PressCeNSE

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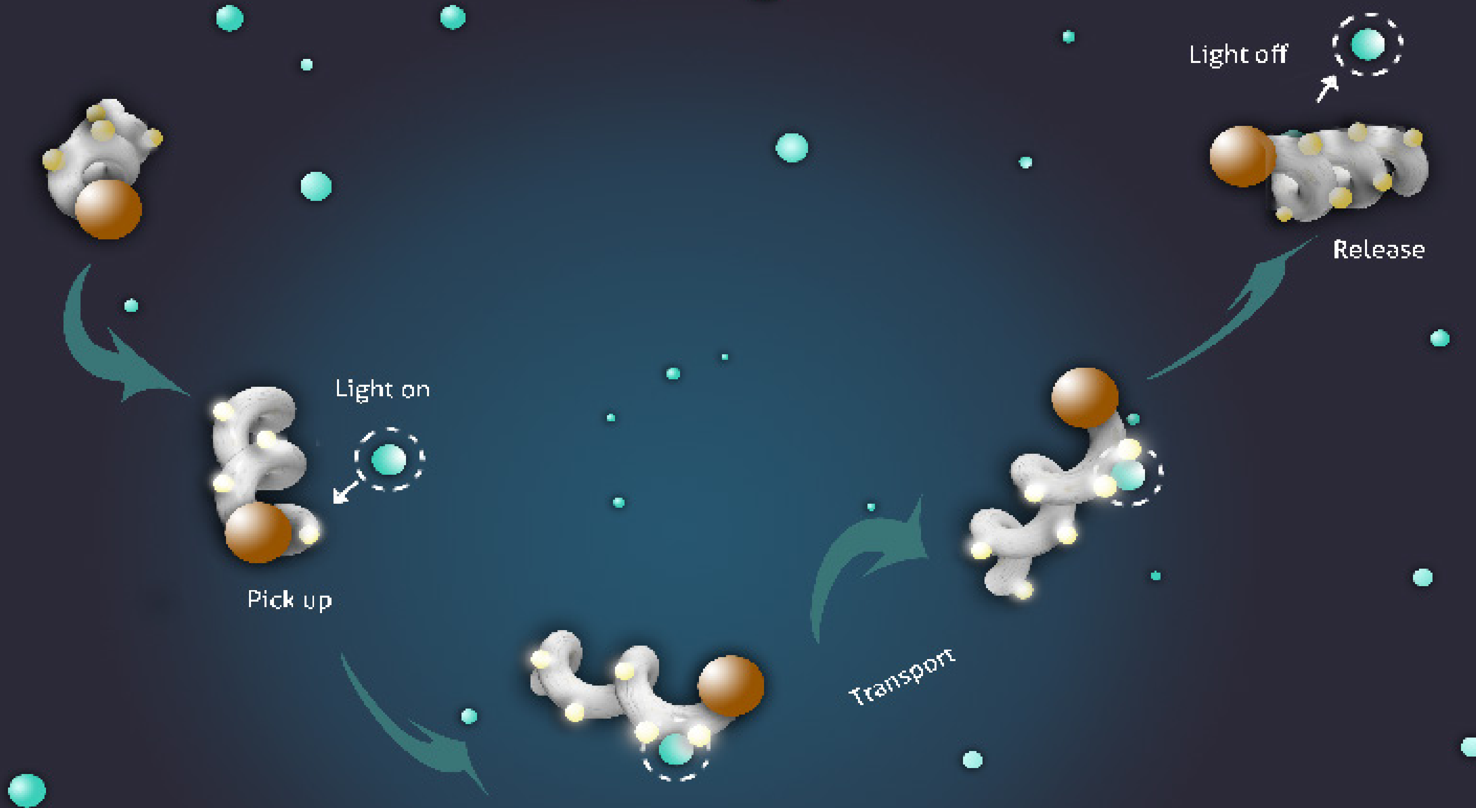

Centre for Nano Science and Engineering (CeNSE)
Indian Institute of Science

भारतीय विज्ञान संस्थान

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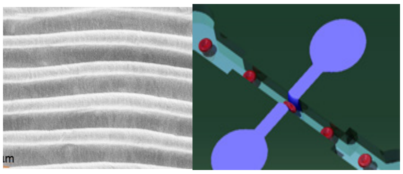

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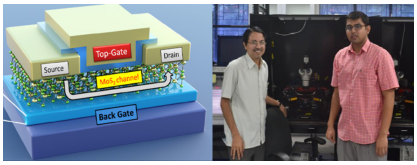

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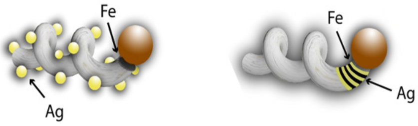

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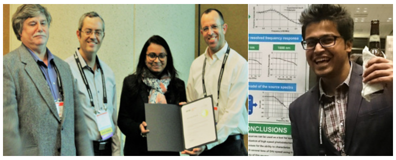

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Cover photo: Schematic of the nano-tweezer fabricated at CeNSE.

A WORD FROM THE CHAIRPERSON

Welcome to the Centre for Nano Science and Engineering (CeNSE) at Indian Institute of Science. Established in 2010, and formally dedicated to the nation in 2015 by the prime minister of India, CeNSE has emerged as a melting pot of different disciplines in science and engineering. The interdisciplinary research in the centre is defining new horizons through scientific discovery and engineering innovation at nano scale. The National Nanofabrication Centre (NNfC), anchored in CeNSE, is one of the best university foundries in the world. The Micro and Nano Characterization Facility (MNCF) is only one of its kind in an academic setting anywhere in the world. This unmatched physical infrastructure is complemented with an exceptional human capital of the centre, consisting of faculty, students, technical, administrative and support staff. The confluence of all these ingredients, provides an unique platform to experiment and innovate with nanomaterials and nanodevices, with unprecedented precision. The research and education in the centre is targeted towards diverse application areas including electronics, sensors, photonics, defence, space, energy, healthcare and agriculture. The underlying theme is to create societal impact by translating the academic research into useful products.

Our outreach programs are designed to ensure that CeNSE family extends beyond the physical confines, thereby creating a larger pool of people and resources. This enables us to achieve our collective vision, as a "team", by leveraging complementary expertise. The Indian Nanoelectronics Users Program (INUP) has spread the awareness of nanotechnology to the remote corners of the country. A strong community of well trained researchers, more than 2000 in number from about 200 institutions, is now accessible through INUP network. We are also engaged in research collaboration with several universities in India and abroad. The Industry Affiliate membership Program (IAP) bridges the gap between academia and industry through sustained scientific interactions and joint research project execution. Nanotechnology start-up incubation program has already created four start-up companies cofounded by faculty, students and technical staff of the centre.

The future looks bright and clear. While we march forward to become one of the finest research centres in the world, we are equally determined to touch the lives of every citizen, by focusing on the bottom of the pyramid. We want to bring-in positive change in the society, through the intervention of nano science and engineering. Together, we can realize this dream. Come and join us; be part of this exciting journey...

What's new in research at CeNSE

MEMS/MOEMS LAB

Micro and Nano Patterning: Vijayendra Shastri & Prof. Rudra Pratap

Recent research is proceeding towards a versatile way of micro and nano patterning combined with reduced fabrication cost, time and resources to achieve advanced devices/systems. In the same context, we have discovered that liquid Gallium, due to the combined effects of temperature and electric field, flows locally in a periodic fashion, forming structures with ripple surfaces. These ripple patterns have wavelengths in the scale of a few micrometres to a few hundred nanometres. The experimental procedure involves a strip of silicon substrate with a thin film metal line deposited over it and a gallium bead placed over the line. When electric current is applied, the gallium metal melts and starts to flow due to joule heating. Under certain ranges of voltage and current, gallium, which usually flows in the direction of electric current, starts flowing in the opposite direction of the electric field forming ripples. The patterns that are formed are initially coarse (of the order of tens of microns) but become fine towards the end of the flow patterns (of the order of a few hundred nanometers). We observe that the temperature gradient and substrate affect the flow patterns and the flow and pattern formations occur even against gravity. This is a simple one step process to produce nano ripples, which could potentially be used in parallel microfluidic channels, diffraction gratings and many more applications which use periodic patterns.

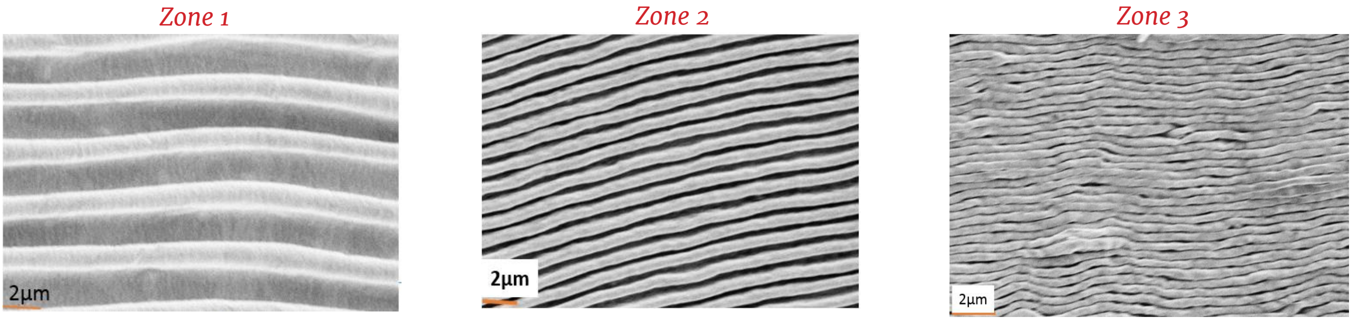


Fig: SEM image of the ripple formed on platinum line

WIDE BAND GAP DEVICES LAB

Interface traps in III-N HEMT on Silicon: Sandeep Kumar, Prof. Muralidharan & Prof. Digbijoy

III-N materials have witnessed a continuous interest among researchers for its applications in RF power amplifiers, power switching transistors, LEDs and UV detectors. Nitride HEMTs are rapidly penetrating the power and RF electronics market due to its unique properties such as high breakdown field and polarization. The active layers of the HEMTs consist of barrier (AlGaN, InAlN) and channel (GaN) layers. The widely used barrier is AlGaN, however InAlN barrier offers higher 2DEG charge. The gate-drain depletion region sustains the lateral electric field in HEMTs however, for 600 V or above HEMT devices, the chances of vertical breakdown increases due to vertical field penetration. The growth of HEMT on Si offers the economic viability of technology and it suffers from large leakage current issues arising due to dislocations in the buffer. These buffers are mostly Carbon or Iron doped which help in reducing the background carrier concentration, eventually leading to low leakage in HEMTs. The carbon doping results in acceptor type energy state and a proper characterization of these trap behaviour needs to be done to realize a high-performance device. Also, high power switching HEMTs necessitates the use of a dielectric for ultra-low leakage and in these cases the dielectric nitride interface needs proper investigation.

