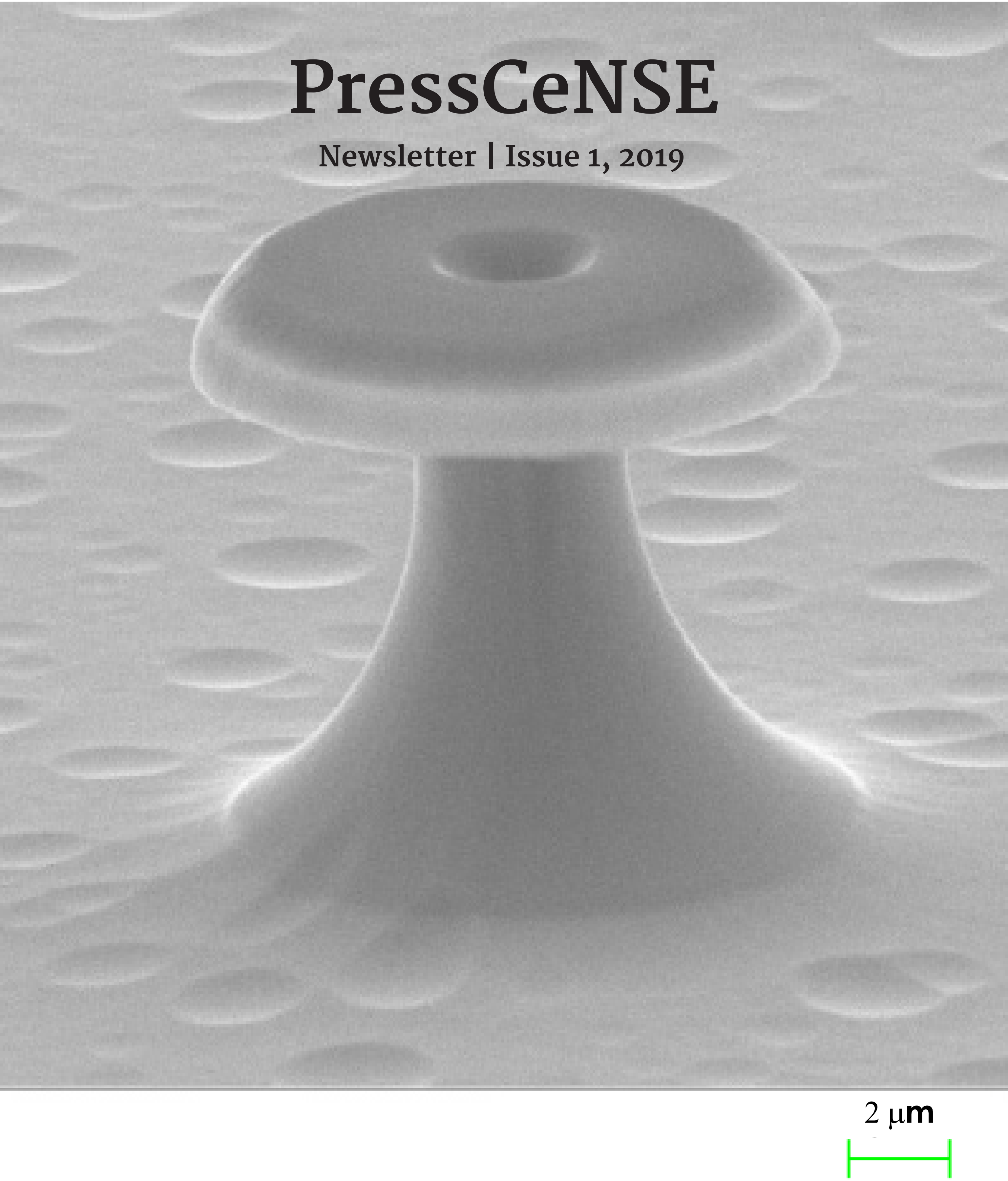
# PressCeNSE

Newsletter | Issue 1, 2019




Centre for Nano Science and Engineering (CeNSE)

Indian Institute of Science

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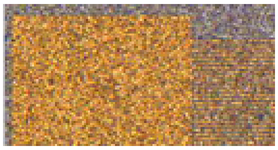
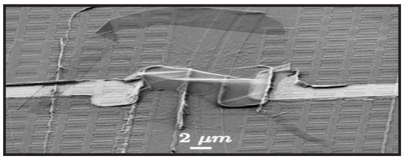






CeNSE INDUSTRY AFFILIATE PROGRAM














*Cover photo: "Micro Mushroom" by Abinash Tripathy and S. Varadharaja Perumal*

# MESSAGE FROM THE CHAIR

Wish you all a very happy new year 2019. I am pleased to present this issue of PressCeNSE, highlighting our recent initiatives and achievements. It is also an opportunity for us to share with you the important events at CeNSE in the last few months.

