updating of FE mass, stiffness and damping matrices [Figure 11 & 12]. Additionally, feedback control strategies were devised for active control of noise in a 3-D vibro-acoustic cavity [Figure 13].

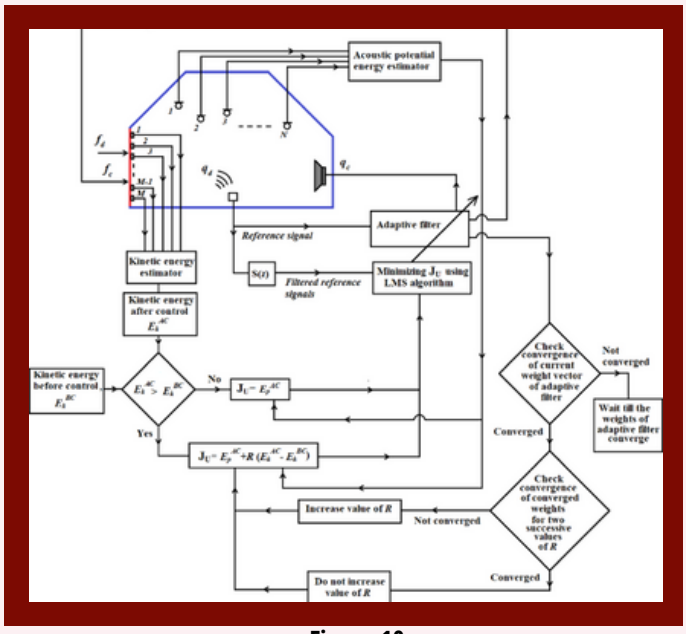


Figure 10

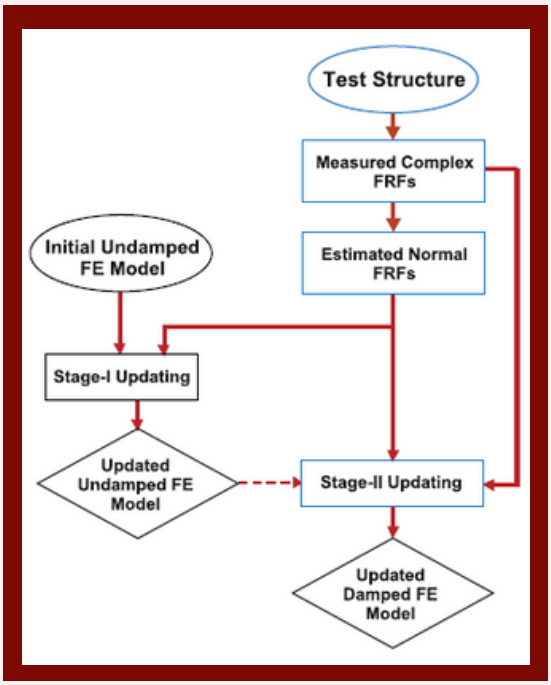


Figure 12

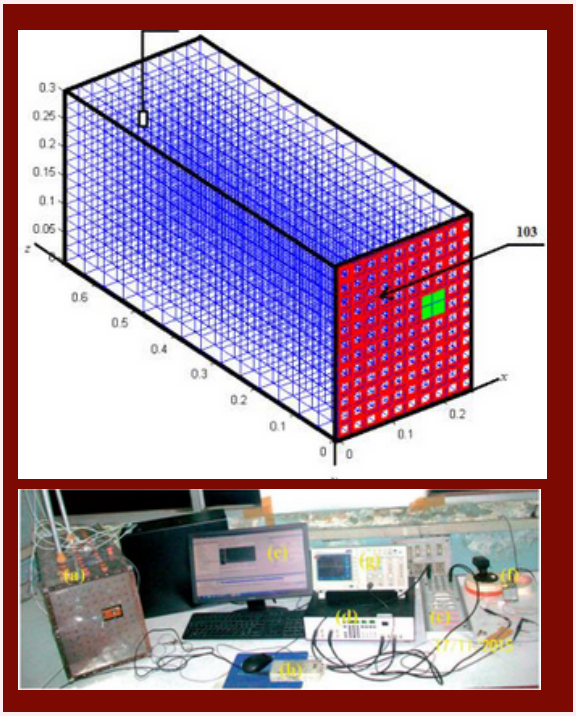


Figure 13

Public Systems

Food systems, Law & Justice system and transport systems are emerging areas of research. A Public Systems Lab has been established at IIT Delhi in partnership with the United Nations World Food Programme (UNWFP), a prestigious multilateral (participation of various governments all over the world) organization. UNWPF is the largest humanitarian organization in the world and a winner of Nobel Peace Prize in the past. This is the first engagement of UNWFP with the Institute. Some projects under this umbrella are research based supply chain solutions (and their deployment) for the government of Uttarakhand, Food Corporation of India and SDG-2 Monitoring Dashboard for the Government of India. A Centre of Excellence on Law & Technology, the first of its kind in the country has been established. A secretariat to run the DIA programme of the Government of India has also been set up. The work has spurred youth-run policy thinktanks and organizations, activities in the area of rural school education and enhanced efficiency in the running of the relevant public systems.

Continuous Casting

With increasing demand for production of high quality steels of various grades, alloy compositions and shapes, industries are facing a tough challenge to figure out best practices for maintaining high productivity without compromise on quality. The continuous casting operation leads and decides production quality, and the mould of the caster is at the heart of the operation. Most of the production defects can be addressed simply by scientific analysis of the solidification, heat transfer, metal flow, stress development and other related physical aspects in the process. In collaboration with Tata Steel, the research group has developed accurate thermo-fluid-mechanical models which provide detailed information on the turbulent flow of molten steel in the mould, differential heat transfer, solidification and stress development in the solidifying strand of steel and the mould [Figure 14]. The most complicated aspect of determination of heat transfer from the solidifying steel strand to the mould have been determined with the help of experimental data obtained from the operational plant at Tata Steel, and through use of inverse models and direct models. These models have been employed to estimate the non-linear taper profile of the billet casting mould at Tata Steel Ltd., which can potentially help to produce mild steel billets with lower casting defects. Further studies have been conducted to determine ways of enhancing the heat transfer from the steel strand to the mould, and the use of electromagnetic forces through stirring and braking have been found to control the turbulent flow behaviour of the metal flow in such a way that higher heat transfer and hence thicker shell can be obtained at the mould exit plane.

Continuous Casting (Contd...)

One of the latest technologies developed in this field has been the use of thin slab continuous casting for producing near net shape cast product and thus minimise the use of subsequent thermal treatment and rolling operations to obtain the final product. Although this process offers tremendous benefits in terms of cost and labour, it has several challenges and is still in the early stages of development. Accurate numerical modelling is also tougher for this process. With the help of experimental data obtained from Tata Steel Ltd., and numerical models employing direct and inverse models, the highly non-linear flow, heat transfer and solidification phenomena have been captured very accurately within the mould of the thin slab caster. The use of electromagnetic braking force has also been found to reduce the turbulence and recirculatory flows inside the mould which lead to uniform solidification, and can thus lead to lesser casting defects [Figure 15].

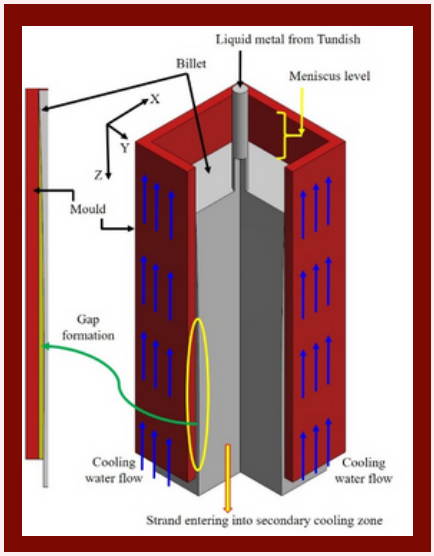


Figure 14

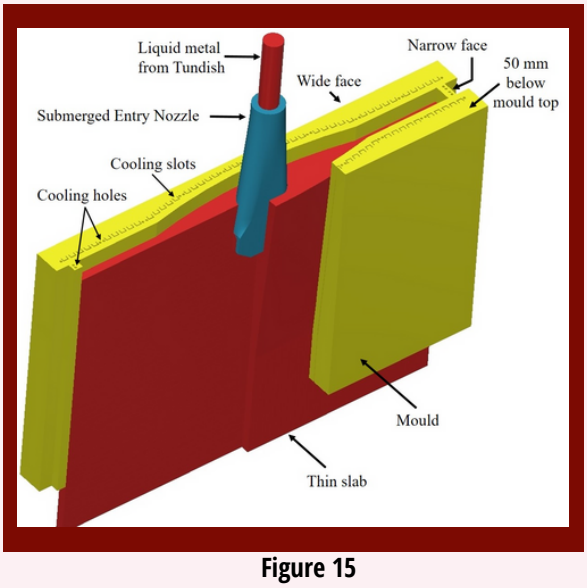


Figure 15

Telerobotic Ultrasound System

In a collaborative research with AIIMS New Delhi, a Telerobotic Ultrasound System was developed [Figure 16]. The control architecture has been developed to teleoperate the ultrasound probe attached to the robotic arm while ensuring the patient's safety and the quality of ultrasound images. The system will target Indian rural as well as global outreach. The radiologist manipulates the ultrasound probe remotely from a remote location, acquires the ultrasonographs, and then transmits them to the monitors at the doctor's end through a Wi-Fi network. Sitting at a remote location, the doctor can visualize all the images and assess the patient, similar to a clinical setting.

Figure 16

Electrohydrodynamics

Unresolved issues in electrohydrodynamics, such as the explanation of the underlying physical mechanism, threshold criteria, and modes of a variety of electrohydrodynamic (EHD) instabilities in microscopic systems, are addressed through the research of this group. These instabilities include those observed in microchip electrophoresis wherein instabilities set in when electric field is applied in a fluid with conductivity gradient. This work is of significant practical importance because the performance of microchip separation techniques, such as for DNA and RNA analysis, is eventually limited by the onset of EHD instabilities at high electric fields. The first experimental measurements of spatio-temporal coherent structures of an EHD instability in micromxier, which led to physical explanation of wavy and pearl-necklace modes of instability have been carried out by the group. EHD flows in multiphase systems is another focus area of research. In a collaborative effort, lattice Boltzmann method-based simulation tools have been developed to simulate flows in multiphase systems under the effect of electric field. The efficient use of electric fields in the formation of those emulsions which are otherwise difficult to generate using shear based methods is an application of this technique. Micrometer-sized electrohydrodynamic jets which form when a liquid flows from a needle under strong external electric fields are used for printing miniaturized structures [Figure 17].