Here interface characterization of Al_2O_3/InAlN/GaN HEMT grown on 200 mm Si and AlGaN/GaN HEMT grown on 150 mm Si were characterized. The InAlN/GaN HEMT stack and the fabricated device are shown in the Fig 1. The interface characteristics were studied using the C-V measurements as shown in the Fig 2. The huge spread in the C-V suggests the poor interface quality of InAlN/GaN interface. Detailed characterization results are available in ref *S.Kumar et.al., Solid State Electron., vol. 137, pp. 117–122, 2017*. Figure 3 shows the AlGaN/GaN HEMT stack and the fabricated device used for interface characterization. Frequency and temperature dependent C-V measurements were performed to characterize the AlGaN/GaN interface. Room temperature frequency dependent C-V measurements shows very less spread in the C-V characteristics (Fig. 4) and it suggests that the AlGaN/GaN interface is good. Temperature dependent C-V characteristics showed a gradual shift of threshold voltage which can be attributed to change in frequency modulatable charge with change in temperature. Detailed discussions on this subject is available in ref *S.Kumar et.al.,IEEE Trans. Electron Devices, 2017*.

Fig. 1

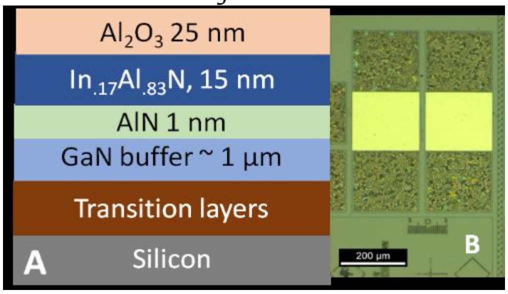


Fig. 1 (A): Epitaxial stack of device (B) Optical microscope image of fabricated FATFET device

Fig. 2

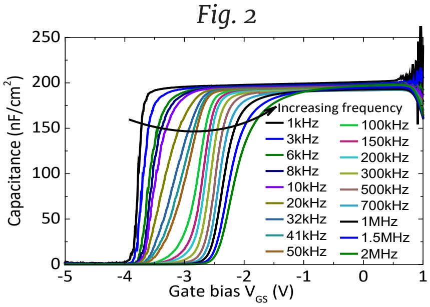


Fig. 2: Capacitance vs. V_{GS} characteristics of FATFET

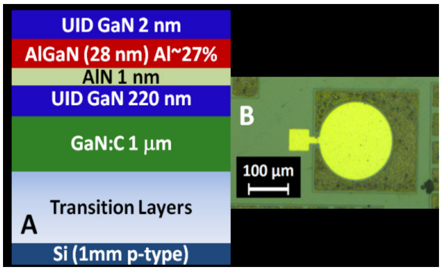


Fig. 3

Fig. 3 (A): Epitaxial stack of device (B) Optical micrograph of circular Schottky C-V pad

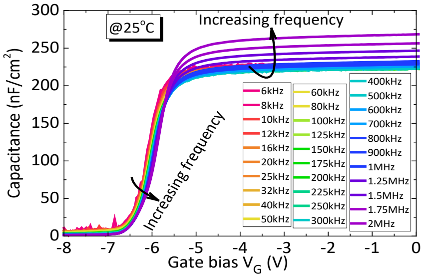


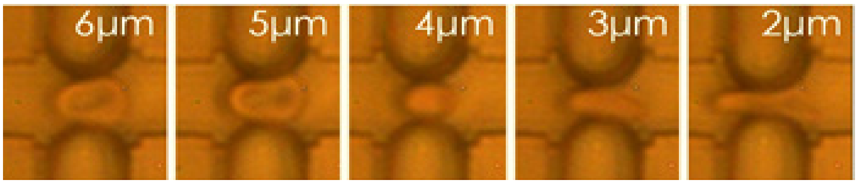
Fig. 4: C-V characteristics at 25°C for various frequencies

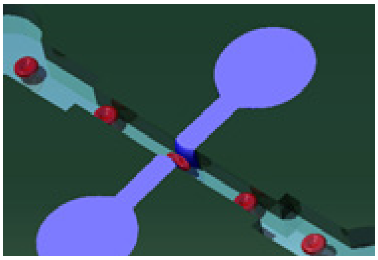
Fig. 4

MICROFLUIDICS LAB

Air-liquid Interface as a novel tool for Mechanodiagnostics: Rahul Singh Kotesa & Prof. Prosenjit Sen

We introduce air-liquid interface as a novel active mechanical element which can deform biological cells and have developed a technique that enables both static and dynamic deformability measurements in live cells ex-vivo. We use the air-water interface (~0.07 N/m) to deform cells at high-throughput in micro-channels. The static mode measures the stiffness of a single cell by calculating change in the Laplace pressure. The dynamic mode allows high throughput deformability measurements (>100cells/s) of Deformability Index (DI) and transit time for tunable air-liquid interface constriction widths. The system replaces the conventional solid mechanical walls with a tunable air/liquid or liquid/liquid interface, which is a unique feature of the technique. The adjustments in constriction width can be made in real time and can be tuned to widths as small as 2µm by controlling the air-flow. This technique provides a better estimate of the mechanical properties of the biological cells as it eliminates the cell-substrate interactions which often hide the true deformability and hence is a major problem in the existing techniques. The technique can be used for different cells with comparable sizes, thereby offering flexibility and scalability. Furthermore, it solves the issue of channel clogging, which is a burden in biomicrofluidics. The system presents a quick, cost-effective, and scalable method for mechanobiological investigations.





NONLINEAR PHOTONICS AND LASERS LAB

Chip Scale Optical Frequency combs

K.P. Nagarjun, Prof. Shankar Kumar Selvaraja & Prof. Supradeepa

An Optical frequency comb (OFC) is an optical spectrum which consists of a series of equally spaced, coherent, discrete lines that can individually act like lasers. OFC's have found immense applications in spectroscopy (Nobel Prize in Physics, 2005), sensing, astronomy, precision measurements etc. making them a highly sought after optical source.

A powerful application of the OFCs is in its use as a source for an optical data transmitter. However, the generation of optical frequency combs can be challenging, since it typically requires the use of complex, bulky and expensive laser systems such as mode-locked lasers. Thus, different research groups across the world have investigated techniques to make compact, portable comb generator systems that can be easily integrated into other subsystems.

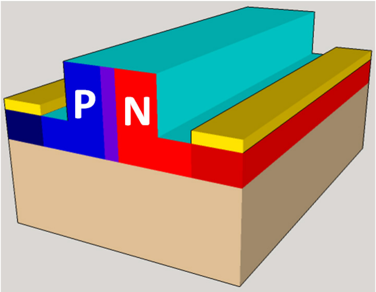


Fig. 1: Cross section of a doped silicon electrooptical modulator: light propagates through a symmetrically doped waveguide while a modulation voltage is applied from electrodes (yellow).

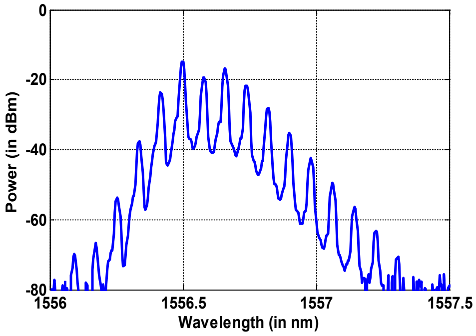


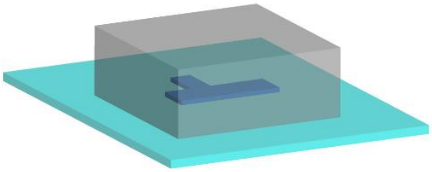
Fig. 2: An OFC generated from the modulator with a line spacing of 10 GHz. A laser with a center wavelength of 1556.6 nm was pumped through the device that is only ~4mm long.

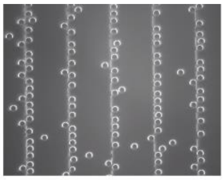
In our group, we have developed a novel technique to generate optical frequency combs at the chip level in silicon. Using the technique of strong phase modulation in PN doped electro - optical silicon modulators, we have investigated through electro-optic simulations and have experimentally demonstrated frequency comb generation in this platform. This generation technique comes right away with fantastic advantages: CMOS compatible fabrication, i.e it can be easily mass produced and integrated with other silicon photonics devices. Secondly, our technique allows us to tune the center frequency of the comb generation as well as tune the repetition rate (i.e the wavelength spacing between the comb lines) to suit a variety of applications. In this platform, we've been able to tune the center frequency over tens of nanometers and tune the wavelength spacing from 5GHz all the way to 15 GHz.