Industry Affiliate membership Program (IAP) is one of the flagship initiatives that we have at the centre to engage with industry. Through this program we build continuous interactions with the IAP members, to develop research collaborations, identify technology development opportunities, enable student placement for internships and jobs after graduation. The article on IAP highlights the achievements in this program, over the last year.

We have recently begun a new international outreach workshop on Science Technology and Innovation policy, targeted for policy makers and senior scientists. This program was funded by the Ministry of External Affairs, Government of India. This is in recognition of the fact that global cooperation is extremely important in evolving policies for science and technology innovation and also create a platform for international researchers to come together to solve global problems. The first such program was conducted at our centre in November 2018, attended by 50 participants from 12 countries, including a member of parliament from Trinidad and Tobago. We received excellent feedback and we hope to continue this series in future.

We also worked with the IEEE Electron Devices Society, Bangalore chapter to organize 4th International Conference on Emerging Electronics. This is a flagship IEEE conference initiated by the South East Asia EDS chapters. The conference also provided an opportunity for all the NNetRA researchers to come together along with stake holders from government and industry. The large number of attendees in the conference was a testimony to the evolving ecosystem in the country, in the very important area of Electronics hardware.

I hope you enjoy going through this issue and stay connected.

-Navakanta Bhat

# WHAT'S NEW IN RESEARCH AT CENSE?

## MEMS/NEMS LAB & PHOTONICS RESEARCH LAB

### Carbon-nanotube-on-waveguide thermo-optic tuners

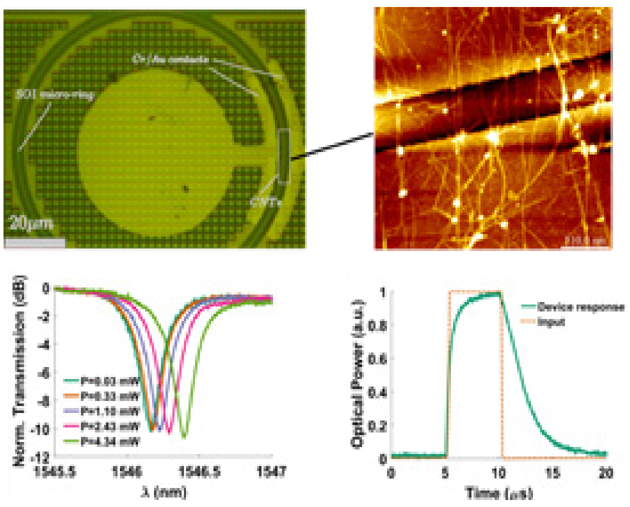
Aneesh Dash, Viphretuo Mere, P. R. Yasasvi Gangavarapu, S. R. Nambiar, Shankar Kumar Selvaraja, and Akshay Naik

Thermal tuning is an easily implementable, low-cost method often employed in electronic and mechanical devices to extract optimal performance or to match the operating points of multiple devices. Similarly, in photonic integrated circuits (PICs), thermal tuners are essential for matching the operating wavelengths of multiple photonic devices such as resonators, gratings, and filters. They are also used for low frequency optical modulation and optical memory applications. The working principle is thermally induced change in refractive index of the materials interacting with guided light.

Conventional thermo-optic tuners are implemented using metal heaters. However, metals absorb near-IR wavelengths, where most of the applications of PICs are, and thus have to be placed a few microns away from the devices to be tuned to avoid degradation in performance of the optical devices. The heating, therefore, is not localized and leads to thermal cross-talk among multiple optical devices. This prevents dense integration of integrated optics. Moreover, these heaters have low power efficiency and a large thermal transient. It is desirable to have a heater closer to the device, yet have it be non-absorbing.

Recently, researchers of Micro and Nano Sensors Lab (NEMS Lab), in collaboration with Photonics Research Laboratory, have demonstrated on-waveguide thermo-optic tuners based on solution-processed metallic carbon nanotubes (CNTs) on silicon-on-insulator (SOI) and silicon nitride (SiN) micro-ring resonators operating around 1550 nm wavelength. On SOI micro-ring resonators using planarized wire waveguides, a thermo-optic power efficiency of 29 mW/FSR and a thermal transient of 1.3 μs are achieved. The heater is shown to be more power-efficient than conventional metal heaters and has lower thermal transient than both metal heaters and graphene-based heaters. On SiN microring resonators using rib waveguides, improvement in power efficiency with an increase in coverage of CNTs is demonstrated, indicating localized heating using the CNTs; this is favourable for low thermal cross-talk. An optimal power efficiency of 142 mW/FSR and a thermal transient of 5.8 μs are achieved.

*The detailed research-findings have apeared in Optics Letters 43, 5194-5197 (2018). https://doi.org/10.1364/OL.43.005194, published by the Optical Society of America (OSA).*



# COMPLEX SYSTEMS AND MOLECULAR SENSORS (CoSMoS) LAB

## Combining microdroplets with microscope - Breath Figures

Harish Sasikumar and Manoj M. Varma

Breath figures refer to the patterns of microdroplets formed when vapor condenses into the liquid phase on an inhomogeneous surface. The density of these microdroplets varies in accordance to the features or contaminants on surfaces. Hence, when the microdroplets scatter light and produce optical contrast, they in turn reveal the properties of surfaces. This can be used in the visualization of extremely thin (as thin as a few nanometers) transparent materials, such as a single layer graphene or thin film coatings.