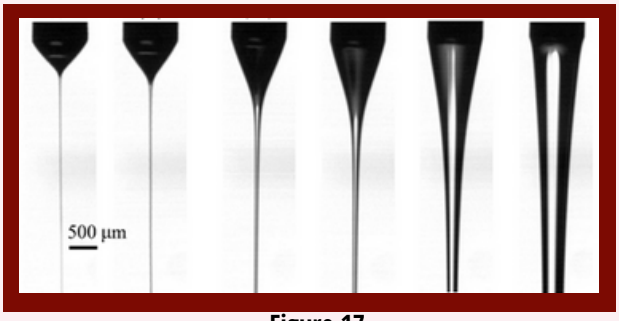


Figure 17

Train Simulation Software 'Runtrain#'

In collaboration with Research Designs and Standards Organisation (RDSO), a train simulation software named 'Runtrain#' has been developed whose output results can be incorporated into timetabling methods. Runtrain# analyzes a wide range of train running parameters (TRP) like running time, fuel consumption, coupler force, and so on, which help the railway personnel in deciding how many locomotives, stock, etc. are to be used and in scheduling. The software's ease of use and visual graphics representation of output make it useful for analyzing frequently occurring planning issues such as the impact of temporary changes in speed restrictions, halts, train configuration, and so on. It is designed to systematically segregate pre-processor, processor, and post-processor using new programming techniques such as Object-oriented programming and employs a variety of data representation modes, such as data-grid and graphical visualization to improve the insights of post-processed data. Characteristics of any train configuration can be studied using a combination of locomotives (Diesel-Electric/Electric) and rolling stock (Passenger/Freight) with ease in almost no time.

Harnessing Alternative Energy Resources

Research in this area that explores various biomass derived energy feedstocks, has successfully achieved methane production from biomass feedstocks through anaerobic digestion route, syngas production from biomass feedstocks through thermogravimetric route, and biogas upgradation/enrichment. Pilot scale projects with integrated water scrubbing based biogas upgrading system and CO_2 sequestration, efficient supersonic ejector, readily deployable hybrid control algorithms in RCCI engines for cycle resolved combustion control, innovative steam turbine blade profiles for minimal secondary losses were launched.

Tribology of Implants

Tribology of implants has an impact for hip, knee prosthetic implants and dental implants. In view of this, a Bio-tribology research lab equipped with Pin-on-disk machines, micro-hardness tester and multi-directional bio-tribometer, and also molecular dynamic simulation that looks at the atomic and molecular level for the mechanisms of lubrication in natural human joints in order to improvise the implant designs, has been established.

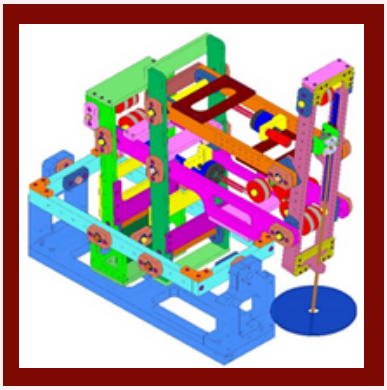


Figure 18

Surgical Robot for Robot-Assisted Minimally Invasive Surgery

A double-parallelogram-based RCM mechanism was designed and developed for minimally invasive surgery [Figure 18]. An adjustable tendon-driven transmission system was implemented. A compliant floating joint was designed for precise adjustment after the assembly. The prototype can be used as a surgical trainer cum simulator for surgery. The system can be further developed for real surgical applications.

Nano-imprinter for Microfluidics

A precision nano-imprinter using hot embossing was designed for replication of microstructures for microfluidic application [Figure 19]. Kinematic coupling has been used to achieve precise positioning of the mould insert with the base. Flexure-based parallel guidance mechanism is used for one DOF motion required for the embossing process. Flexure-based kinematic coupling with the thermal center has been designed to mitigate thermal stress build-up during heating and cooling of the mold insert. A prototype was fabricated, and experiments performed with an aluminum mould insert on a PMMA substrate. The results show the feasibility of the concept, and that the setup can be used to develop a cost-effective precision hot embossing machine for creating micropatterns for microfluidic applications.

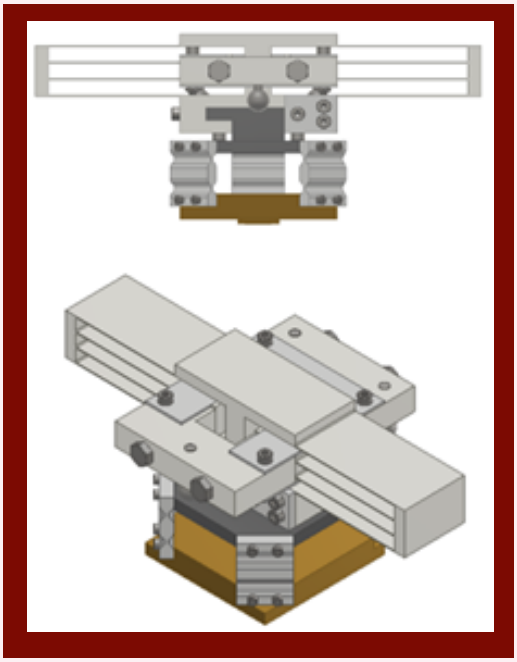


Figure 19

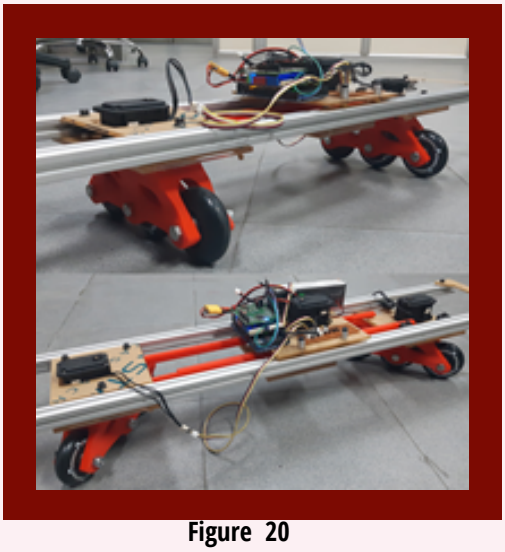


Figure 20

Robotic Platform Using Roller Skates

A robotic platform was developed with three actuated degrees-of-freedom—orientation of two skates and distance between them, utilizing continuous contact-based skating technique [Figure 20]. The skates remain in contact with the surface, thereby circumventing the stability-related issues. The robotic platform follows the desired motion profiles like straight-line motion, motion in a curve, and lateral motion. The platform can be effectively used in a structured environment for indoor/ outdoor or icy terrains.

Compliant Robotic Gripper

A 5-DOF flexure based passive gripper was designed for pick-and-place and insertion task [Figure 21]. The proposed design eliminates the use of actuators and sensors to achieve proper alignment during insertion. The gripper consists of picking, aligning, and releasing mechanisms. The gripper is capable of picking 1.5 kg rectangular object and handling 2 mm linear and 5° rotational misalignments. The gripper can be customized for various geometric shapes, sizes and alignment requirements depending on the application.

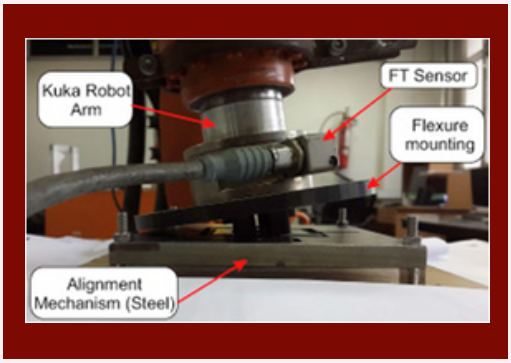


Figure 21

Flexible Crutches

A Flexmo crutch is an award-winning design improvement of the traditional crutch [Figure 22]. It is crafted to improve the mobility of a person using crutches. It is the world's first self-standing crutch. By using specially crafted flexure-based tip design, the FlexMo Crutch substantially improves the stability and mobility of a patient while keeping the cost low.

Figure 22

Liquid Bio-methane Production and Storage

Research aimed at improvements in energy conversion systems and processes has entailed application of alternative fuels in combustion engines, development of advanced combustion engine concepts like HCCI and RCCI, development of hybrid control algorithms for RCCI engine by combining combustion physics with machine learning, development of supersonic ejectors for defence and aerospace applications, experimental, analytical, and numerical study of heat transfer and fluid flow in microchannels, conceptualization of advanced reheat organic Rankine cycles for maximum power recovery, development of hydrokinetic turbines, design of textured surfaces for friction reduction in positive displacement devices, experimental and numerical study on forced convection in pillow plate channel, intelligent fault diagnosis and control in coal mills and the improvement in thermal compactness of fin and tube heat exchanger.

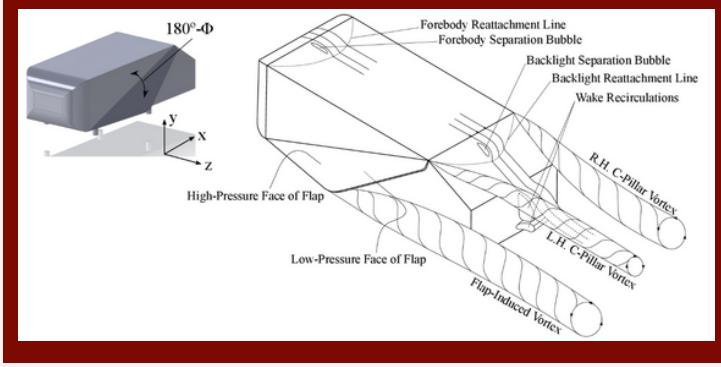


Figure 23

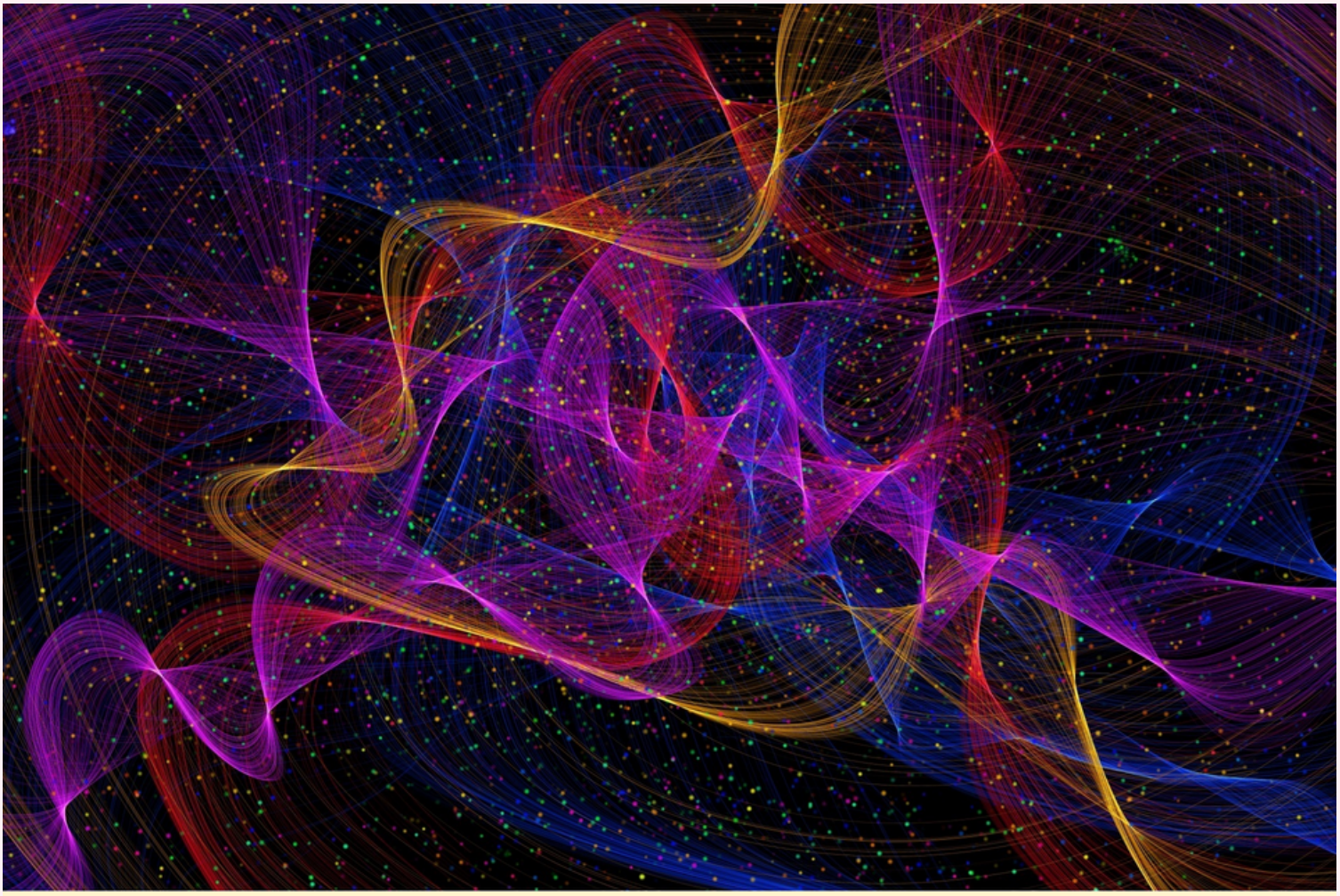
Probabilistic Modelling, Simulation and Optimization