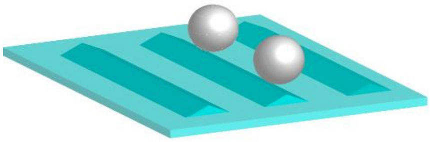
COSMOS LAB

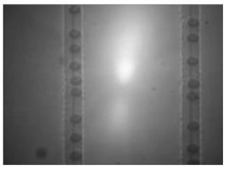
Trapping/Pinning of colloidal microspheres over glass substrate using surface features : Praneet Prakash & Prof. Manoj Varma

There is a lot of interest in studying collective phenomena. Although there are numerous studies of collective phenomena in homogeneous environments, there is relatively much less work on collective effects in disordered systems. Part of the difficulty is in preparing disordered systems with prescribed characteristics over a large area in a simple manner. In this context, we have found that when a colloidal solution (solution with micro-particles) is flown over a microstructure substrate, symmetry breaking in the motion of microspheres as they move past the microstructures leads to their pinning in the downslope region. These microstructures are in the shape of symmetric 'triangular crests' having heights as small as 1 micron. The experiments and mathematical modelling indicate that pinning of the microspheres occur due to a combined effect of hydrodynamic and DLVO interactions between the microsphere and the substrate. This method allows trapping and pinning of microspheres in any arbitrary pattern with a high degree of spatial accuracy which can be useful in fundamental studies of collective phenomena in the presence of disorder as well as in the applications such as bead detachment based biosensors.









MEMS/NEMS LAB

Coherent Strong Coupling among Mechanical Modes in MoS_2 Drum Resonator: Parmeshwar Prasad, Prof. Akshay Naik

Coupled systems are ubiquitous in atomic and molecular to macroscopic scale. At the atomic and molecular scale, this is equivalent to two level system where the energy level start mixing with each other in the presence of an external field. Several examples of such strong coupling are observed in lasers, Raman spectra, Zeeman effect, Rabi Oscillations and so on. For example, two energy levels coherently exchange energy in lasers in strongly coupled regime. Similarly, in the case of macroscopic systems two strongly coupled pendula shows normal mode splitting. It is interesting to study these systems from a fundamental and application point of view. In our lab, recent work focuses on coupling of mechanical modes in a NEMS resonator based on two-dimensional material. We show tension mediated strong coupling among the mechanical modes in a MoS_2 drum resonator using parametric pumping. We modulate the tension in the resonator using red and blue detuned pump and study the effect on the coupling among modes. In the strongly coupled regime, we observe coherent exchange of energy among the different modes. Such a strongly coupled system in nanoscale opens up the possibility of quantum mechanical experiments in macroscopic systems.

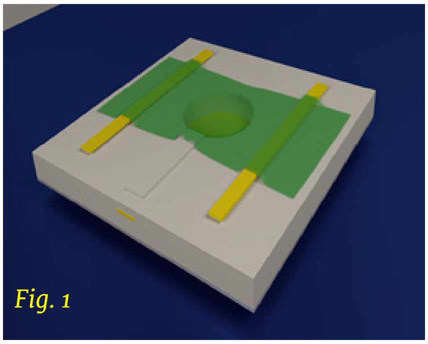
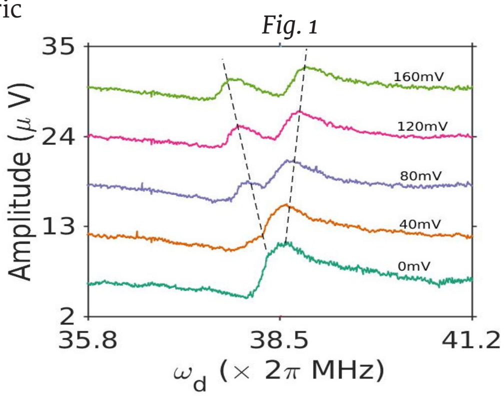


Fig. 1: Schematic of NEMS drum resonator. The membrane is suspended over the circular trench.

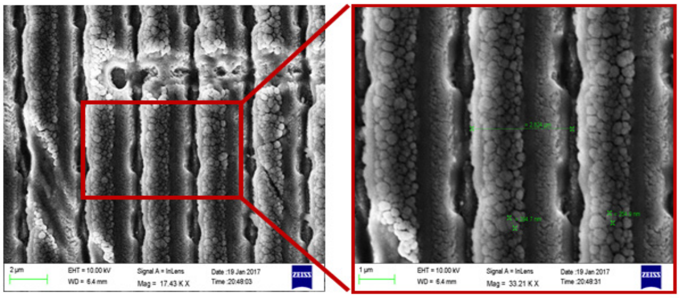
Fig. 2: Normal mode splitting of mechanical mode in strongly coupled regime in the NEMS drum resonator. Amplitude vs. frequency curve shows splitting increases with increase in the coupling strength.



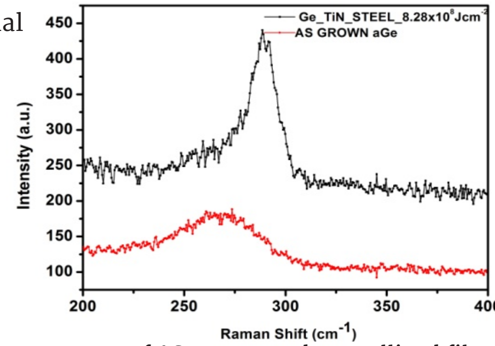
HETERO-JUNCTION LAB

Thin Film Solar Cells : Saloni Chaurasia, Prof. Sushobhan Avasthi

Thin film solar cells on flexible substrates form an attractive alternative to conventional solar cells due to their lower cost and wide range of terrestrial applications. High-efficiency III-V solar cells on low-cost substrates such as steel are limited because of two issues. First, the overlying semiconductor stack gets contaminated with iron and second, it is not easy to deposit high-quality crystalline germanium (Ge) thin-films on amorphous steel substrates which is required as a buffer layer for III-V solar cells on steel. Therefore an iron diffusion barrier is required between the semiconductor and steel. Hetero-junction lab has for the first time successfully demonstrated crystallization of germanium on titanium nitride (TiN) on steel where TiN acts as the iron diffusion barrier. We report a method to crystallize amorphous germanium thin-films using laser annealing. Laser crystallization was chosen as it offers low thermal budget specially for thin film solar cells on steel which otherwise may get saturated with iron diffusing from steel into the device layers at high temperatures. In this method, PECVD deposited amorphous germanium films are irradiated with a 532 nm laser. Films irradiated at higher fluence and films with higher thicknesses are found to have more crystalline order. The work enables future development of lost-cost GaAs solar cells.



SEM image of aGe(500nm)/TiN/steel irradiated at 8x108 J cm^{-2}

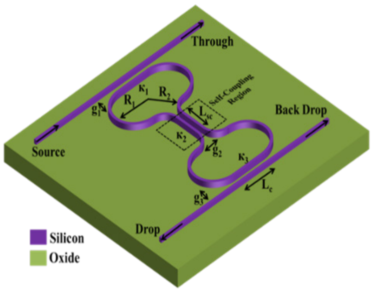


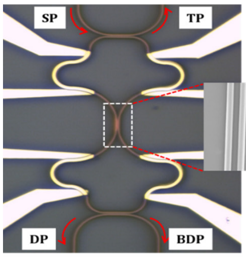
Raman spectra of AS grown and crystallized films.

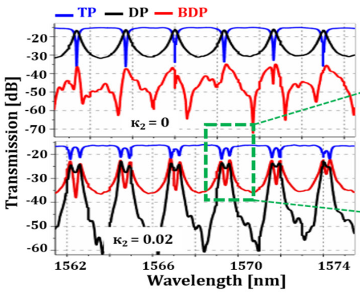
PHOTONICS RESEARCH LAB

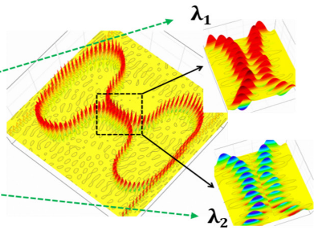
A Self-Coupled Micro Ring Resonator: Awanish & Prof. Shankar

CMOS compatible Silicon Photonic integrated circuit has emerged as a platform technology for multiple applications. Primarily explored as an alternative to copper interconnect in microprocessors, the technology has evolved to find applications in bio-sensors to RF communication. One of the key optical functionality in a photonic integrated circuit is wavelength filters and routers. Wavelength selective devices play a key role in realizing various signal processing units on a chip such as wavelength conversion, logic-gates, optical buffer, and differentiators/ integratorsand so on. Particularly, Micro Ring Resonators, a simple ring cavity optically coupled to a waveguide, offers a compact solution to realize on-chip wavelength selective signal processing. One of the undesirable effects in such a resonant cavity is parasitic coupling and scattering induced unpredictable resonance splitting due to degenerate mode excitation. We address this issue using a self-coupled micro ring resonator (SCMRR) geometry where coupling of counter-propagating degenerate modes excitation is regulated. The structure regulates the existence of clockwise and anti-clockwise mode in the resonator through the central self-coupling. Such control enables predictable resonance splitting. Using the proposed structure, we were able to demonstrate the degenerate mode excitation/ resonance splitting control experimentally. Furthermore, we exploit the spectral feature offered by SCMRR to demonstrate multiple applications that include high-speed all-optical wavelength multicasting, optical single sideband generation, RF-phase shifters, and wavelength interrogators.