In this work, the researchers in CoSMoS group have developed an imaging method to visualize transparent polymer thin-film patterns 2 nm in thickness and a few microns in lateral extension. This method is tailored to image materials coated on substrates in cases where the hydrophobic contrast of the material and the substrate is small. This is achieved by imaging at the "right moment" when the deposition and evaporation of the microdroplets, hits an optimum. The hypothesis put forward from the observation of the image space was confirmed using the changes in the Fourier space (using a diffractive structure).

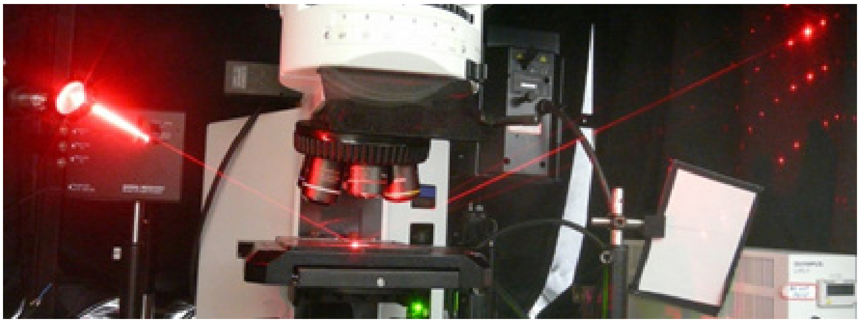


*Figure: The setup to image the real and Fourier space*

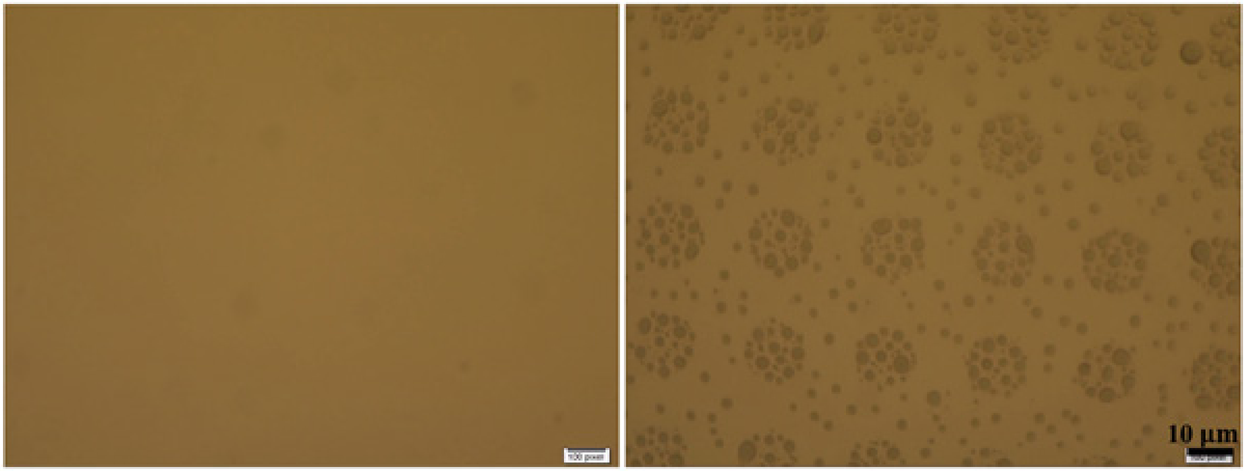


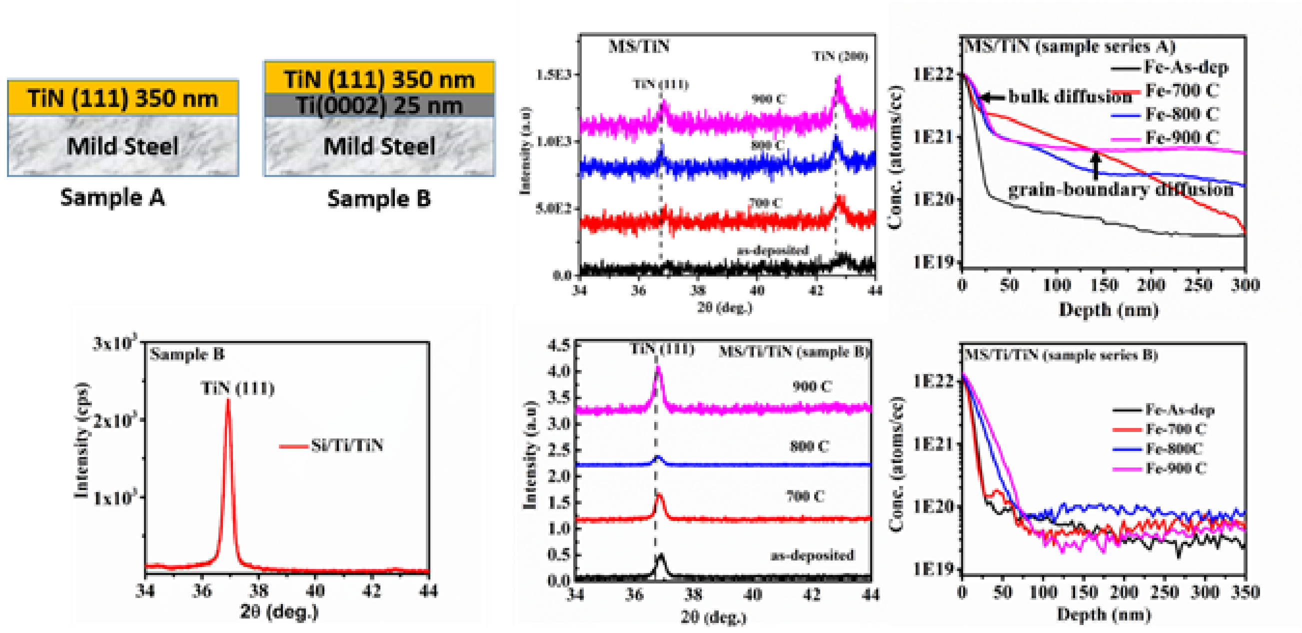

*Figure: Microdroplets revealing the surface features which were originally invisible under bright field microscope*

# HETERO-JUNCTION LAB

## Suppressing the grain boundary diffusion in titanium nitride diffusion barrier on steel substrates

Pankaj Kumar, Jithin M. Arvind, S. Mohan, and Sushobhan Avasthi

The search for a reliable diffusion barrier which is stable at high temperatures has been an active topic of research. Recently, thin film solar cells on low cost substrates such as steel have been envisaged as a cheap alternative to expensive silicon or germanium substrates. However, diffusion of iron (Fe) from the substrate (steel) into the semiconducting layers severely limits the efficiency of the devices. For thin film solar cells, it is essential to understand and quantify diffusion through grain-boundaries because concentration of Fe as low as $10^{14}$ atoms/cc in top semiconducting layers, can reduce the efficiency of the device to unacceptable values. Titanium Nitride (TiN) thin films are ubiquitously used as diffusion barriers for a variety of applications. Several methods to reduce the grain boundary diffusion have been tried, such as stuffing the grain boundaries with the formation of Al-oxide and depositing denser TiN films. The strategy of stuffing the grain-boundaries is limited to applications utilizing Al-metallization as the formation of Cu-oxide or Fe-oxide in the grain boundary