Research in this field has yielded applications in healthcare delivery systems, biomedical engineering, and health economics. It addresses the operational aspects of delivery of public primary and secondary healthcare. A significant channel of public healthcare delivery in India comprises primary healthcare centres (PHCs) and community healthcare centres (CHCs). There are nearly 30,000 PHCs and 5,350 CHCs across India. Approximately 10 PHCs and 3 CHCs in a nearby district were visited to understand their healthcare delivery processes, and to develop discrete-event simulations of the medical care processes at these facilities. These simulations, in addition to providing insights regarding the operational efficiency of PHCs and CHCs in terms of patient wait times, resource utilization, etc., can also serve as components of the computational infrastructure (similar to digital twins) required to analyse public healthcare delivery. These simulations can be used for for capacity planning and facility location in a pandemic, illustrate patient diversion mechanisms making use of real-time delay predictions and to reduce computational overheads of network simulations.

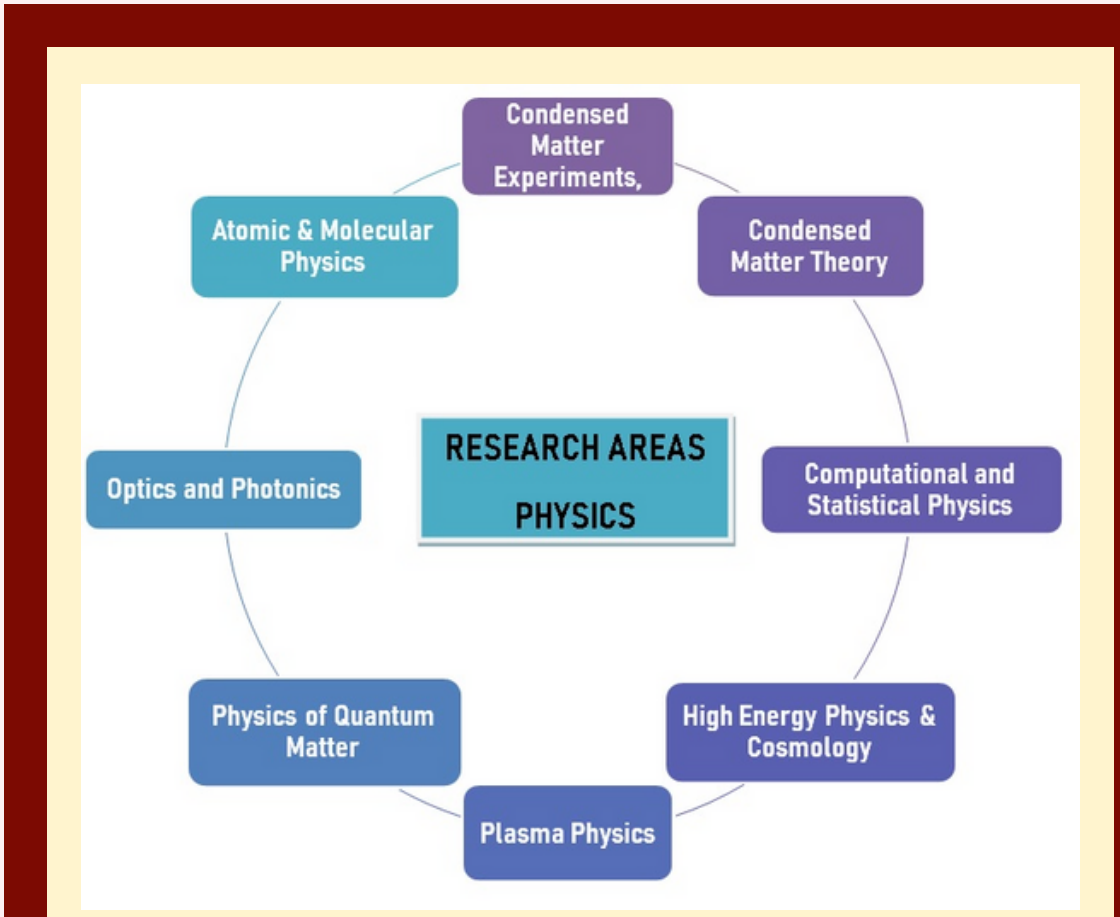
Safety in Motorsports Applications

The present work is inspired by the innumerable incidents of accidents and risk of loss of life and property during the critical event of turn negotiation in formula and motorsport races. The vehicles moving at very high cruising speeds often have to rely on downforce generated by front and rear wings and tire friction at reduced speeds for stability during cornering. This, however, fails to suffice, and results in becoming a major cause of fatal accidents, as has been seen practically in various races and circuits.

Keeping the aforementioned problem in mind, a novel concept of variable flap actuation at a location has been proposed. The imparted aerodynamics result in multiple advantages from the points of view of safety, stability and overall driving dynamics. This strategy of risk mitigation holds significant potential to totally change the scenario of formula and motorsport races by reducing track time, wheel-change time, enhancing driver and car safety and stability, in addition to potential applications in private and commercial vehicles. Ahmed body and the characteristic flow structures are shown in Figure 23.



PHYSICS


Condensed Matter Experiments,
Atomic & Molecular Physics
Condensed Matter Theory
RESEARCH AREAS
PHYSICS
Optics and Photonics
Computational and Statistical Physics
Physics of Quantum Matter
High Energy Physics & Cosmology
Plasma Physics

The Department of Physics at IIT Delhi established in the year 1961, is one of the largest departments in IITD with nearly fifty faculty members, many of them having international research collaborations and recipients of prestigious awards and fellowships such as the Bhatnagar & ICO Galileo Galilei awards, MRSI medals, and the APS, Japan Research & Development Corp's STA, INSA, OSA and Humbolt Fellowships.

Macroscopic Scale of Bulk Plasma

A six-decade-old notion about giant magnetic fields in high-intensity laser-produced plasma was challenged through a collaborative work with Japanese scientists. As against the popular belief that the giant magnetic fields evolve at small, nanometre scale in the bulk plasma the team has shown that the field actually originates at macroscopic scales. Besides, it is defined by the boundaries of the electron beam that is propagating in the plasma. The new mechanism gives a new perspective on magnetic fields in astrophysical scenarios and laser fusion. A Pulse Laser Deposition instrument is shown in Figure 1. Different laser sources are used in the work [Figure 2]. A view of plasma preparation chamber is seen in Figure 3.

Optics and Photonics

The research group proposed a novel technique for the excitation of Fano resonance in THz deep-subwavelength meta surface cavity in the absence of structural asymmetry. They proposed and experimentally demonstrated a novel cavity sensing technique with superior sensitivity in the range of ~ 1 THz/ RIU. An Indian patent has been filed for the method in 2020.

High Precision Atomic Structure Calculations

Significant achievements have been made in high precision atomic structure calculations for new frequency and time standards. They also work in the area of Density functional theory-based first-principles simulations of ferroic oxides for fundamental and technological applications.

Condensed Matter Experiments

Research on transparent superhydrophobic surfaces by ZnO nanowire coating and the study of its photo-induced reversible wetting properties has been much acclaimed. A a smart mesh coated by ZnO-nanowires with reversible wettability for an efficient on-demand oil/water separation has been fabricated. The mesh has high demand in oil, shipping and marine industries. Besides, the work on a mechanical strain-induced tunable anisotropic wetting on buckled PDMS silver nanorod arrays has paved a new way of controlling the direction of liquid flow in microfluidic devices [Figure 1 & 2].

Wave-Particle Duality in Classic Optics

The research team working on quantum science, developing quantum technologies, and converting optical coherence and polarization theories into experiments, recently observed wave particle duality in the classical optics domain, explored the polarization coherence theorem, investigated partial coherence, polarization and entanglement, generated single photons and developed methods for quantum communication leading to photonic quantum technologies.

Computational and Statistical Physics

A new model to reveal the kinetics of protein aggregate formation inside cells of the human body has been proposed. Such protein aggregates are implicated in neurogenerative diseases such as Alzheimer's disease, Parkinson's disease and type II diabetes. In yet another breakthrough, the group has accomplished high precision atomic structure calculations for new frequency and time standards. The first product prototype of a digital holography instrument in diagnostics and pathology was successfully launched – a contribution of the department's Computational Imaging research. The work was also granted a US Patent.

Figure 1

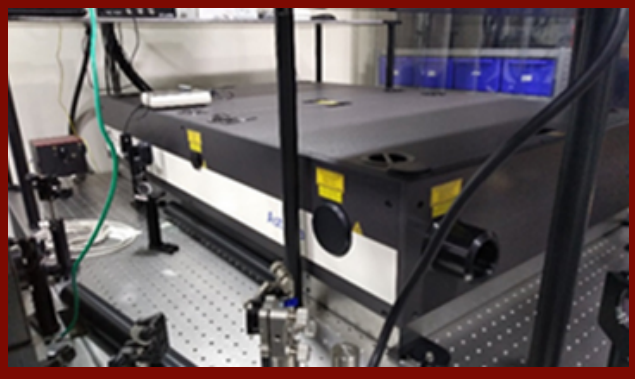


Figure 2

Spintronics and Magnetism

The spin Hall effect and its inverse, spin-orbit torques, magnetic skyrmions, spintronic based THz emitters, and 2D-spintronics are active areas of research. Magnetoresistive Tunnel Junctions (MTJ) for ultrahigh sensitive magnetic field sensors, microwave oscillators and next generation Magnetic Random Access Memories (MRAMs), Transparent Ferromagnetic Semiconducting (FMS) oxides for semiconductor spintronics, growth and characterization of epitaxial half-metallic (100% spin polarized) ferromagnetic thin films, fabrication of spin ice structures, magnetism in bulk and thin Films of metallic ferromagnets, Heusler alloys, superconducting oxides and other oxides have been developed .