Breaking the Boltzmann limit for low power nano-transistor

Shubhadeep Bhattacharjee (Prof Navakant Bhat)

The fundamental unit of computation and storage, the transistor, is essentially an electronic valve which controls the flow of current. Several decades of reducing the dimensions of the 'field effect transistor' (FET) have enabled reliable and affordable electronics and information access around the globe. However, this has been a path laden with complex problems requiring concerted multidisciplinary effort from physicists, engineers, chemists, material scientists etc. As we are nearing the end of this tremendous run, the difficulties of squeezing better performance at lower cost seems exponentially harder, but for the undying human spirit to innovate. There are two fundamental issues when we attempt to scale the dimensions of the transistors. The first challenge is that as the device dimensions shrink, the close proximity of electric fields starts interfering with each other and disrupt the transistor's operations. This phenomenon is called Short Channel Effects (SCE). Second, concurrent (quadratic) reduction in power consumption, an important aspect of scaling, is not possible because of the inability to reduce supply voltage below 1 V. This is primarily because the fundamental nature of charge transport governed by Boltzmann's statistics restricts the Sub-threshold Swing (SS, abruptness between OFF to ON transitions) of FETs to the thermionic limit of 60 mV/dec at room temperature. In order to circumvent the Boltzmann's limit, where the thermally generated carriers have to 'jump over' an energy barrier, scientists created a new class of 'tunnel transistors' or TFETs where the charge carriers can simply tunnel through the energy barrier. However, though the same Band-to-Band Tunelling mechanism which provides sub-thermionic low power operation results in drastically degraded ON currents. Hence, as we cram in more transistors into the same footprint, energy dissipation and heat management have become

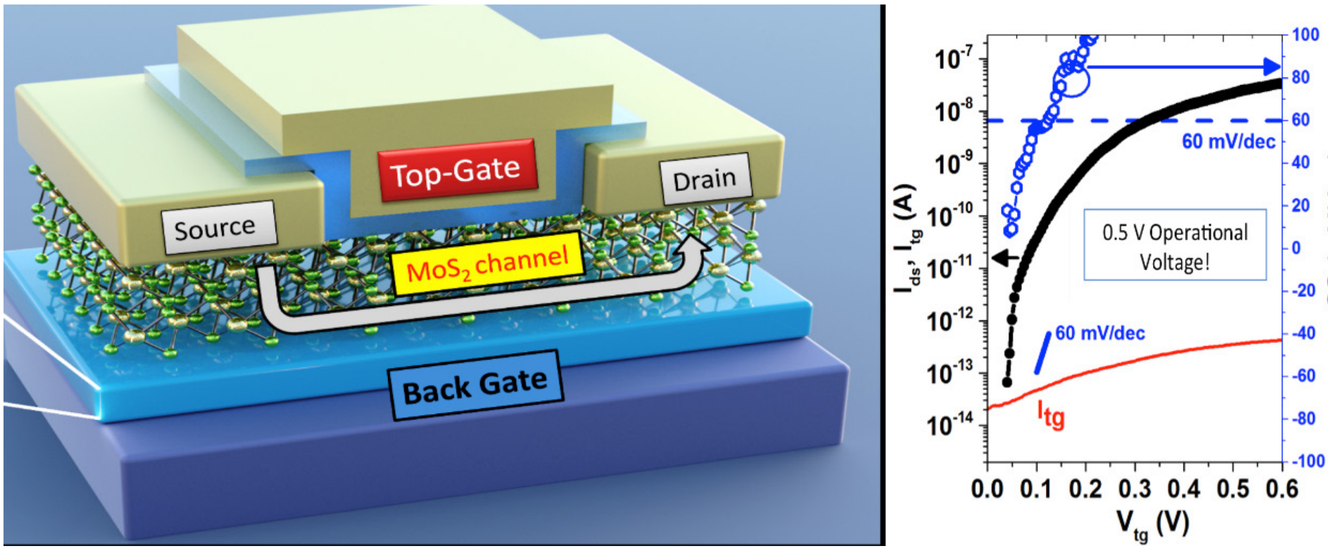


Figure 1: (left) Device struture of the dual gate MoS2 FET and (right) transistor charactaristics of sub-thermionic SS< 60 mV/dec operating at drain voltage of 10 mV.

fundamental bottlenecks. Clearly, the road ahead needs breakthroughs in new materials and device design.

In this work, we attempt to tackle, both these challenges (SCE and power consumption) by developing high performance, sub-thermionic (SS<60 mV/dec) transistors on 2D semiconductors [1]. This is facilitated by addressing a fundamental question in the affirmative: Is it possible to combine the excellent SS characteristics of the TFET with the high ON state current characteristics of the conventional thermionic MOSFET? To engineer this amalgamation, we adopt a conscious design strategy to employ metal/semiconductor Schottky junctions as the switching elements, which, unlike Band-to-Band Tunnelling (BTBT) junctions allow for both thermionic and tunnelling current components. We replace the traditional bulk semiconducting channel material like silicon, germanium, aluminium arsenide etc. with the new class of two-dimensional semiconductor, moly-di-sulphide. Excellent electrostatics inherent to 2D semiconductors make them promising candidates

Figure 2: Performing Temperature dependent measurements in Helium Probestation (in MNCF) to understand the transport mechanism of the transistors.

for mitigating SCE, with recent demonstrations of sub-10 nm channel length Molybdenum disulphide (MoS_2) FETs. Furthermore, unlike traditional semiconductors, they have no out-of-plane bonds, thus enabling a wide range of defect-free crystalline heterostructures even when the lattice mismatch between the component layers is large.

However, despite the significant advantages of 2D semiconductors, the development of high performance, sub-thermionic, low power transistors on 2D semiconductors have been heavily stymied owing to inefficient contacts, doping and dielectric integration. In this regard, an important aspect is the top high- /MoS_2 interface, when deposited through ALD requires surface functionalization to facilitate nucleation on inert basal plane of 2D materials, thus potentially compromising this critical interface. To circumvent this issue we optimize functionalization-free ultra-thin high- hafnia (HfO_2) and alumina (Al_2O_3) dielectric deposition directly on MoS_2 by e-beam evaporation. Next, we employ ammonium sulfide treatment on MoS_2semiconductor which not only helps in passivating charge impurities but also reducing contact resistance by controlling the Schottky barrier height at the metal/semiconductor interface. We fabricate dual gated transistors on an ultra-thin (5-7 nm) MoS_2 channel (Lch=1 µm) with architecture that allows independent control of barrier height (from back gate) and channel population; hence barrier width (from top gate). To ascertain the generality of this concept we demonstrate devices with different combinations of top (TG: HfO_2 or Al_2O_3) and back (BG: SiO_2 or HfO_2 or Al_2O_3) gate oxides.efficient contacts, doping and dielectric integration. In this regard, an important aspect is the top high- /MoS_2 interface, when deposited through ALD requires surface functionalization to facilitate nucleation on inert basal plane of 2D materials, thus potentially compromising this critical interface. To circumvent this issue we optimize functionalization-free ultra-thin high- hafnia (HfO_2) and alumina (Al_2O_3) dielectric deposition directly on MoS_2 by e-beam evaporation. Next, we employ ammonium sulfide treatment on MoS_2semiconductor which not only helps in passivating charge impurities but also reducing contact resistance by controlling the Schottky barrier height at the metal/semiconductor interface. This facilitates the appropriate tuning of thermionic and tunnelling currents thus allowing the device to work in 2 regimes: **Case 1**: Large barrier height enables only tunnelling currents and hence a steep SS. This allows the tuning of thermionic currents to below noise levels and make tunnelling the dominant conduction mechanism in OFF state, yielding superior Sub-Threshold Slopes [Figure 6.2(c)] and Case 2: Small barrier height enables sizeable thermionic component resulting in large Ion. Hence the Gate tunable Thermionic Tunnel FET (GT3FET) has the flexibility to operate either in the sub-thermionic tunnel regime, yielding steep SS<60 mV/dec OR thermionic high mobility regime This is the first demonstration of the ability to tune the transport of the same transistor in a tunneling or thermionic mode by simply adjusting the back-gate voltage. In the tunnel mode the transistor smashes the Boltzmann's limit by registering minimum and average Sub-threshold slope of 4.2 mV/dec (against 60 mV/dec in conventional FETs) and 25 mV/dec for 3 decades (against ~100-120 mV/dec in conventional FETs), thus consuming a fraction of the supply voltage required by traditional FETs. Additionally, this happens to be only the 2nd transistor to demonstrate average sub-60 mV/dec for 4 decades of drain current, a necessary condition stated by the International Technology Roadmap For Semiconductors (ITRS) consortium for next-generation low power transistors. The icing on the cake is the fact that the ON currents in the GT3FET also exceed the state-of-the-art transistor by a factor 2.5 at ultra-scaled drain voltages of 10 mV! In the thermionic mode, the GT3FET behaves like a conventional thermionic transistor which although loses the sub-60 mV/dec advantage, it delivers very high ON drive currents and field effect mobility crucial for high performance computing. in OFF state, yielding superior Sub-Threshold Slopes [Figure 6.2(c)] and Case 2: Small barrier height enables sizeable thermionic component resulting in large Ion. Hence the Gate tunable Thermionic Tunnel FET (GT3FET) has the flexibility to operate either in the sub-thermionic tunnel regime, yielding steep SS<60 mV/dec OR thermionic high mobility regime This is the first demonstration of the ability to tune the transport of the same transistor in a tunneling or thermionic mode by simply adjusting the back-gate voltage. 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In the thermionic mode, the GT3FET behaves like a conventional thermionic transistor which although loses the sub-60 mV/dec advantage, it delivers very high ON drive currents and field effect mobility crucial for high performance computing.

In summary, we demonstrate that through appropriate control of the tunneling and thermionic components through a Schottky junction, it is possible to facilitate sub-thermionic conduction and high ON currents in the same device. The gate tunability feature which allows to transition from the sub- thermionic steep SS region to the high current region would be a great match for modern day VLSI CMOS circuits which require a small subset of transistors to yield higher performance at the cost of off currents. Earlier, if one would require two different transistor operations in the same chip, it was fabricated by separate lithography and processing steps, making it expensive and tedious. With our technology you can achieve this flexibility just by controlling the back-gate voltage. We envision this work to change the conventional narrative, influencing the design of low-power, high performance and pave a new path in the development of transistors operating in the sub-0.5 V 'green computing' regime.