is thermodynamically not favorable. In this work, the researchers have investigated the effect of morphology on the diffusivity of TiN films. To the best of their knowledge, there has been no systematic study on the effect of morphology on the grain boundary diffusivity of TiN films. Two sets of samples (A and B) were prepared: Sample series A has a (111) preferred orientation, with (200) grains present as well. In sample series B, we used a Ti buffer layer to grow highly (111) oriented TiN films on steel substrates. SIMS analysis of the annealed samples allowed us to quantify the bulk diffusivity as well the grain-boundary diffusivity separately. It was found that the diffusivity, especially, grain boundary diffusivity is strongly tied to the microstructure of the film. TiN films (sample A) deposited on a substrate at room temperature showed both bulk diffusion and grain-boundary diffusion. Interestingly, no grain boundary diffusion was observed in TiN films grown on a carefully designed Ti buffer layer. The diffusivity of steel/Ti/TiN stack annealed at 900 °C was 0.25 $nm^2\ sec^{-1}$, which is 250 times less than that of TiN films with mixed (111) and (200) grains (sample A).

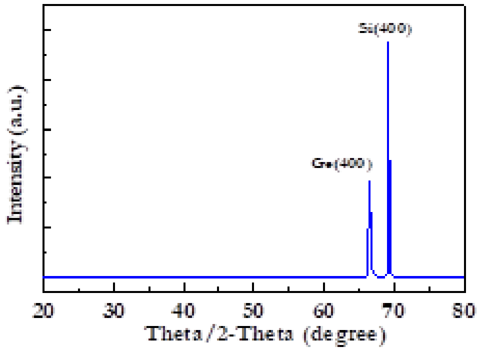


# Ge-on-Si near infra-red photodetector

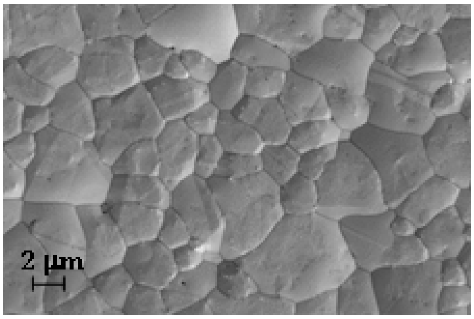
Sandeep Kumar and Sushobhan Avasthi

Wavelengths in the near-infra red (NIR) range are suitable for many applications such as in optical communications, metrology, imaging and spectroscopy. Germanium (Ge) is an indirect band gap ($E_g$ = 0.66 eV) material of group IV, similar to Si. However, its direct band gap of 0.8 eV is only 140 meV above its dominant indirect gap. This results in significant optical absorption in the wavelength range of 1300 nm to 1550 nm, thus making Ge a potential candidate for NIR photodetector applications. When used as a crystal, the Ge photodetector requires a cooling system to reduce dark current, thereby making them expensive and of limited use. The epitaxial growth of Ge-on-Si can reduce the cost and provide mechanical strength. However, the 4% lattice mismatch between Ge and Si results in high surface roughness and high threading dislocation density.