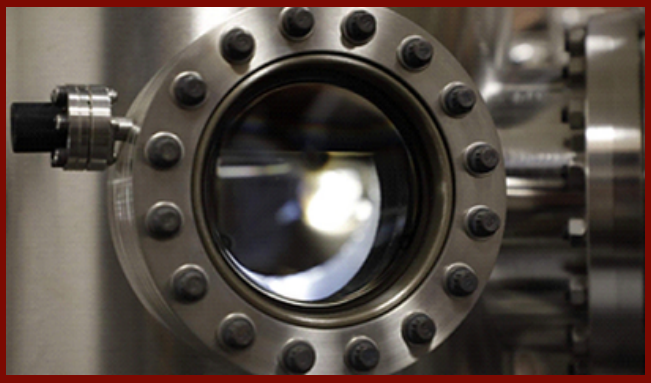


Figure 3

Devices from Condensed Matter Experiments

Condensed Matter research has also resulted in socially relevant products in the market such as those enlisted below:

- A device to generate electricity from raindrops, water streams and ocean waves was developed. This has been achieved using "Triboelectric Effect" and "Electrostatic Induction". The device is called "Liquid-solid Interface Triboelectric Nanogenerator" [Figure 4]. The generated electricity can also be stored in batteries for further use.
- A smartphone-based biosensing application developed for detection of viability and antibiotic resistance in bacterial strains based on a novel idea of rapid and drastic variation in colorimetric and water wetting properties of silver nanorods array. This novel research has a significant demand in health-care in particular to diagnose the bacterial infection and determination of antimicrobial resistance (AMR).
- A handheld Surface-enhanced Raman Spectroscopy (SERS)-based device for early diagnosis of dengue virus that can provide dengue test results within one hour [Figure 5].

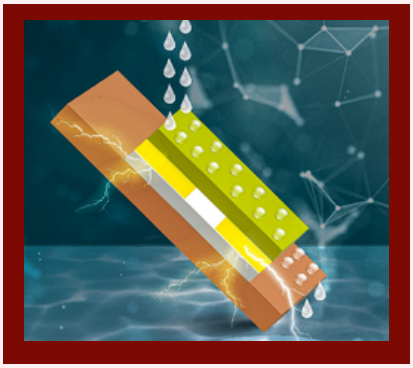


Figure 4

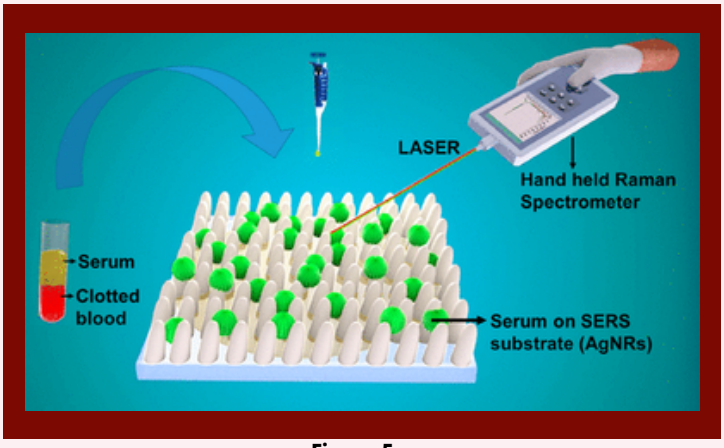


Figure 5

Devices from Condensed Matter Experiments (Contd...)

- A flexible and robust Surface-enhanced Raman active substrates for rapid conformal detection of pesticide residues in fruits, which can be a promising tool for rapid monitoring of adulteration in fruits and vegetables.
- A hand held surface-enhanced Raman spectrometer for Dengue and HIV-1 diagnosis from clinical serum samples with a potential need in hospitals and clinics for rapid and mass monitoring, thus reducing the burden on health workers.
- A smart mesh coated by ZnO-nanowires with reversible wettability for efficient on-demand oil/water separation having high demand in oil, shipping and marine industries to separate the oil from the oily water.
- Highly flexible, electrically conducting Ag nanorods embedded PDMS based electrodes flexible and wearable electronics. For the work on polymer embedded Ag nanorods based ECG electrodes, an Indian patent is pending.

Demonstration of the selective electrochemical reduction of CO_2 to CO using CuO/In_2O_3 nanocomposites to address a smart solution of CO_2 conversion into fuel. Development of a photomechanical and chemomechanical actuator for multi-mode soft grippers and volatile organic compounds detection for targeted drug-delivery, soft robotics, and non-invasive diagnosis of diabetes, breast and lung cancers. Sunlight-driven eco-friendly smart curtain-based on infrared responsive graphene oxide-polymer photoactuators.

Condensed Matter Theory

Highly flexible, electrically conducting silver nanorods-embedded PDMS based electrodes has resulted in flexible and wearable electronics. For the group's work on polymer embedded silver nanorod-based ECG electrodes, an Indian patent is pending. Demonstration of a selective electrochemical reduction of CO_2 to CO using CuO/In_2O_3 nanocomposites has provided a prospective solution for converting CO_2 into fuel. Further, the group has developed a photomechanical and chemomechanical actuator for the multi-mode soft grippers. It has also developed volatile organic compounds detection for targeted drug delivery, soft robotics, and noninvasive diagnosis of diabetes, breast and lung cancers. Lastly, a sunlight-driven eco-friendly smart curtain based on infrared responsive graphene oxide-polymer photoactuators is also a contribution of the lab. Another group's research on half-Heusler thin films has provided insights that the strained lattice of RPdBi thin films clearly demonstrate the properties of 2D topologically non-trivial surface states that are suitable for spintronic applications. Research on strongly correlated complex oxides and magnetic materials for spintronic and magnetic refrigeratorapplications are the other areas of strength in the department. In a breakthrough experiment, it was established that nanophase oxide ceramics have better radiation resistance as compared to their bulk counterpart. The study was carried out with respect to the environment in the vicinity of a nuclear reactor core, thus solving a long-enduring puzzle for nuclear scientists and engineers. In a combination of experimental- and DFT-based studies, a shape-engineered metal nanoparticle embedded thin silica matrix has been established as a novel, third-generation, highly stable electron source for electron microscopes. The group's expertise in nanoscale magnetic elements and arrays has been applied to memory, high-density storage media, logic devices or miniaturised field sensors. The patterned nanomagnets placed in proximity to each other interact via magnetostatic interaction. High-sensitive magnetic field sensors have been fabricated to investigate the changes in the bistable behaviour of elongated artificially patterned nanomagnets.

High Energy Physics

Physics beyond the SM (BSM) remains inescapable even after Higgs discovery in 2012 to answer a few doubts where the SM appears inept. On the other hand, apart from the detection of neutrino masses (bagged 2015 Noble prize), any confirmed discovery from BSM territory (e.g., the dark matter) remains missing till date. The latter has indeed questioned the existence of BSM physics within experimental reach. The researchers are promoting the idea of complementary searches together with modified search strategies that might act as the saviour [Figure 6 & 7].

High Energy Physics (Contd...)

In brief, they identify a few BSM scenarios where the same set of parameters are instrumental in generating different BSM signals like, neutrino masses and mixing, dark matter, charged lepton flavour violation, same sign di-leptons and/or displaced vertices at colliders etc. Subsequently, the researchers scrutinize the concerned parameter space by using limits/bounds from experiments that are sensitive to different sectors (e.g., neutrino and flavour violation or neutrino and dark matter). Finally, through experiments, modified search methods that could help us to detect the much anticipated BSM physics, have been also proposed.

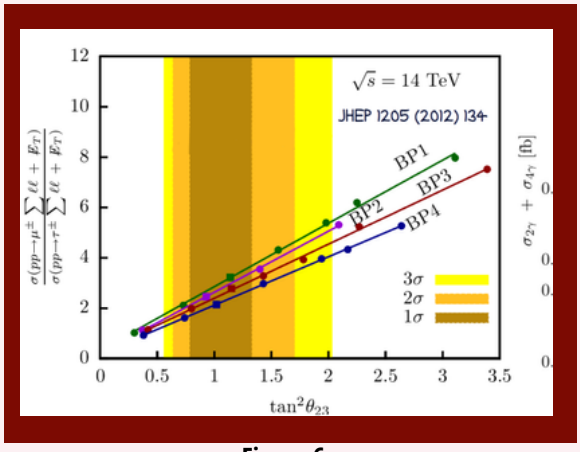


Figure 6

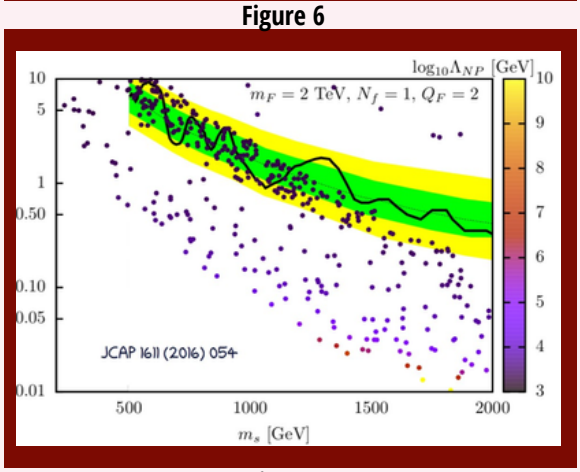


Figure 7

Quantum Matter Physics

Research on "coldatom sensing" and "Rydberg atom quantum computing" involving ten atom qubits is in progress. In the last few years, work on Half Heusler Thin films of nanometer-scale has established their use as an experimental platform for exploring topological quantum phenomena and magnetism. A significant breakthrough in quantum transport in low dimensional condensed matter systems has resulted in Quantum Hall Systems, graphene and surface states of Topological Insulators, etc. The first sighting of the mysterious 'Majorana Fermion on Gold' has also been accomplished. A robust, scalable platform in collaboration with the Massachusetts Institute of Technology and the University of California, USA has been established. The work has been granted a US Patent (2021) US11100419B2.

ENGINEERING

TEXTILE AND FIBRE ENGINEERING

RESEARCH AREAS

- Technical Textiles
- Smart Textiles
- Biotextiles
- Nanotechnology Applications
- Functional Apparel

The Department of Textile and Fibre Engineering was founded in 1961. The department has dedicated focus on teaching in textile and fibre engineering and conducts research in all major areas of textiles such as polymers & fibres, yarn, fabric, nonwovens and chemical processing.