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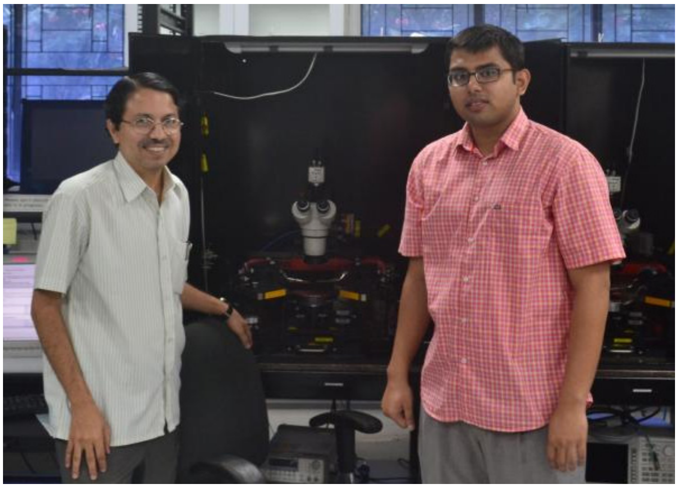


NANO-ROBOTS AS MOBILE NANO-TWEEZERS

Souvik Ghosh (Prof Ambarish Ghosh)

In his 1959 lecture titled 'There's plenty of room at the bottom', Richard Feynman envisioned the possibilities of manipulating and controlling things on a small scale. Today controlled manipulation of nanoscale objects, whose sizes are about a billionth of a metre, is a vast area of research. Manipulation of such nanoparticles requires trapping forces that can be focused and translated precisely. More than thirty years ago Bell labs first proposed a device that used focused laser light to trap objects. These devices are known as Optical tweezers and now a key instrument in biology, soft matter physics and quantum optics research. In a recent study, researchers from CeNSE have designed a new class of Optical tweezers to trap and manoeuvre objects as small as 100 nm in a three-dimensional volume of liquid.

A major problem faced with optical tweezers and other conventional trapping techniques is their inability to hold extremely small sized objects, also called cargo. Imagine picking up grains of salt using only a pair of needles! What makes it tough is that the force required to capture a particle reduces as it's size decreases.

The key technological breakthrough for enabling these optical tweezers to reach deeper into the nanoscale and become so-called "nanotweezers" has been plasmonics. When illuminated by light, noble metallic nanostructures create a strong electromagnetic field around themselves that can attract and trap nanoparticles that are close.

However, plasmonic tweezers have a limitation. With a limited range of influence and being fixed in space, these tweezers can only capture nanoparticles in their vicinity; hence being inefficient. "So, it is necessary to design a technique that has the efficiency of a traditional plasmonic tweezer but, at the same time, is manoeuvrable", says Souvik Ghosh, a student of CeNSE, and a co-author of this study.

In this study, published in the journal Science Robotics, Mr. Ghosh, along with Prof. Ambarish Ghosh from Centre for Nanoscience and Engineering, IISc, have designed a new class of nanotweezers, that combines plasmonic tweezers with micro robots to design 'mobile nanotweezers' (MNTs) that bring together the best of both world. These nanotweezers can be driven to the target objects as small as 100 nm with precise control to capture, transport and release small sized cargo made of various materials with high speed and efficiency. "Microbots can carry/push objects very quickly, but do not work well for sub-micron objects. By combining the functions of these two technologies, we can not only trap but move very small objects very quickly" adds Mr. Ghosh.

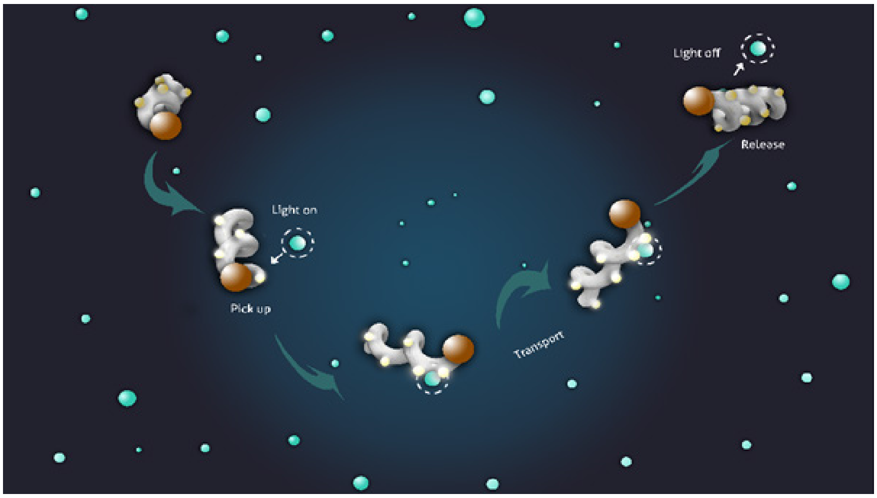


Figure 1. Schematic of the nano-tweezer fabricated at CeNSE.

The design of these mobile nanotweezers is inspired by microorganisms. Akin to a bacterium that moves by rotating its helical flagellum — a cellular protrusion used for swimming — these ferromagnetic, helical nanostructures can be moved by a uniform, rotating magnetic field, which moves and rotates along the direction of the magnetic field. By controlling the magnetic field, the motion of the nanotweezers can be controlled.

The researchers have designed two similar MNTs made of silicon dioxide. Silver and iron, combined with the nanostructures, provide plasmonic properties and magnetic properties. While the first design contains silver nanoparticles distributed across its surface, alternating layers of silver and iron are combined within the structure of the second.

The researchers tested the two designs in a fluid chamber containing some cargo particles. They magnetically steered the nanotweezers towards the cargo and when the chamber was illuminated, they observed that the nanotweezer trapped the cargo which was subsequently maneuvered and released by decreasing the illumination intensity. "The first design works very well for particles that accumulate near hot places like silica particles, while the second is very general and does not care whether the particles like heat or not. For a general application, the second design is preferred", says Mr. Ghosh. In addition, the researchers observed that when two particles of different sizes are present in the cargo, by decreasing the illumination, the smaller particle can be released, whereas increasing the frequency of the rotating magnetic field would release the larger particle. This unique sorting behaviour allows the transport of nanoparticles of different sizes by simply varying the two influences.

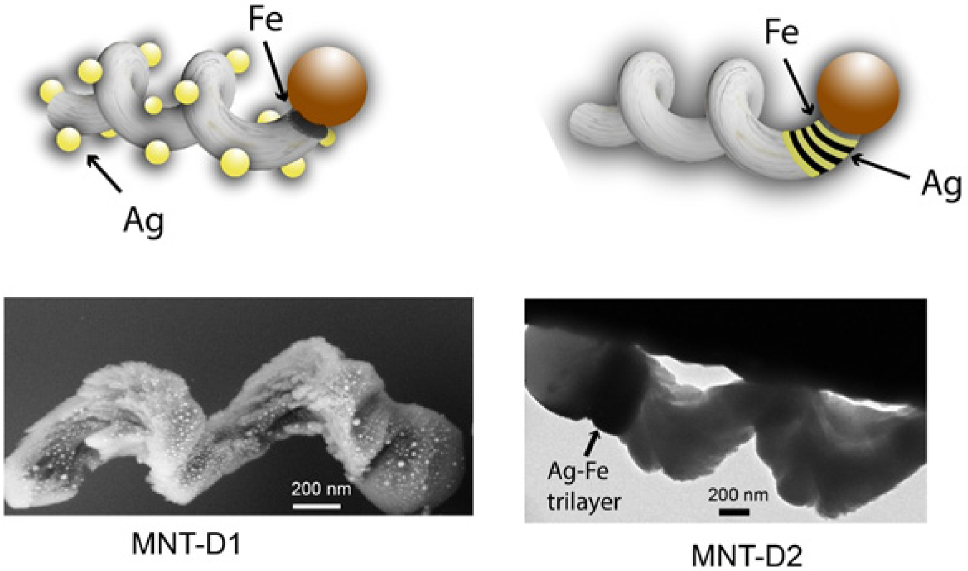


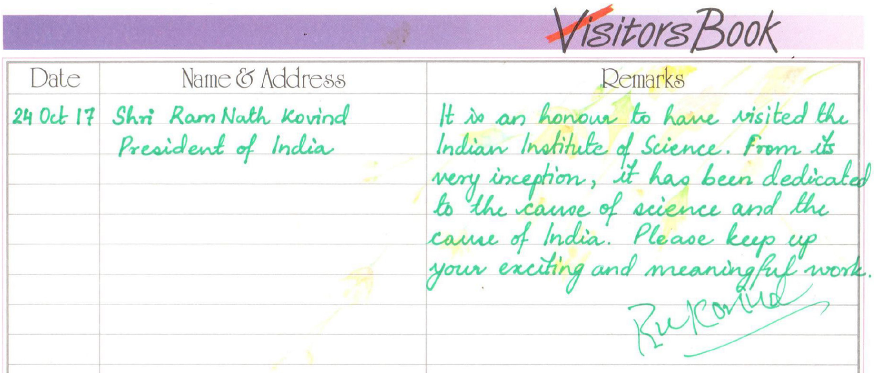
Figure 2. Cartoon of the nano-robots and realization of the same. Nano-robots with(left) and without(right) silver nanoparticles are shown.

The researchers also tested their devices beyond plastic and glass particles. They successfully trapped and transported Staphylococcus aureus bacteria and subsequently released it by turning the illumination off. Illumination intensities required by these nanotweezers are almost two orders lower than that can damage living bacteria. Fluorescent nanodiamonds, an excellent candidate for quantum sensing, was also maneuvered using the MNTs. "From being able to carry live bacteria to placing very small objects such as nanodiamonds and quantum dots at specific positions on a device, their applications could range from biomedicine to quantum technologies, sensor devices and many more", Prof. A. Ghosh explains.

Apart from carrying small objects to various spots of a microfluidic device, the researchers can also localize them with high spatial resolution and then take them away if necessary. "This should open up new avenues in nanoscale assembly that did not exist before" adds Prof. Ghosh. What comes next in this 'small' journey? The team is working on parallelizing the nanotweezers so that a collection of them can sort and assemble at nanoscale, just like a group of robots would work in an industrial assembly line. This will allow for to scaling up of the technology and will surely have tremendous commercial impact.