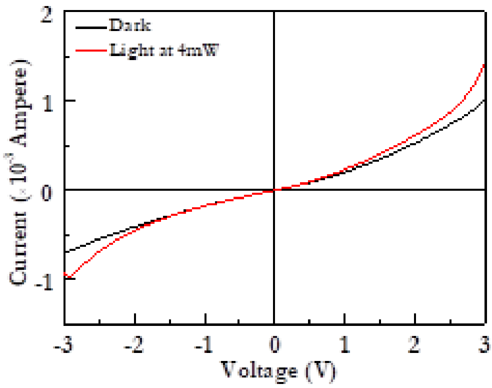
In this lab, amorphous Ge is grown on Si substrate using plasma-enhanced chemical vapour deposition. A two-step liquid phase crystallization (LPC) process is used to crystallize these films. The motivation behind this approach is the well-known Czochralski (CZ) process used in the microelectronics industry. In LPC, as in the CZ process, films are annealed at above the melting point of Ge (937°C) in the first step; in the second step, they are allowed to cool down in a controlled fashion, and annealed at a temperature lower than its melting point, before being brought to room temperature. The process results in crystalline films of Ge-on-Si with grains of size ranging from 2-5 µm. Metal-semiconductor-metal photodetector are also being fabricated with these films. The concept of introducing an interlayer between metal and semiconductor to reduce the dark current is being investigated. Further, the integration of these detectors with Si photonics is being attempted.



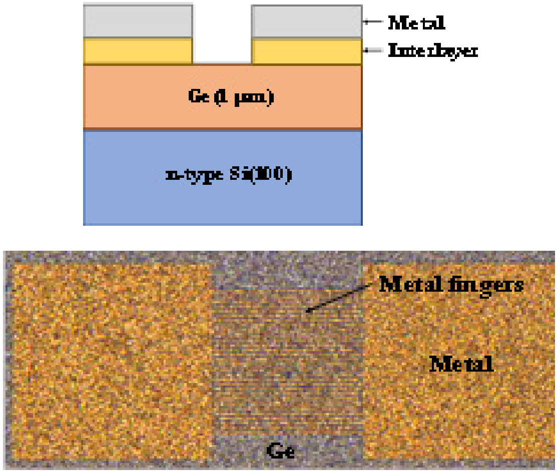

*X-ray diffraction measurement of annealed Ge-on-Si sample*




*Scanning electron microscope image of annealed Ge-on-Si sample*




*Current-voltage characteristics of metal-semiconductor-metal photodetector*




*Top: Schematic of metal-semiconductor-metal photodetector*
*Bottom: its top-view*