Soft Body Armour Development

Soft body armours are used by deference and police personnel to ensure protection against 9 mm bullet. The main research challenge is to minimise the soft armour weight (3.5 kg/m2) while ensuring 25 mm or lower blunt trauma. Silica based shear thickening fluid (STF) was prepared using silica nano particles and suitable dispersing medium. STF demonstrated discontinuous rise in viscosity beyond the critical shear rate. The long debated role of dilatancy of STF in energy absorption was also settled through the understanding of this research. Hybrid soft body armour was developed using unidirectional (UD) ultra-high molecular weight polyethylene fabric and STF treated woven para-aramid fabric. A gradient soft armour structure was developed and tested against the 9 mm bullet at TBRL, Chandigarh [Figure 1]. All the bullets were stopped and the blunt trauma was lower than 25 mm. A 9 mm live bullet (left) and shattered bullet (right) [Figure 2]. The weight of the soft armour was reduced by 20% as compared to the solution available in the market. The developed technology will be transferred to the DRDO for the development of lightweight bullet-proof vest. The work has received many recognitions including Gandhian Young Technological Innovation (GYTI) Award 2017, IIT Delhi Industry Day Award (2017), Best Doctoral Research Paper Award at 18thAUTEX world textile conference and INNOTEX (National Technical Textile Innovation Award) 2021.

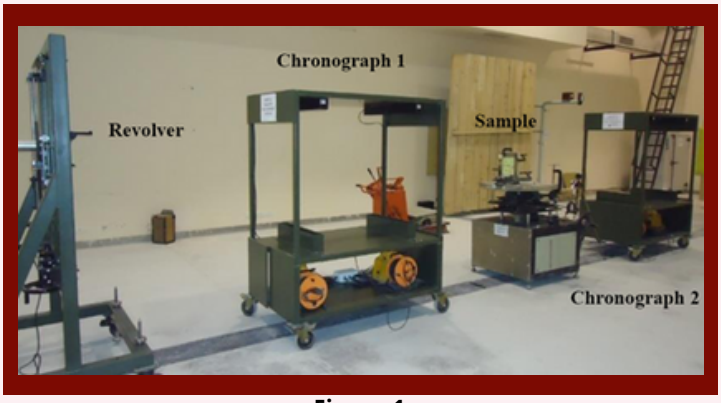


Figure 1


Figure 2

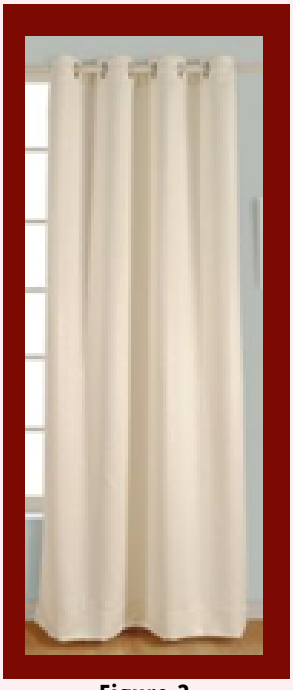


Figure 3

Pollutant Absorbing Smart Fabrics

Smart cotton fabrics have been developed using nanotechnology that can readily absorb various aromatic pollutants and can be regenerated for multiple reuse. Such fabrics can be used as curtains or upholstery items to help keep VOCs lowered in closed rooms [Figure 3].

High Comfort Sportwear

Microdenier polyester fabric is usually used as sportswear so that it may wick away the wearer's sweat and keep the body dry. However, the current fabrics are not that comfortable to wear as they do not wick away and dry the sweat readily. SMITA Research Lab has developed a wash durable nanotechnology-based finish for sportswear that can enhance the moisture management properties of the fabric. It significantly enhances wicking, spreading and drying of the sweat to keep the sportspersons comfortable and help maintain their performance [Figure 4].

Figure 4

Figure 5

Antiviral Coating Spray

Contaminated surfaces can spread bacterial and viral infection in hospitals and public places, etc. In order to provide better protection to the users from surface-based contaminations, Aqua Silver Technology has been developed by SMITA Research Lab. This technology has been used to make antiviral coating that can be easily applied by spraying [Figure 5].

Nasofilters for Protection From Particulate Pollution

People who are allergic to dust and pollens need to cover their faces with half face masks. However, these are uncomfortable to wear for long hours. Nasofilters are worn outside of the two nostrils to block these allergens. These are un-noticeable from a distance and allow the wearer to carry out their duty/work comfortably while providing them sufficient protection from particulate pollution [Figure 6].

Figure 6

SCHOOLS

- Amar Nath and Shashi Khosla School of Information Technology
- Bharti School of Telecommunication and Management
- Kusuma School of Biological Sciences

AMAR NATH AND SHASHI KHOSLA SCHOOL OF INFORMATION TECHNOLOGY

RESEARCH AREAS

- Embedded Systems and Sensor Networks
- Security
- Geographical Information Systems
- Human-Computer Interface (HCI)
- High-speed Networks
- Optical Information Processing
- Multimedia Systems
- Web-based Computing
- Robotics & Intelligent Systems
- Dependable Computing
- Information Security, Storage and Retrieval
- E-Commerce
- Nano-technology Modeling and Bio-informatics

The Amar Nath and Shashi Khosla School of Information Technology was established in 2004, under the aegis of IIT Delhi, with an endowment from the distinguished Institute alumnus, Vinod Khosla (B.Tech., EE 1976). The objective of the school is to foster inter-disciplinary, goal-oriented research, innovation and post-graduate education in Information Technology. Equipped with state-of-the art laboratories, the school caters to students and faculty working in diverse interdisciplinary areas using Information Technologies. The school also sponsors researchers from different disciplines and departments for collaborative research.

The ACT4D Group

At the School, the Appropriate Computing Technologies for Development (ACT4D) group has been working on the use of voice-based interfaces for communication and information sharing, meant for the less-literate populations for several years. This has been attempted without the use of smartphones or internet enabled devices. More recently, the group has also leveraged AI/ML techniques to build new solutions like the automated question-answering and voicebots for data collection that can operate through feature phones over a simple voice call. These technologies are in use through a wide network of civil society partners, including the social enterprise Gram Vaani that was incubated by IIT Delhi during its early years, The technology proved to be instrumental during the Covid-19 pandemic in supporting the vulnerable social groups such as the migrant workers, physically disabled people, senior citizens, and the remote rural populations. People were able to reach out for emergency food and cash support The requests were mapped to local relief groups operating on the ground to provide assistance. Those facing problems in accessing social welfare benefits announced by the government, were able to seek guidance from a network of local community volunteers. Question-answering systems helped people clear their doubts about the pandemic - its symptoms, virulence, cures - and especially, to understand the relevance of vaccination while countering misinformation leading to resistance in vaccination. Over one million users engaged on the voice systems, recorded more than 18000 reports, questions, and concerns, and nearly 3000 impact stories of successful interventions for problem resolution were shared. The voice reports and additional surveys of users were analyzed and emerged as a useful resource for framing public policies lessons to ensure maximum inclusion of eligible citizens in availing social benefits. A network of research and advocacy partners used these insights to write reports and policy briefs that were shared with several government departments and provided crucial nuanced feedback to implementation agencies about the challenges faced by people on the ground. Recent research by the ACT4D group is focused on the use of big-data such as satellite imagery, news articles, censuses and surveys, to analyze socio-economic development patterns at fine spatial and temporal scales. This can help identify pockets that are vulnerable to exclusion from resource allocation, prevent over-exploitation of the environment, and recommend timely corrective policy action [Figure 1].

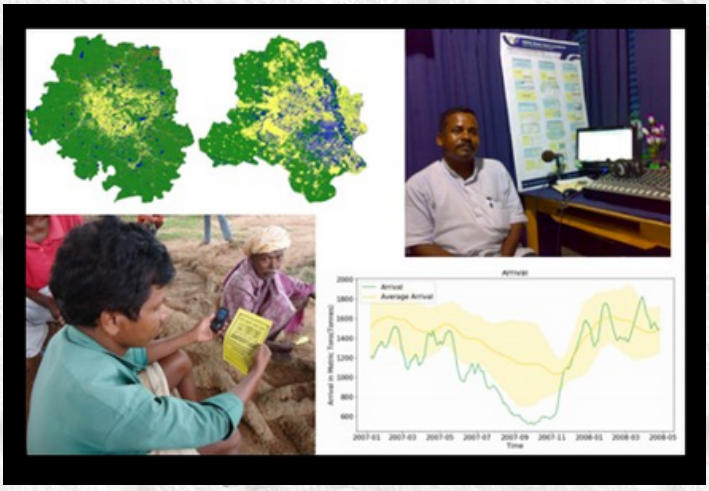


Figure 1

The AssisTech Group

Assistive Technology for Mobility & Education (AssisTech) group for the visually impaired in its twelve years of existence, the AssisTech group at the School has been working on addressing the problems of mobility and education of the visually impaired in India which is currently home to fifteen million visually impaired people. Mobility and access to education are the key challenges faced by the visually impaired for their inclusion in the society. Global solutions are very often completely unsuitable and almost always completely unaffordable. The laboratory has not only been successful in developing a number of solutions but also has been successful in taking it to the end-users in partnership with industry as well as user groups. In the last five years, AssisTech has launched two products/solutions - the SmartCane™ and the DotBook™ [Figure 2].

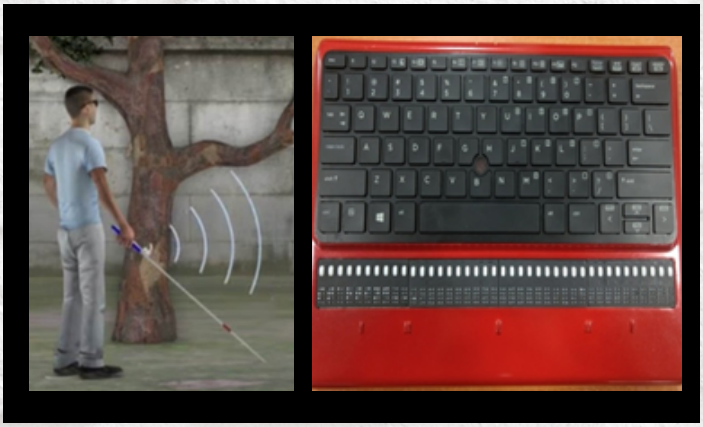


Figure 2

SmartCane™

SmartCane™, an obstacle detection and warning system launched in 2014 is today being used by nearly 100,000 visually impaired users [Figure 3]. White cane used by people with visually impairment cannot help in negotiating obstacles which are knee to head height. Smartcane overcomes this problem. It is mounted on a white cane and uses ultrasonic ranging and vibratory feedback. The product was developed at Assistech Lab, IIT Delhi and is licensed to Phoenix Medical Systems, Chennai. Multiple patents and design registrations filed. The product has been CE Marked and US FDA approved. It was released for public use in 2014 [Figure 4]. It has now reached about 80000+ users in India and in fifteen other countries.