Honbl. President & Vice President of India Visit CeNSE

In October 2017 and September 2017, CeNSE was proud to welcome the honourable President of India, Shri Ramnath Kovind and the honorouble Vice President of India, Shri Venkaiah Naidu for a tour of the facility and a discussion of various R&D activities that are being carried out in the department. The president of India was accompanied by the honourable governor Karnataka, Shri Vajubhai Vala. The vice president was accompanied by the honourable governor of Karnataka, Shri Vajubhai Vala and the honourable home minister for the state of Karnataka, Shri Ramalinga Reddy. In addition to a tour of the nanofabrication and the characterization facility, several demos were put together for them in the aisle of the cleanroom showcasing recent research and technology developments at the centre. The visits were very successful and the president and vice president shared with us their thoughts to further strengthen our capabilities and contribute to the country.



A snapshot of the message penned by Honbl. President of India on the CeNSE Visitors Book

Faculty members giving Shri Kovind a tour of the National Nano Fabrication Centre (NNfC)

Faculty members and staff of CeNSE with Shri Ramnath Kovind

Faculty members giving Honbl. Vice Preseident of India, Shri Venkaiah Naidu a tour of the National Nano Fabrication Centre (NNfC)

Introduction to our new faculty member Dr Saurabh Chandorkar

CeNSE is very happy to welcome the newest faculty member Dr Saurabh Arun Chandorkar. He obtained his BTech in Mechanical Engineering from IIT Bombay in 2003 and received his M.S. and Ph.D. in Mechanical Engineering with a minor in Electrical Engineering from Stanford University in 2009. He worked as a postdoctoral fellow in the area of adaptive Nanoimprint lithography in the Electrical Engineering Department of Stanford University from 2009 to 2010. He worked in Intel Mask Production facility in an R&D group for 6 years where his efforts were directed toward providing complete turn-key solutions for newly emergent issues in 1276 and 1278 nodes. He was awarded two Intel Logic Technology Development (LTD) Divisional awards. In 2017, he worked in Stanford University as a lecturer. He joined IISc Bangalore as an Assistant Professor in December 2017 where he conducts research on MEMS/NEMS with special interest in resonators, packaging solutions and advanced system development. Below Saurabh details the exciting aspects of his research program and his goals for the years to come.

Research Interests:

A. Study of energy loss mechanisms and phase noise in mems/nems resonators

MEMS resonators form the building block for several applications such as timwing references, mass sensing, temperature sensors, accelerometers, gyroscopes and strain sensors. MEMS resonators are characterized by two fundamental quantities: i) Frequency and ii) Quality Factor, a measure of energy loss in the resonator. Stability of frequency in short term is directly measured using phase noise, a fundamental characteristic that determines resolution of resonator-based sensors and jitter of timing references. Quality factor of MEMS/NEMS based resonators are limited by a variety of energy loss mechanisms. Our research seeks to explore the space of phase noise, quality factor and materials in MEMS/NEMS resonators under the influence of controlled external inputs such as temperature and pressure.

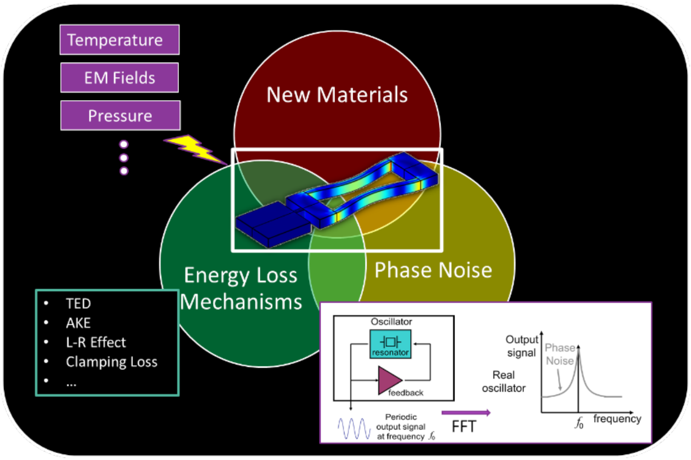


Figure 1: Schematic showing space of our research interest in MEMS/NEMS resonators

B. To develop novel ultra-stable wafer scale packaging for open systems

High performance MEMS sensors and RF MEMS devices with ultra stable performance require packaging that offers i) robust hermetically seal to protect the device from the environment ii) electrical interface/ integration iii) control of pressure in the cavity iv) ease of die separation after wafer dicing.

Integrated Epitaxially grown silicon seal (Epi-seal) process is an ultra-stable wafer level packaging process that meets all the requirements of packaging of MEMS with very high yields. The process was invented in Stanford University has been developed comprehensively since.

One of the major challenges for MEMS sensors that depend on material interaction with the surrounding is that the environment itself diminishes the high quality of resonators, thereby debilitating their performance, while adding considerable reliability issues. We seek to develop a packaging methodology based on epi-seal process that enables creation of partially open systems where devices can interact with environmental inputs without adverse impact on performance.

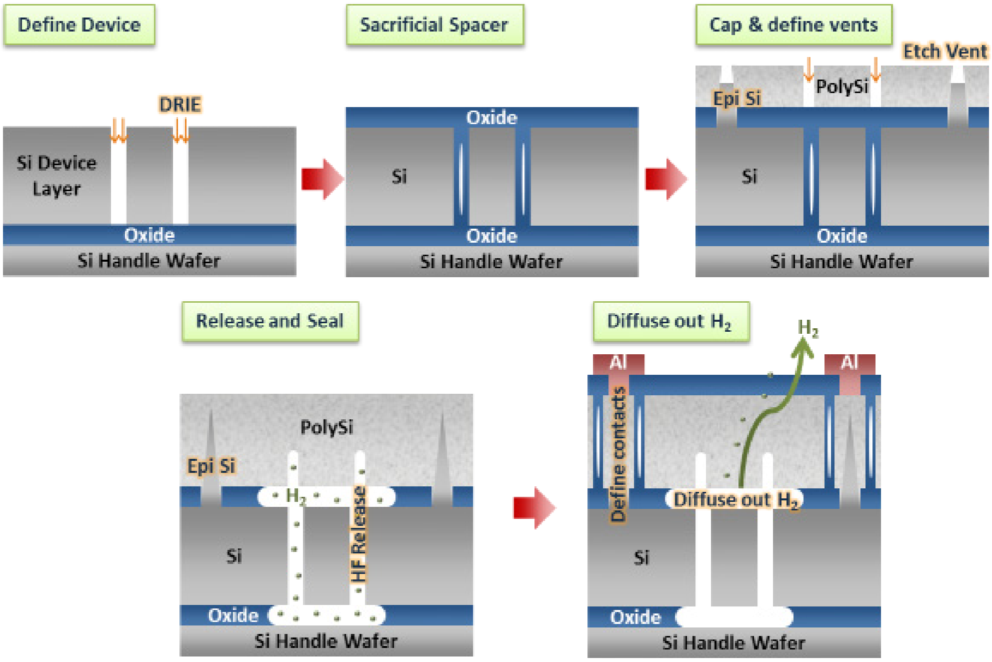


Figure 2: A brief overview of Epi-seal process

C. To develop low cost MEMS/NEMS based sensor systems

To functionally utilize MEMS/NEMS devices as sensors, a full system including mechanical, electrical and computational intelligence needs to be designed. We seek to find novel applications for MEMS/NEMS devices and develop complete systems for deployment.

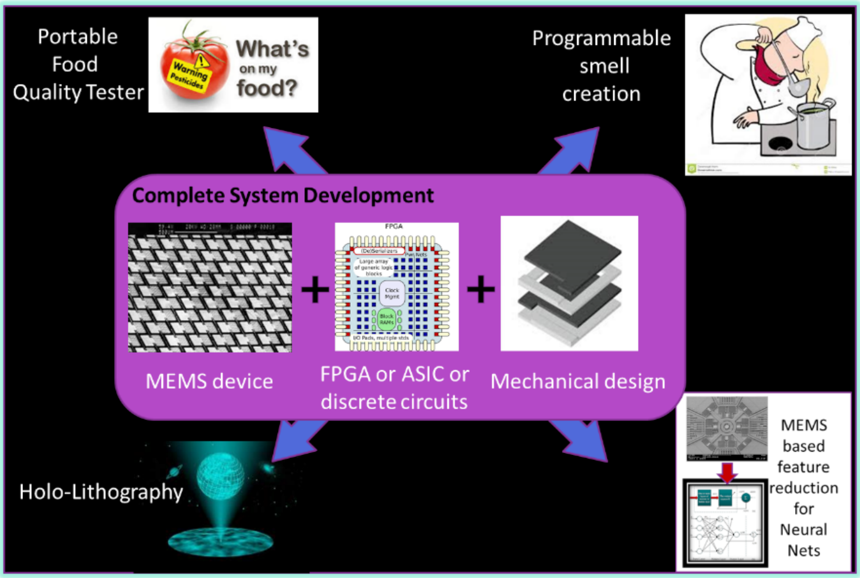


Figure 3: MEMS/NEMS based system development

Representative Publications:
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Impressions From International Conferences

Some of the most invaluable learning experiences and skill development in grad school happen through attending academic conferences. These conferences provide an excellent platform to connect and collaborate, establish personal and professional relationships and most importantly present, discuss and receive feedback on your work from peers and leading academicians in your field of research. With tutorials, public lectures by research idols, talks, posters, exhibitions, networking opportunities and a n ocean of new ideas and motivation, these conferences help in building a diverse professional network and broaden the perspective with which a research problem is addressed. There's no experience better than sharing space with like-minded people, all curious to learn, understand and challenge themselves. International conferences kindle our spirits to explore the world of research while exploring the world we live in. This makes for a memorable rounded experience.

CeNSE is widely known for its interdisciplinary research in fields such as materials, electronics, photonics, bio-technology and electro-mechanics (NEMS/MEMS). Many research scholars from the centre attended and presented their work in reputed international conferences over the past few months. Here are a few excerpts from some of these students!