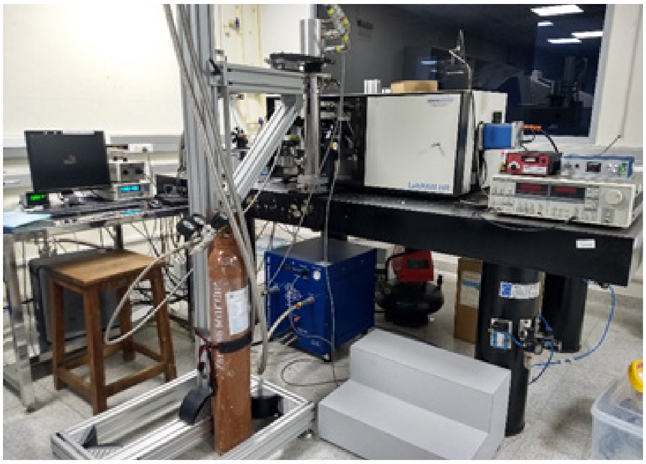
# FACILITY UPDATES

## MICRO AND NANO CHARACTERIZATION FACILITY (MNCF)

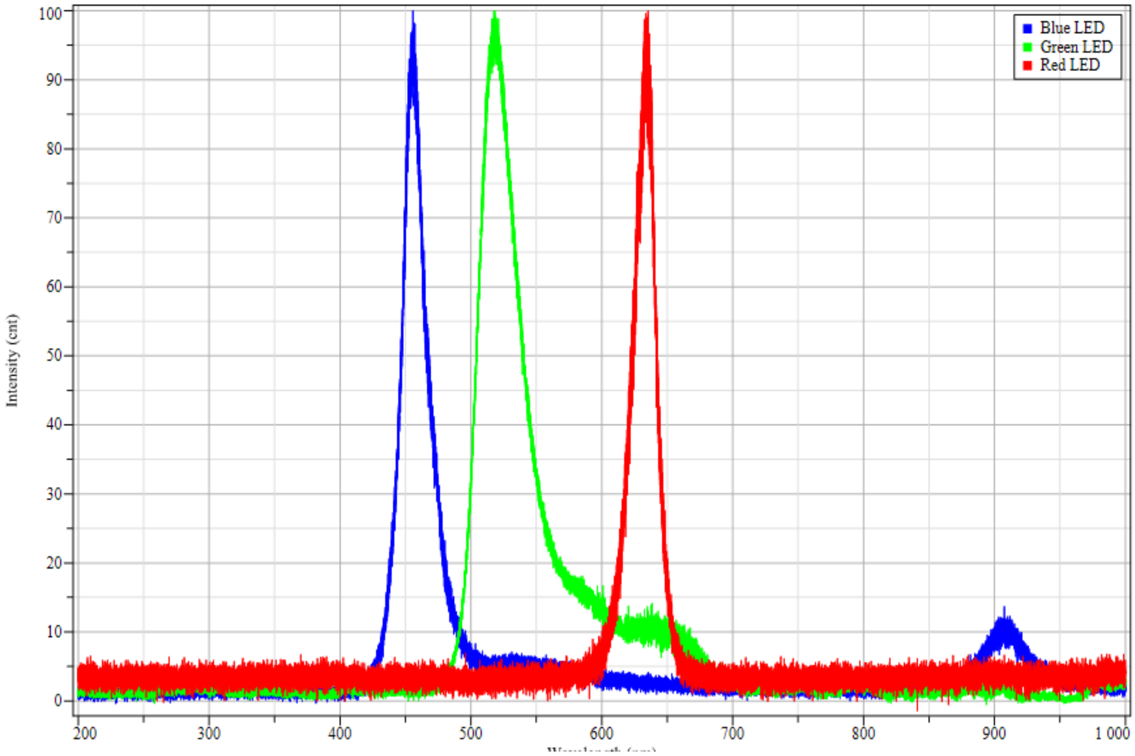
Suresha S.J.

Micro-Raman Spectroscopy is a spectroscopic technique based on inelastic scattering of monochromatic light, in which the frequency of the scattered photons is shifted up or down relative to that of the incident monochromatic radiation. This shift provides information about vibrational, rotational and other low frequency transitions in molecules. The Confocal Raman Spectrometer in the optical bay of MNCF is widely used for material characterization by users from industry and research institutions. This state of art instrument is capable of Raman, Photoluminescence and Electroluminescence studies: it can record Raman spectra at a spectral resolution of 0.7 $cm^{-1}$ and Raman and PL mapping at 100 nm spatial resolution. Though most of the sample analyses are done with 532 nm DPSS laser, the instrument has a 785 nm laser for the analysis of biological samples. Raman and PL measurements at low temperature are made possible by a liquid He-cooled cryostat, capable of reaching the lowest temperature of 7K and available once every three months.

Recently, the capability for electroluminescence in the Raman spectrometer was demonstrated using LEDs of different wavelength. Electroluminescence can be recorded from 200 nm – 1600 nm using various detectors (CCD, InGaAs). Various objectives are available to capture the electroluminescence from in the UV (UV-B, NUV), and visible parts of the EM spectrum.



***Confocal Raman Spectrometer***




***Recorded EL -spectrum of different LEDs using a CCD detector***

# OUTREACH

## INDUSTRY AFFILIATE PROGRAM - *An update on the activities in 2018*

A. Peter Manoj and S. Mohan

The Industry Affiliate Program (IAP) at CeNSE aims to network with the Industry Affiliates (IA) and academia for jointly tackling complex problems, establishing research collaborations through scientific interactions, pursuing technological developments in nano science & engineering, exclusive skill development, and utilization of centralised research facilities and resources. After identifying potential industry partners and briefing them about CeNSE and IAP, a visit is organised for a tour of our facilities and a discussion of industry requirements and CeNSE capabilities. Once synergy is identified, features of the IAP program are explained to the industry partner and the partner is inducted as an affiliate upon payment of an annual grant of  INR 12 lakhs, after which the IA can avail of the benefits of the program throughout the year. The features offered to the members are:

•Facilitating Industry-Academia interactions

•Enabling joint research projects

•Exclusive skill development through dedicated training programs

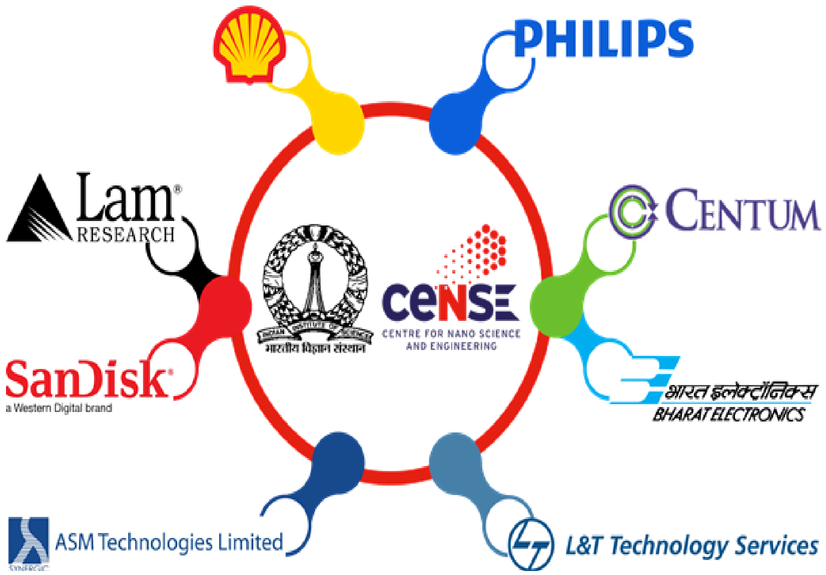
•Utilization of centralised facilities at CeNSE at special rates and on priority basis

•Facilitation of student placements and Internships

•Privileged access to CeNSE Annual symposia/seminars

•Distinguished lectures named for the Industry Affiliate

•Other operations-related/academic requests




***Industry partners with CeNSE since the official start of IAP in June 2013 and the completion of five years in 2018.***

The IAP team has specialized experience with each of the affiliate(s) in fulfilling their requirements, which has strengthened the partnership with CeNSE.  Some of the success stories with our CeNSE Industry Affiliates in 2018 are as follows.

**Projects**: The joint research project is a key feature which enables handholding with Industry for research collaboration and technological development. Projects are identified and supported in each phase: proposal/approval/funding/monitoring/closure. The projects with Industry Affiliates for the year 2018 are:

| *Title of project* | *Status* | *Industry Affiliate* |
|---|---|---|
| Evaluation of the properties of Silver Paste | Oct 2018-ongoing | Centum/Rakon |
| Unlock Ideas Campaign University Proposals '17: Thin film material properties characterization | Sept 2017-18 | Lam Research |
| Monitoring of electrolyte concentration using integrated photonic device | Oct 2018-ongoing | Shell |
| Fabrication of a microchannel electrolyser | To be started in 2019 | Shell |



**Training**: Exclusive Skill Development Training on technology and sophisticated experimental techniques using advanced instrumentation helps industry manpower to hone their skills, and adopt new technologies/methods. IAP team receives specific training requirements from IAs for their employees, which are reviewed as below:

•Identification of subject matter experts

•Preparation of course agenda

•Budget and planning of training

•Delivery & feedback for next steps

The training programs offered to IAs during 2018 were:

| *Title of the Training Program* | *Industry Affiliate* |
|---|---|
| Training on Vacuum & Thin Films | Centum/Rakon |
| Training and project to implement FPGA for various applications | Lam Research |



**Facility Use**: Access to CeNSE Centralized Facilities is another key feature of the IAP. To facilitate IAs to utilize the research facilities at CeNSE, Facilities Utilization Credit worth INR 2 lakhs is given per year and any additional use beyond this is to be paid separately at IAP rates (discounted from external industry rates). It is worth noting that several IAs use the facilities at CeNSE beyond the INR 2 lakhs credit.

**Placements/ Internships/ International Conferences**: The IAP team facilitates the IISc Placement process (Nov. – Dec.) and coordinates with IAs by organising preplacement talks, receiving job descriptions, coordinating with IISc Placement Officer/ Student Placement Coordinator, and connecting our current students with CeNSE alumni. IAP office has enabled several student placements. For the year 2018, the students placed and pursuing internships are:

| *Company* | *Number of students hired* |
|---|---|
| SanDisk | 1 placement, 2 interns |
| Lam Research | 1 placement |
| Philips | 2 placements |

To attract students from other universities/institutes, the IAP supports summer internships at CeNSE in which 23 students were supported for the internship during May-July 2018. The program also provides partial support to CeNSE students participating in international conferences; in 2018, sixteen students were supported.

**Annual Research Symposium**: The 6th CeNSE Annual Research Symposium was held on 22$^{nd}$ and 23$^{rd}$ Feb., 2018. The symposium gives an overview of research activities at CeNSE and an outstanding opportunity to showcase emerging technologies at a pre-competitive stage to CeNSE Industry Affiliates. During the symposium, IAs are given the opportunity to make a presentation on trends, technologies and highlights in their industry. A dedicated room is given to each member to enable one-on-one discussion with the CeNSE community and networking with other IAs. In 2018, IAP organised a special keynote address by Mr. Srinivas Prasad, VP and Head, Philips Innovation Campus, Bengaluru.