Figure 3

Figure 4

DotBook™

DotBook™ is a Refreshable Braille Display device with 20- and 40-character Braille display which can be used by people with blindness to access digital content [Figure 5]. For the visually impaired, accessing of digital content has been possible only through audio using text to speech software like Jaws or NVDA. There has been a need for devices that enable active reading of digital content using Braille rather than continuous passive listening. Refreshable Braille Display (RBDs) is a device that enables the visually impaired people to read digital text through tactile interface. RBDs available from international companies were unaffordable and had really no penetration in India. AssisTech along with industry partners has launched a 40-cell RBD with laptop-like features at very affordable prices. Using DotBook, blind users can read, write, edit, listen, chat and browse digital text from internet, cloud or any digital device. The product was released in the market and the technology has been transferred to Kritkal Solutions and Phoenix Medical Systems. Multiple Patents and Design registrations were filed. The product has won many national and international awards including the DST's National Award to Scientists Working on Improving Accessibility for the Disabled.

Figure 5

Tactile Diagrams

Students with visual impairment and blindness have serious challenges in accessing pictorial content and diagrams from books. An affordable way to produce tactile diagrams using 3D printing and thermoforming has been developed [Figure 6]. This technology is being taken to people and society through an IIT Delhi incubated social enterprise, Raised Lines Foundation (incubated at IIT Delhi Sonepat Campus). So far 1,50,000+ diagrams have been produced and more than 6400 tactile books delivered to 50 schools and institutions. Access to these diagrams has been one of the key challenges in providing education to the visually impaired; especially in subjects like science, mathematics, geography, economics etc. Tactile diagrams are a solution to counter this problem. Raised Lines Foundation, a non-profit section 8 company was launched using the know-how developed in IIT Delhi for making tactile books and kits for supporting education of the visually challenged.

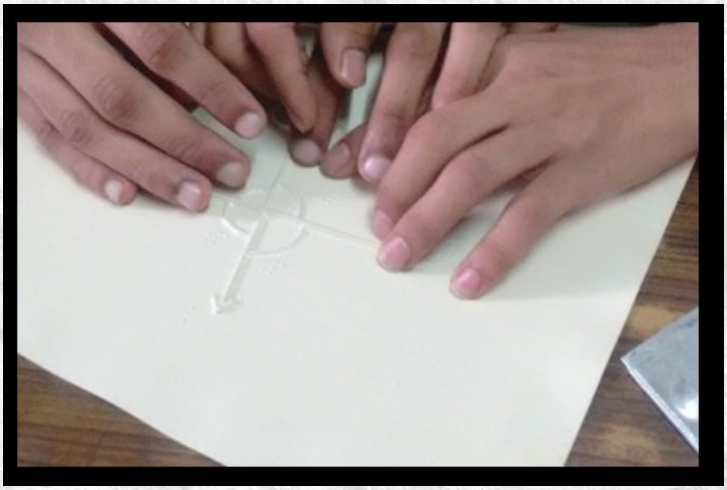


Figure 6

BHARTI SCHOOL OF TELECOMMUNICATION TECHNOLOGY AND MANAGEMENT

RESEARCH AREAS

- Telecom Networks
- Telecom Software
- Wireless Technologies
- Optical Networks
- Signal Processing
- RF Technologies
- 5G Security
- Internet of Things
- Telecom Systems Design
- Planning and Management
- Regulatory and Policy Aspects of Telecom Services and Systems
- Embedded Telecom Systems
- Telecom Network Management
- 5G Research Area
- Edge
- Indigenous 5G Security Testbed at IIT Delhi
- Security Demo
- Energy Harvesting

The Bharti School of Telecom was set up in the year 2000 through a joint initiative of IIT Delhi and Bharti Enterprises to fulfill the emerging technological and managerial needs in the telecom sector. The school itself is housed in a modern building with advanced facilities and, aims to develop leaders in the telecom sector through education and research and empower them through exposure to cutting edge innovations in the field. It provides state-of-the-art labs to its students that are at par with the best in the world.

Research in Indigenous 5G Testbed

Research on the DoT funded 5G testbed initiated in 2018 is now in the final phase of development & demo. This testbed has enabled R&D for the development of 5G solutions while simultaneously encouraging existing and new product startups in India [Figure 1].

Figure 1

Development Activities

Faculty & scholars are developing 5G applications and core 5G components aligned with the 5G/ITU-R IMT 2020 objective. The testbed is currently in Version 3, the final phase of development. The applications under development address the requirements of Massive Machine Type communications & Ultra Reliable & Low Latency communications by integrating Machine Learning technologies. These unique R & D efforts have also led to standards development, publication of research papers in renowned journals and patents.

Energy Harvesting

In the area of Energy Harvesting, two different prototypes addressing industry & societal requirements are under development - the Air Pollution Monitoring device and the Smart Meter [Figure 2]; solar energy harvesting wireless sensing nodes have been designed & fabricated with a learning based smart sensing method which reduces sensing energy consumption by adapting the sampling interval of the sensors, based on temporal correlation. A smart meter prototype with univariate and multivariate data compression algorithm which will lead to significant data transmission bandwidth saving is also in the pipeline.

Figure 2

Security

Security is a major concern in 5G deployments, specifically the 5G futuristic vehicular network which has stringent latency requirements [Figure 3]. Focus areas of development is on authentication mechanisms, key Management & provenance algorithms. Modules under development include Road-Side Unit (RSU), Vehicle 5G Authentication & Agreement Key (AKA), Vehicle to Vehicle (V2V) authentication, V2V secret key generation (cryptographic primitives & physical layer security dynamic key generation), Topology learning with single-source multi-packet embedding & multi-source single-packet embedding, Provenance with novel efficient topology learning algorithms for sparse networks.

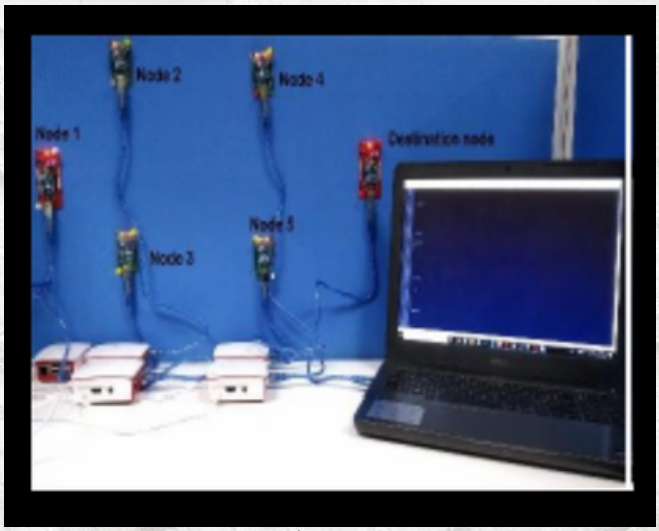


Figure 3

Security (Contd...)

One of the unique features of 5G, defined by 3GPP is the separation of the User & Control plane. This enables the telecom service provider to bring the User Plane Function (UPF) closer to the edge, reducing bandwidth & latency. The European Telecommunications Standards Institute (ETSI) standard Multi-access Edge Computing (MEC) Platform (MEP) has been established with three UPF implementations, along with Network Function Virtualization (NFV), The MEC host selection logic integrated with 5G core is being readied at IIT Delhi. The MEP is running on a virtual infrastructure, providing compute, storage & network resources for MEC applications, integrated with the 5G core components, thus acting as a virtual MEC host. The data and control paths have been established between all core components following a service-based architecture.

LiFi

Light Fidelity, LiFi is an exciting new field which can deliver 5G speeds to the end user. The R&D team on LiFi has demonstrated proof-of-concept with the transmitter receiver (16 QAM) on FPGA board and the control plane [Figure 4]. This technology has a basic frame structure implementation according to the IEEE 802.15.7. Besides, it will have the functionalities such as MAC-like visibility support, dimming, flicker management, QoS control, multiple user support, multiple access points, handover, enhancing distances & speeds.

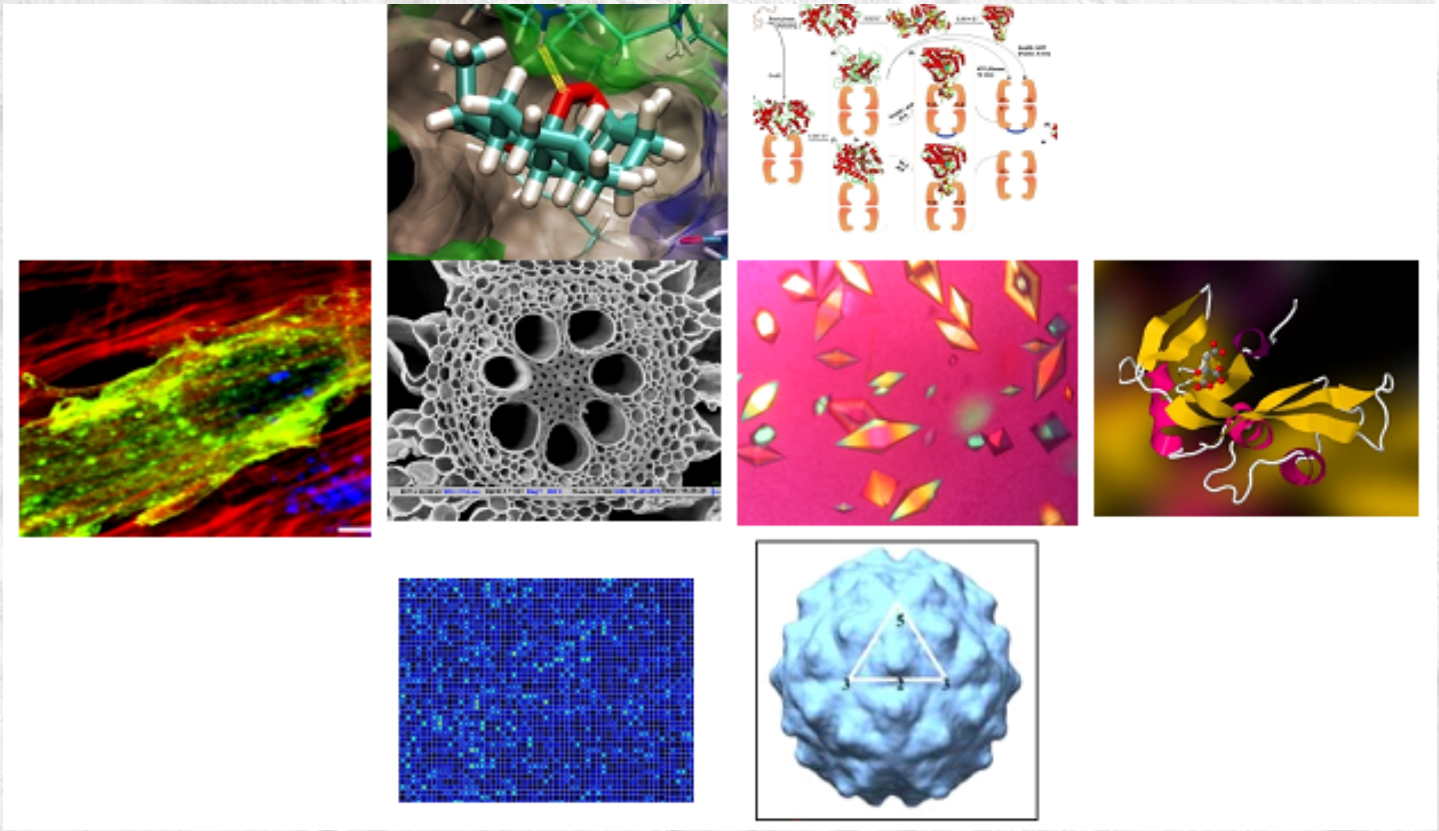
Figure 4

Haptics Application

The challenging Haptics application being developed by the collaborative efforts of the Institute's mechanical and telecom departments is a unique research and development effort in which low latency will be tested and demonstrated. The application will demonstrate a tele-operative control of a robotic hand system. The feedback from the haptic glove and the robotic hand system will be transmitted over 5G for swift control of the robotic hand. This application ported as an MEC app will highlight the low latency feature of MEC.