Photonics and Lasers Group @ CeNSE

Conference: ***SPIE Photonics West 2018, San Francisco, CA***

Roopa & Santosh: SPIE Photonics West is the world's largest photonics technologies event and this year it was held at Moscone Center, in the golden city of San Francisco from 27th Jan to 1st Feb. California has emerged as one of the major hubs for R&D in the field of photonics. With top-notch universities such as Stanford and University of California-Berkeley less than an hour's drive from the convention center, and many leading industries headquartered in the state of California, this conference is a dream platform for photonics enthusiasts to share their research, showcase new ideas, establish contacts and discuss prospects. It was incredible to have CeNSE get a 100% acceptance with 5 papers from PRL, 8 papers from Nonlinear Photonics and High-Power Lasers group including 2 papers in collaboration with the aforementioned groups and 3 papers from CoSMoS group. The entourage of zealous student presenters (from left) Vikram, Mere, Roopa, Swathi, Vadivu, Vishal, Santosh, Arun and Bala along with professors Shankar and Supradeepa were eager to embark on this journey. New Whatsapp groups were created abuzz with discussions on filling visa documents, common interview questions, travel and accommodation tips, GARP advance application, currency conversion strategies and last but not the least, poster and presentation preparation.

SPIE Photonics West comprised of cutting-edge research and courses, two world-class exhibitions and sessions for industry training and three distinguished conferences: BiOS, LASE and OPTO. The conference BiOS was earmarked for biomedical optics, biophotonics, new imaging modalities, optical coherence tomography, neurophotonics and nano/biophotonics. OPTO addressed the latest developments in a broad range of optoelectronic technologies and their integration for a variety of commercial applications. LASE was the go-to conference for a myriad of Laser Sources, their use in Micro/Nano/Macro Applications, Nonlinear Optics and Beam Guiding. With several sessions running in parallel SPIE released an iOS and Android friendly app to keep track of the events and plan our schedule accordingly.

The entourage of zealous student presenters (from left) Vikram, Mere, Roopa, Swathi, Vadivu, Vishal, Santosh, Arun and Bala

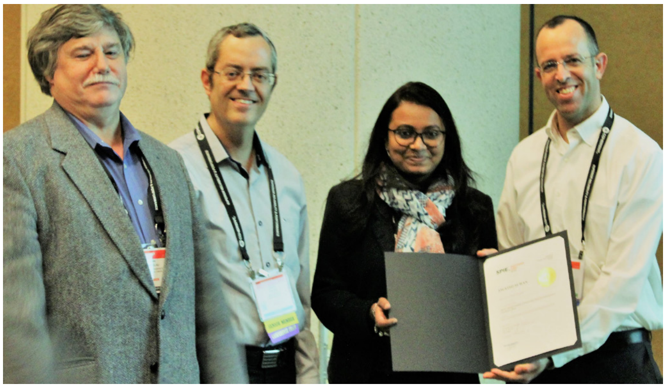
Conference: PW2018 had an eclectic mix of over 5200 technical presentations from participants all around the globe. The plenary sessions were extraordinary with interesting talks on Silicon Photonics: Bigger is Better, Hot Topics in BiOS, Shaped Light for BioNanophotonics, Gigahertz Laser Frequency Combs and Dual-Comb Spectroscopy to name a few. SPIE Fellow and Chemistry Nobel Laureate W.E. Moerner gave a presentation on photonics and single molecules, "from early spectroscopy in solids to Super-Resolution (SR), nanoscopy in cells and beyond," a story, as he noted, about optics, detection, lasers and biology. And, as it turned out, a story that included a Simpsons reference, too. There was even a start-up challenge for select participants to pitch their idea in five minutes and win a prize money of $10,000 to make their dream, a reality.

Nobel Laureate and SPIE Fellow W.E. Moerner and 2018 SPIE President Maryellen Giger

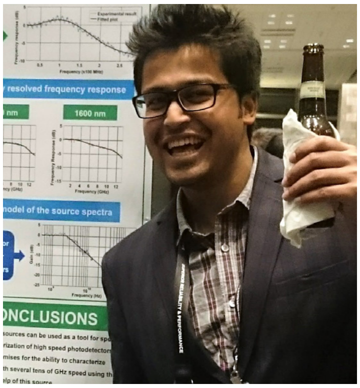
Courses, Professional development and Industry Workshops: PW2018 had 70 courses and numerous industry events in a single week. There were several professional development workshops free for all technical attendees. It enabled us to focus on learning and honing valuable job skills essential for a career in the industry/academia. Some notable mentions include: Craft to Scientific Writing and Presentation, Essential Skills for a Career in Industry and my personal favourite, a short course on Resumes to Interviews conducted by the vivacious Heather Welch, Sr. Recruiter for Daylight Solutions in San Diego.

Presentation and Awards: Basking in the limelight in our newly tailored suits waiting to present our work in front of an audience with pioneers we worship daily, was a thrilling experience. To have an opportunity to discuss our research with the great minds of the industry on such a mammoth platform is truly a blessing. Such proximity to genius made us feel super smart!

Swathi Suran from Prof. Manoj Varma's group won the prestigious 'Prizmatix Young Investigator Award' for notable contribution of her presented work at SPIE Nanoscale Imaging, Sensing, and Actuation for Biomedical Applications XV conference.



A Proud Moment!! *(From Right)- Dr. Assaf Deutsch, Prizmatix Ltd. CEO; Ms. Swathi Suran, Indian Institute of Science; Prof. Dror Fixler Bar-Ilan University and Prof. Dan V. Nicolau McGill Univ.*



Exhibition: Around 400 companies from around the world had gathered to display their products in the exhibit hall. The exhibition was grand. Every company had goodies such as writing pads, pens, fidget spinners, rubix cubes, lab snacks, stuffed Lamb-Da! (pun fully intended :-D), T-shirts and more kept beside their respective stalls to entice participants. We witnessed some cool demonstrations of LiDARs, autonomous vehicles (Megabot style), interactive multi-dimensional displays and imaging systems that show veins lying underneath the skin by just shining light on any part of the body. This non-invasive technology could substitute angiographs, helping doctors look at the veins and easily determine if there was any constriction in them.

We learnt a great deal from many of these exhibits. Knowing the market, the key players, range of products offered, current trends in research, novel developments and network with the best in the field. If we expressed an interest in any of the vendor's products, they would scan our badges at their stall and mail us the details of the product. There was a job fair too with companies such as Intel, Lacroix, Quantel Laser, KM Labs, DRS Daylight Solutions, Epigap and PG&O eager to hire suitable candidates.

Exploration: Our Air India flight from New Delhi to San Francisco landed at SF just before the break of dawn. Sitting on the right wing of the plane, the view was stunning. The beautifully lit city, its extending coastline, the shimmering Oakland bay bridge amidst the darkness of the ocean; all made for a breathtaking entrance. It was 6 degree Celsius when we exited the plane. By the time we cleared the Border Check and Customs, it was bright and pleasant outside. The weather is San Francisco is unpredictable, so a carry-on jacket is a must have. We took a Super Shuttle to our booked dorm rooms at the HI San Francisco hostel. Here's an account of the places we visited in SF:

Pier 39 and Fisherman's Wharf: Serene place, looks like it's been taken out of the cover of a travel magazine. Makes for some great photos under the sun. Must try out the bread bowl in Boudin Bakery and some fresh produce. The street performances are amazing and makes for an entertaining trip along the boardwalk, but don't forget to tip!

Alcatraz: A prison like no other. A complete audio tour with screeching noises and real inmate testimonies to make for a surreal experience. Make reservations or be ready to wait in line before dawn. The early bird definitely gets the worm!

Golden Gate Bridge: Choose to bike/walk along the bridge. The cool winds amidst the warm sun combined with the spectacular view of the city and the ocean makes for a great ambience. Continuing further along, will take you to a small picturesque town beyond the bridge called Sausalito and a detour will lead to Muir Woods, famous for its towering Redwood trees.

Chinatown: For yummy fortune cookies fresh-out-of the oven, Chinatown is the place to be. It's rich with culture and deliciousness.

Cable car ride: The cable car is the perfect ride to enjoy the scenic beauty of the city as it climbs up and down the hilly streets of San Francisco. Along the way, you'll encounter the crookedest street, a.k.a. Lombard Street which is a steep, one-block section with eight hairpin turns.

Oakland Bay Bridge: Take a cab ride from Oakland to San Francisco when it's dark outside and watch the lights on the bridge shimmer like diamonds.

Other notable places: Golden Gate Park (green until the eye can see), California Academy of Sciences (in here, the rain forest comes alive!), Union Square, Japan-town (cultural exposure), Twin Peaks (secluded but scintillating), Ghirardelli Square (for relishing chocolate made the old-fashioned way)

Attending an international conference of this magnitude along with a group of fun-loving, enthusiastic peers made for some beautiful, cherishable memories. We learnt a lot intellectually, professionally, personally and spiritually through our journey.

Wide band-gap Devices Group @ CeNSE

The research focus of the wide band-gap devices group is realization of optoelectronic and power electronic devices based on wide band-gap semiconductors such as Gallium Nitride, Gallium Oxide and their alloys. 2017 was an amazing year for the group since the group members got to showcase their research work at multiple international conferences. While Anisha and Shashwat represented their work on III-nitride epitaxy and devices at International Conference on Materials for Advanced Technologies (ICMAT 2017), Singapore and International Conference on Nitride Semiconductors (ICNS'12), Strasbourg, France, it was a solo-trip to Italy for Anamika, who presented her work on Gallium Oxide based photodetectors at the International Workshop on Gallium Oxide (IWGO 2017), Parma. We have collected brief accounts from them, where they share their experiences and learnings from the conference and the international travel.

Anisha: From the end-time rush of somehow finishing abstract submission just before the deadline to the joy of having your work accepted for presentation at international conferences, from the hustle of finishing documentation for the first international travel to the beautiful conference and travel memories, 2017 was truly an eventful year, a year that I will definitely cherish throughout my life. I, along with my lab mate Shashwat, had the opportunity to attend two international conferences: 9th International Conference on Materials for Advanced Technologies (ICMAT 2017), Singapore in June and International Conference on Nitride Semiconductors (ICNS'12), Strasbourg, France. Where ICMAT was a multidisciplinary conference organised by the Materials Research Society, covering various aspects important for science, engineering and technology of materials under its broad umbrella, ICNS was a conference centred around the materials of the III-nitride semiconductor family, covering aspects such as epitaxy, devices and technology and this made the experience of participating in the two entirely different. ICMAT 2017 was held at the Suntec Singapore International Convention and Exhibition Centre from June 18-23, 2017 and was organised jointly by the Materials Research Society, Nanyang Technological University (NTU) and National University of Singapore. We reached Singapore on June 17, an evening prior to the conference. The first thing that caught our attention was the beautiful Singapore Changi Airport. During our pre-travel internet research, we had read so much about the airport, the amazing things it has in store for the travellers and how it is a travel destination in itself and undoubtedly, it was all that and much more. The next morning, we reached the convention centre and were amazed by the sprawling, flawlessly clean glass-walled centre, with big LED televisions flashing information about the event and guiding the attendees to the registration desk. The second and third floors had multiple auditoriums, conference rooms and lecture halls, and it was on these floors that the conference events were scheduled. The entire registration process was extremely well organised and we were guided to the opening ceremony post-registration.

The opening ceremony was a perfect amalgamation of scientific and cultural exchange, with cultural performances interspersed between key-note lectures by distinguished researchers such as Nobel Laureate Prof. Hiroshi Amano. The conference consisted of 29 symposia and multiple plenary and invited lectures. We were informed about a mobile application that had all information about the talks across these symposia and we could sync the ones we wish to attend with our calender and any change in the schedule was instantly updated in the application. There were more than 150 industry exhibits and it was a great way to sync up with what's out there in the market to give you that edge.

I had my talk scheduled on the first day of the conference and being my first international conference, I had mixed feelings of excitement and anxiety about how it will go. Fortunately, the talk went smoothly and I received positive fedback about my work from many people. In addition to presenting our work, we also presented on behalf of our lab mates who could not make it to the conference. Fortunately, I also got the opportunity to volunteer the nitrides symposium and this allowed me to very closely interact with all the speakers and peer researchers. We discussed at lenght about our work, our cultures, our families back home and it was amazing to see how grounded these people were despite their professional achievements. Since III-nitrides formed a small part of the otherwise broad conference, we all became a close-knit group in no time. The dynamics was pretty interesting and the group had people from all across the world ranging from student researchers to young faculty members, from industry members to senior academicians. The food arrangements also deserve a special mention. Considering the large number of Indian participants, there was a separate section labelled "For our Indian Vegetarian Guests", serving some lip-smacking Indian cuisine. Then there was a huge variety of continental food and desserts, making lunch hours the best time of the conference.

The conference was conducted over five days, with symposia lectures from 9 a.m. to 5 p.m., followed by a Nobel Laureate public lecture each day. On the second day of the conference, we had the pleasure of listening to Dr. Hiroshi Amano from Nagoya University, whose work on III-nitride based blue light emitting diodes lead him to win the prestigious Nobel Prize in Physics in 2014, along with Prof. Isamu Akasaki and Prof. Shuji Nakamura. He took all of us through the journey that led to the invention and shared hillarious anecdotes about the evening preceding the announcement. It was a treat to listen him talk so vividly about his experiments, the failures and how when he lost all hope, the idea behind the invention struck him. We were also lucky to talk to him after the talk, share about our work and we were totally impressed by how humble he was. The following days, there were equally gripping public lectures by Prof. Kostya Novoselov and Prof. J. Fraser Stoddart. It is not every day that you get to learn from the experiences of your research idols and we could not have asked for anything better than having to end each day with one such lecture.

The last day of the conference however formed one of the best expriences of the six-day event. All the talks scheduled for the day had been re-scheduled to previous days, leaving us with a free day. The symposium chair for the nitrides symposium, Prof. Sudhiranjan Tripathy, organized a tour for all interested participants to Institute of Materials Research and Engineering (IMRE), which was almost a one hour drive away from the convention centre. We were briefed about the research and development (R&D) capabilities, commercial partnerships and strategic alliances of the research institute along the way. Spread over five floors, IMRE houses two class 100 clean rooms and some of the state-of-the-art material growth and characterization facilities. Prof. Tripathy and his team provided a detailed guided tour of all the facilities and what all they were capable of delivering. It provided us with a great platform to interact with some of the research scholars at the institute and forge new collaborations. Post the visit, we all had lunch together in a restaurant serving Indian food and it was amazing to see how much the food was being enjoyed by everyone. It was a beautiful day, with occasional brief rain showers and lassi and tea kept pouring in as we sat in the restaurant for almost 3 hours listening to Ph.D. time stories of some of the young faculty members and getting inspired by some of the researchers who went ahead to set up start-ups post Ph.D. The discussions soon rocketed to chocolates and tea and all things one could think of. All in all, it was an amazing day, a great day to end the conference with!

The busy conference schedule however did not leave us with much time to explore Singapore so we decided to take up one place every day, post the conference talks, so that we could cover the main attractions. What helped us was the exceptionally well planned public transport that connected the entire city and made every place equally easily accessible. The city is beautiful in the day, but surreal at the night. The cool breeze from the Singapore river, the beautifully lit sprawling buildings,

the oh-so-amazing street food, there is nothing more you could ask for. Through the six day trip, we explored the Sentosa Island, enjoyed a serene and amazingly relaxing river cruise on the Singapore River, went for a Night Safari one night, strolled in the breathtaking Gardens By the Bay on the other and enjoyed a birds view of the city from the second largest observation Ferris Wheel in the world, the Singapore Flyer.

In a nutshell, it was a great trip, full of memories that I will cherish all through my life. I made friends for life, was fortunate to interact with some of the leading researchers in my field and explore some of the best research facilities.

A month later, it was a trip to France to attend the 12th International Conference on Nitride Semiconductors and this time around, we were also joined by Prof. Srinivasan Raghavan. Unlike ICMAT, it was a nitirde centric conference with talks focussing on various aspects of nitride epitaxy, devices and integration with other semiconductors. The conference was featured by plenary sessions, parallel topical sessions, poster sessions and an industrial exhibition. Nine abstracts from our group were selected for poster presentation at the conference and we were representing their work as well along with ours. It was a mad rush during the poster session since we got most of the poster presentations on the same day and we were juggling between our posters and those of our lab-mates but the experience was totally worth it since we got some amazing feedback on our work. It also felt like a sort of reunion and we were happy to meet our ICMAT friends again here. The conference experience was amazing and we got to learn a lot through the talks. There were so many interesting talks running parallely that the three of us had to split and attend each and the lunch and coffee breaks would be spent discussing the new learnings. At times when we found something really intriguing, we just could not wait till lunch and would message or mail one another to update.

The best aspect of the conference however was the beautiful host city of Strasbourg and the follwing few lines from the city's official website that calls it *a medieval past and a dynamic future*, sums up the place aptly.

"Strasbourg is the perfect overture to all that is idiosyncratic about Alsace – walking a fine tightrope between France and Germany and between a medieval past and a progressive future, it pulls off its act in inimitable Alsatian style."

The city is located along the west banks of the serene Rhine river and is connected well through trams. We were provided with a public transport pass during registration and that made the entire travel even smoother. We used to hop-on the tram after the conference talks and get down at the place that seemed best through the glass windows of the tram.

The weather during that time of the year was amazing and just to stroll around the green city, around the beautiful cathedrals and museums and opera houses, along the river, watching people play music, appreciating the beautiful architecture, was extremely satisfying and relaxing. We relished some of the best French cuisine while there, from Crepes served at street stalls to Formage foods served in fine dining restaurants. The variety of bread and cheese available at the Patisseries was unbelievable and these shops would the first one to open in the morning. The best memory I have from the travel is watching the breathtaking light show, sitting in the courtyard of the Notre-Dam Cathedral. The cathedral looked even more elegant when lit and the fact that everyone was loving the show absolutely was evident from the fact that it was raining and was getting really cold but the courtyard was brimming with people. The entire experience was made better by the amazing company we had in Prof. Raghavan's family and we made a new little friend in his daughter Urvi. We shopped, sketched, chatted, sang and needless to say, had a blast together.

To sum it up, it was a great year, lots of learning experiences both professional and personal, a whole lot of cultural immersion and some new relationships for life.

Anamika: I was delighted as it was my first solo international trip in mid-September 2017 to the beautiful Italy. After finishing the on-desk registration, I sat in an auditorium filled with unfamiliar faces. Introducing myself to people whom I thought were strangers around me slowly became what was like conversations with my lab mates. We conversed about our research, scientific backgrounds, and undergraduate life. The primary focus of the conference was on gallium oxide and its ternary alloys with indium and aluminium. The workshop was organized by the University of Parma and it brought together more than 200 scientists and engineers working on various aspects of materials and device technology.

I had the opportunity to speak about my work on "Carrier transport and spectral responsivity studies in MBE Grown -Ga2O3 MSM Solar-Blind Deep-UV Photodetector" in front of a huge audience from whom I received a positive feedback. In addition to this I also presented papers on behalf on my colleagues. I also had the chance to discuss many exciting ideas with the stalwarts of gallium oxide research. The other oral and poster presentations were very intellectually stimulating and showcased the magnificent progress of this emerging research area. The conference had participants from all over the world and this opened up the possibilities of collaborative talks. I received many offers of short-term exchange visits and collaboration. And of course the luscious food, the drinks and the beautiful city of Parma had added to the experience which was invaluable.

Again, in December 2017, I had privilege to present my work at IWPSD-2017, Delhi, along with my lab mates, where I received the best poster award as well. It was also a great pleasure meeting fellow member of the community, and I have become good friends with some individuals whom I've met before in IWGO, Italy. I also got chance to watch on-stage theatre performance organised as an excursion by the conference committee. Overall, both these international conferences were a productive and also a fun experience.

IWPSD-2017, Delhi. From left to right: Nayana, Anisha, Shashwat, Prof. Digbijoy, Sandeep and Anamika.

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