Other Development Efforts

The other ongoing development efforts are in the Internet of Technology (IoT) space. Technologies such as the fabrication of air pollution monitoring sensors, fabrication of wireless sensor nodes, Prediction Model Analysis using LSTM and GRU models, data visualization, a real-time dashboard for the iOS and Android platforms are in the pipeline. Development work on FR1/FR2 MIMO entails development of channel estimation algorithms on base station receiver as well as for single stream channel equalizer. A C++ code for Blind Decoding of PDCCH has also been developed & tested.



KUSUMA SCHOOL OF BIOLOGICAL SCIENCES

RESEARCH AREAS

- Chaperone Assisted Protein Folding
- Protein Engineering
- Amyloids
- Virus-Host Interactions
- Cell Penetrating Peptides
- Diabetes
- Kinetcs of Self-Assembly
- Protein Folding

Modern Biology has evolved into an inter- and multi-disciplinary quantitative science aimed at molecular, structural and systems level understanding of natural phenomena that form the wonder considered as life. In order to contribute to this fascinating and emerging area of science, the Kusuma School of Biological Sciences was established in December 2008.

Evaluation of Medicinal Plants for the Management of Covid-19

The Covid-19 pandemic created an immediate need for cost effective therapeutic options which can curb the severity of the viral disease in humans, with minimal toxicity. In this context, about 51 medicinal plants which may provide a way to treat the disease by targeting specific essential proteins of the virus were screened. Tea (*Camellia sinensis*) and Haritaki (*Terminalia chebula*) plant aqueous extracts showed potential anti-viral activity via in-vitro inhibition of the proteolytic activity of the main protease of the virus 3CL pro, with an IC50 value for Green Tea as 8.9 ± 0.5 µg/mL and Haritaki as 8.8 ± 0.5 µg/mL. The inhibition in the protease activity may be able to halt the SARS-CoV-2 replication cycle. Hence, Tea and Haritaki plant extracts act as two potential therapeutic candidates for the SARS-CoV-2 infection. Further investigation on the role of active constituents 'Gallotannin' in the extracts is needed to establish the molecular basis of inhibition and towards expedited drug discovery [Figure 1].

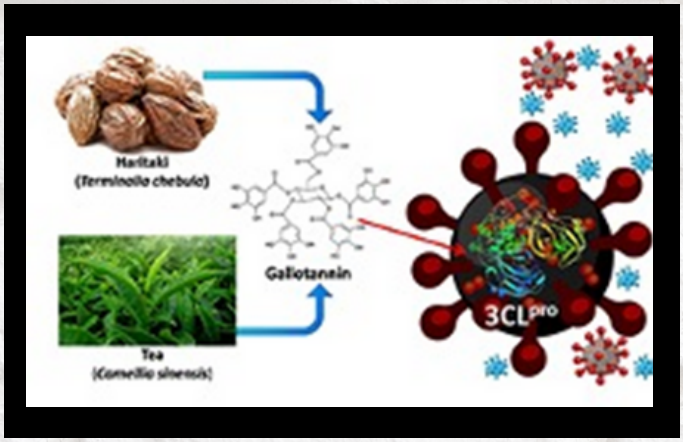


Figure 1

Therapeutic Potential of Teicoplanin Against SARS-CoV-2

In search of a quick, safe and successful therapeutic agent; various clinically approved drugs were screened for the in-vitro inhibitory effect on 3CLPro which may be able to halt virus replication. Teicoplanin was found to be the most effective drug with IC50 ~ 1.5 µM. The results provide critical insights into the mechanism of action of Teicoplanin as a potential therapeutic against Covid-19. The researchers found that Teicoplanin is about 10–20 fold more potent in inhibiting protease activity than other drugs in use, such as lopinavir, hydroxychloroquine, chloroquine, azithromycin, atazanavir etc. Therefore, Teicoplanin emerged as the best inhibitor among all drug molecules that were screened against 3CLPro of SARS-CoV-2. The relative efficacy of the drugs to inhibit the protease activity of main protease of SARS-CoV-2 was analysed using protease assay. Teicoplanin emerged as the most potent inhibitor with IC50 value at 1.5 µM in tested 23 drugs [Figure 2 & 3].

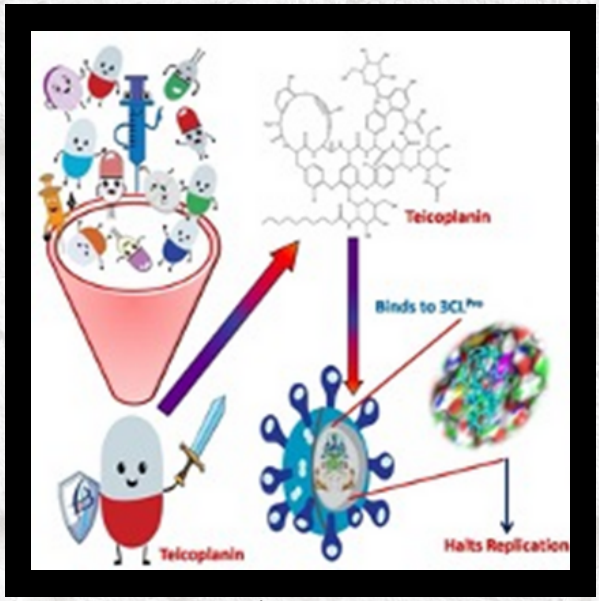


Figure 2

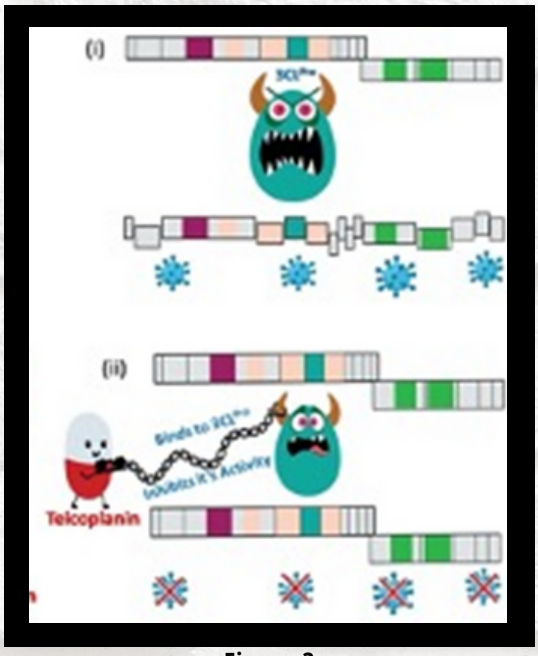


Figure 3

Peptide Mediated Therapeutics

The dual properties of membrane active peptides i.e. cell penetrating as well as antimicrobial peptides are being studied. Peptide-based ocular disease management is effective in fungal keratitis, keratoconus and other anterior eye diseases/ infections. In case of fungal keratitis management, the researchers have shown that Cell Penetrating Peptide (CPP) conjugated Natamycin shows higher penetration in rabbits as well as enhanced antifungal efficacy in murine model than Natamycin alone. Increase in penetration of Natamycin was observed in rabbit eyes when treated with CPP Natamycin conjugate in comparison to Natamycin alone [Figure 4]. The enhanced antifungal efficacy of CPP Natamycin conjugate-resolution of fungal keratitis from Grade 3 to Grade 0 has been shown in Figure 5.

Peptide Mediated Therapeutics (Contd...)

Further, work is in progress towards designing and developing novel and effective, stable membrane active peptides (AMPs/CPPs) from venom peptide toxins particularly from marine organisms, snakes and spiders. Such membrane active peptides have shown enhanced activity against pathogens such as *Fusarium, Leishmania*.

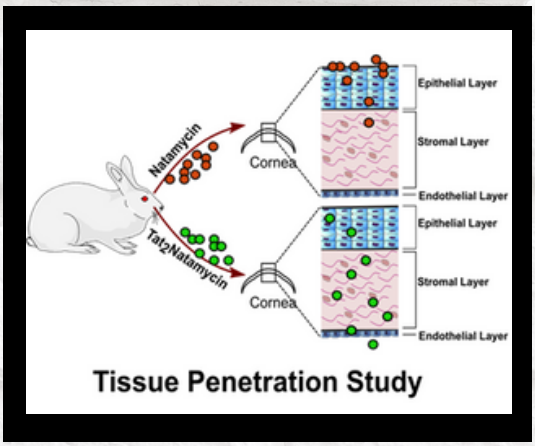


Figure 4

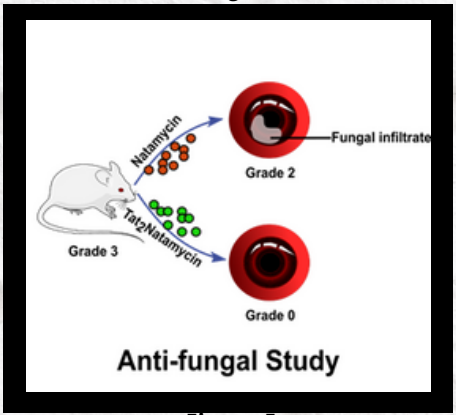


Figure 5

Computational Study of SARS-CoV-2 Membrane Fusion

In this work, computational methods were used to identify the fusion peptide (FP) region from SARS-CoV-2. Simulations of a dual membrane system with multiple oligomeric forms of putative fusion peptides were carried out and it was shown that the trimeric form of a 40 residue region from the Spike protein of SARS-CoV-2 is the most effective in initiating fusion bridge formation. This putative FP partitions deep inside opposing membranes, causes large-scale lipid tilting, and pulls lipids from the lower to the upper leaflet through interactions with a large loop at its C-terminus.

Computational Study of SARS-CoV-2 Membrane Fusion (Contd...)

This method provides a quick way of functionally assessing fusion peptides from enveloped viruses, which is essential for devising prevention strategies [Figure 6].

PKCα: Prospects in Regulating Insulin Resistance and AD

PKCα is known to participate in various signaling pathways, due to its ubiquitous and dynamic characteristics. Previous studies report that PKCα abrogates peripheral insulin resistance, and recent publications shows that it takes part in regulating Alzheimer's disease (AD). Based on literature evidences, the research group has highlighted the interesting observation that many of the substrates of PKCα, in its signal transduction cascade, are common in AD and in diabetes and may have the capability to regulate both of them simultaneously. Signaling pathways crosslinking these two diseases by PKCα have not been explored. Understanding the complexities of interactions of PKCα with common molecules will deepen our understanding of its regulations of relevant pathophysiologies and, in future, may broaden the possibility of being a therapeutic target.

Structural Analysis of Virus Disassembly

The stability of icosahedral viruses is crucial for protecting the viral genome during transit; however, successful infection requires eventual disassembly of the capsid. Incremental heating was used to systematically characterize the disassembly pathway of a model non-enveloped virus, and an intriguing link between virus maturation and disassembly was identified. Further, two intermediates were isolated and characterized by cryo-electron microscopy and 3D reconstruction, without imposing icosahedral symmetry. The first intermediate displayed a series of major, asymmetric alterations; while the second showed that the act of genome release, through the 2-fold axis, is actually confined to a small section on the capsid. The study presents a comprehensive structural analysis of non-enveloped virus disassembly and emphasizes the asymmetric nature of programmed conformational changes. This method may be utilized in future to structurally characterize disassembly intermediates of human viruses. Since disassembly is a key step during establishment of infection, an understanding of the structural alterations during this process would pave the way for the development of effective antivirals [Figure 7].

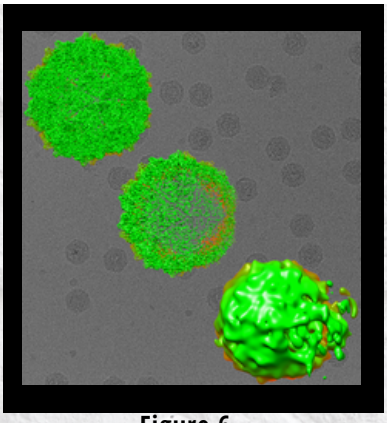


Figure 6

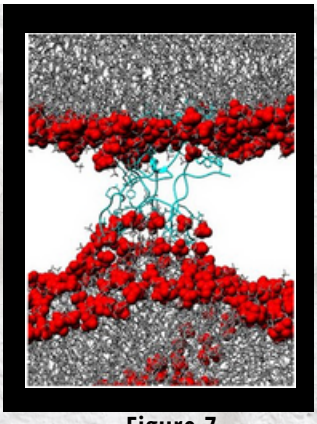


Figure 7

Fate-mapping Neurons Involved in Corpus Callosum Development

During nervous system development, the generation of the contributing neuronal and glial cells is regulated through a tight multistep control exerted by several transcription factors. One such example includes members of the developing brain homeobox (Dbx) family of transcription factors which have been found to be expressed in the developing nervous system. During the early development of the murine forebrain at E10.5-E11.5, Dbx1-positive progenitors at the pallial-subpallial boundary (PSB) and septum give rise to two molecularly distinct subtypes of tangentially migrating Cajal-Retzius (CR) cell populations. These CR populations are important for early cortical regionalization and generation of a subset of transient pyramidal neurons and thalamic nuclei. The role of Dbx1 in the cerebral cortex and corpus formation is, however, still largely unknown. The derived lineage of the Dbx1-expressing progenitors was traced and unique Dbx1-derived populations of neuronal, glutamatergic and GABAergic, and glial cells characterized. These Dbx1-derived cell populations occupy the corpus callosum and its surrounding regions in addition to the developing cortical region. Subsequently, a selective genetic ablation strategy was used by expressing diphtheria toxin in the Dbx1-positive progenitors specifically. The loss of molecularly distinct Dbx1-derived neurons and glia was shown to lead to severe midline patterning defects of the corpus callosum characterized by cellular disorganization and disorientation of the projecting callosal axons [Figure 8]. These experiments demonstrate a new role of Dbx1 in embryonic brain development. Loss and disorganization of glial cells and associated defects of callosal axons in the NesCreDbx1DTA mouse. Immunohistochemistry for GFAP and SNAP25 on coronal sections of brains of control mice (A1-A3) and of NesCreDbx1DTA mice (B1-B3) at E18.5. Bar = 220 µm for A1, B1; 110 µm for A2-A3 and B2-B3.

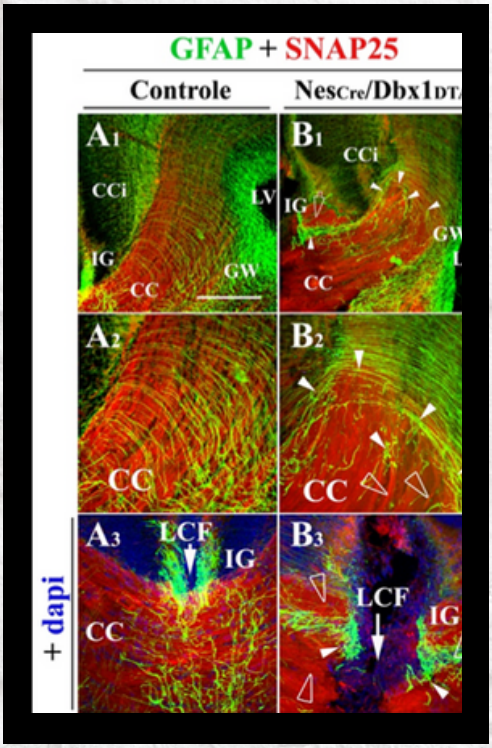


Figure 8

Ligand Gating and Allosteric Communication in Acetylcholine Receptors

Structural dynamics studies of ion channels and receptors expressed in neurons revealed that the neuromuscular acetylcholine receptors (nAChRs) are typical hetero-pentameric, ligand-gated ion channels. They belong to a superfamily of pentameric LGICs that play critical roles in chemical communication in the nervous and immune systems, including attention, memory formation, auditory response, and muscle contraction. They are implicated in many human diseases, such as, Alzheimer's, Schizophrenia, depression, epilepsy, and congenital myasthenia syndrome. The binding of the neurotransmitter ACh to the receptor promotes a global conformational change leading to opening of the channel and the conduction of ions across the membrane. The allosteric communications in these receptors is a focus area of study. Here, by measuring free energy changes from single channel currents recorded from AChRs and meta-dynamics (MTD) simulations, the presence of a hydrophobic 'gate' between 9'-16' positions in the pore-forming helices is elucidated. It offers a broad energy barrier of +9.3 kcal/mol to ion conduction in the closed pore. This energy barrier is a function of an interactome network of hydrophobic residues that collapses with mutations of any of the 9' or 13' residues. Results suggest that channel opening involves relay of allosteric communication, upward and outward rigid body movement of the pore-forming helices, local "melting" of the gate, rotation of side chains, and wetting of the pore that lowers the barrier to ion permeation and stabilizes the open-gate conformation. The detailed structure-dynamics study on AChRs will help in understanding the inner workings of the macromolecular machine and future therapeutic development [Figure 9 & 10].

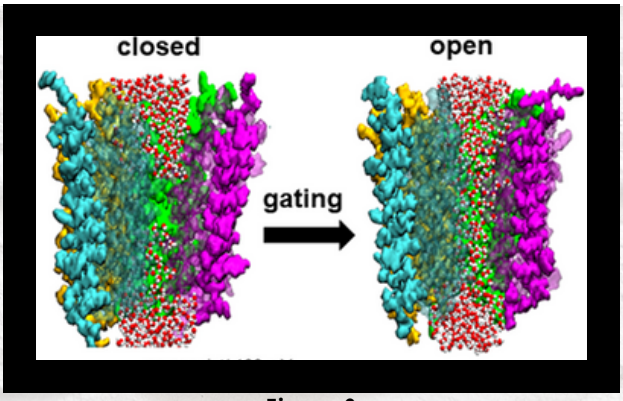


Figure 9

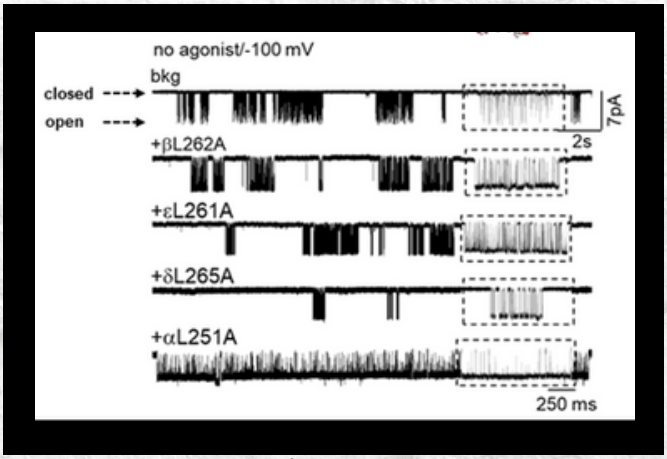


Figure 10

Diagnostic and Molecular Microbiology

A real-time PCR assay for the diagnosis of SARS CoV-2 was developed. This assay was approved by the ICMR and licensed by FITT, IIT Delhi to ten companies. Four of these companies have procured the CDSCO approval for the assay. This is a probe-free assay and is among the most affordable RT-PCR assays in the country. In July 2020, the then Union Education Minister launched the kit and this assay is now sold and used in India for the diagnosis of SARS CoV-2. In addition, a US-based company is in the final stages of obtaining US-FDA approval for this assay. Six patents include two granted US patents in the area of diagnostics, one PCT application filed in the area of diagnostics, and three Indian patents filed in the areas of diagnostics and anti-bacterial coating. Three of these patents have been transferred to companies. One of them has been fully commercialized for use as the SARS CoV-2 RT-PCR assay [Figure 11]. The research group is also pioneering work to map G-quadruplexes in virus genomes and identify their biological roles resulting in a body of literature with over 170 citations in four years. This work led to the identification of several yet unknown functional aspects of G-quadruplexes in microbial genomes including in transcription, replication, virion secretion, recombination, modulation of virus encoded miRNA and virus packaging.

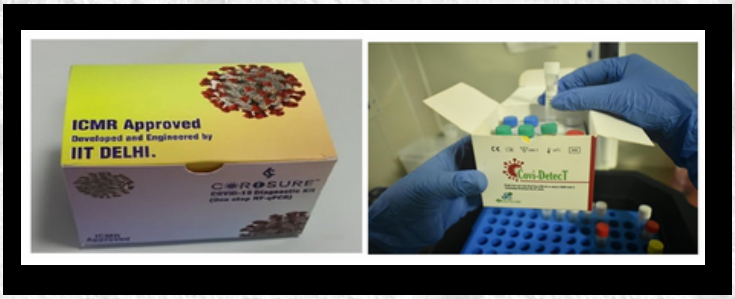


Figure 11

The Way Forward...

The present ebook compiles major research carried out by faculty members and students of the Institute in recent significant research contribution of IIT Delhi towards 'Azadi ka Amrit Mahotsav'.

The Institute aims to focus research in the areas in sync with global priorities in the areas of Artificial Intelligence/Machine Learning,& Data Sciences; Climate Changes, Sustainable Environment & Green Energy; Healthcare Technology; Science & Nanotechnology; and Smart Materials & Advance Manufacturing - areas, in which future research at the Institute will be focused.

The persistent efforts of the Institute's research fraternity in the above areas will continue to empower the nation and secure its place globally among the technology innovators.

Let's continue to strive to take research at IIT Delhi to greater heights and to address the new national and global challenges by leveraging the research strength of the Institute.

"We do not need magic to change the world, we carry all the power we need inside ourselves already: we have the power to imagine better" - J.K. Rowling

A Compilation by Industrial Research and Development (IRD), IIT Delhi