In addition to this, the IAs also participated in:

•The Micro and Nano Fabrication and Characterization (MNFACS) Symposium organised by CeNSE and held at IISc on $11^{th}$ and $12^{th}$ July, 2018. The event saw IAs participating and familiarizing themselves with operations and management of the fabrication and characterization facilities, strategic sector labs and other industrial facilities.

•The $4^{th}$ International Conference on Emerging Electronics (ICEE) organised by IEEE-EDS Chapter, held at Royal Orchid Resort, Yelahanka, Bengaluru on the $17^{th}$, $18^{th}$ and $19^{th}$ of December 2018, enabled the IAs to interact with subject matter experts ranging from materials for devices to integration in systems. The symposium had a keynote talk by Dr. Siva Sivaram, Western Digital (IA and Platinum Sponsor) entitled "*Scale or Perish, Memory and Storage in the Age of Big Data*", an industry pitch talk by Krishnan N, Senior VP at ASM Technologies (IA and Silver Sponsor) entitled "*ASM Technologies – Engineering Innovation*".


**Distinguished Lectures**: The IAP enables IAs to participate and network through distinguished lectures, each named for a particular Industry Affiliate and broadcast to the institute fraternity. Lectures held in 2018 were:

| | |
|---|---|
| *Established Emerging & Non-conventional 2D Materials, Devices and Technology.*<br>Prof. Deji Akinwande University of Texas, USA | Lam Research |
| *High-performance Heteroepitaxial Nanolaminate Device Layers.*<br>Prof. Amit Goyal Director RENEW University at Buffalo, USA | ASM Technologies |



At present, the IAP is managed, under the supervision of Prof. Navakanta Bhat (Chair, CeNSE), by the team: Prof. S. Mohan, Emeritus Professor and Faculty in-charge of IAP, A. Peter Manoj (IAP Outreach and Coordination), and Mamatha B.B. (Administrative Assistant), with wholehearted support from the CeNSE fraternity. The IAP is targeted to reach many more industry affiliates and promises to build an ecosystem that potentially leads to win-win-win model benefiting the industry-academia-government.

# RECENT PhD THESIS COLLOQUIA

## Integrated Graphene Nano-Opto-Electro-Mechanical System

Aneesh Dash

Micro-electromechanical systems (MEMS) have become ubiquitous in modern technology and have found applications in sensing, micro-manipulation of light and particles, switching, etc. The most successful application has been in micro-mechanical sensing using suspended MEMS devices. The scaling of MEMS into nano-electromechanical systems (NEMS) was spurred primarily by the expectation of higher sensitivity. NEMS resonators offer unique attributes like vibrating frequencies in the radio-frequency (RF) and microwave range and vibrating mass in femtograms. They hold promise for ultra-low mass-sensing, force-sensing, charge-sensing, and the study of nonlinear dynamics. One of the most exciting materials for NEMS is graphene, the thinnest mechanical membrane to date.

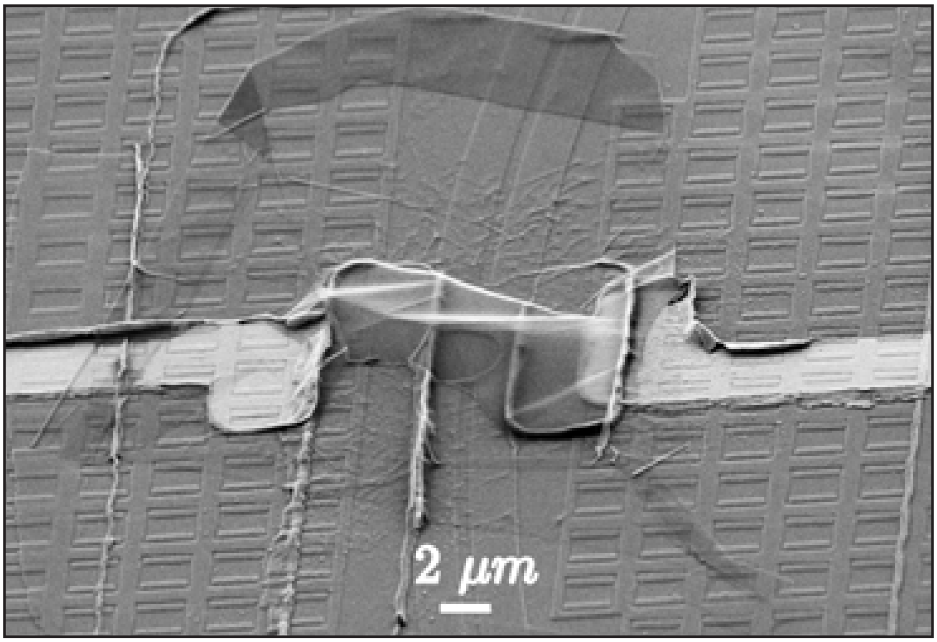
The interesting question is, how the mechanics would behave when the size is scaled to one or two atomic layers? Characterizing mechanical behavior of such materials with current techniques becomes extremely challenging. While electrical transduction is quite favorable for MEMS, it is a challenging to implement similar techniques in high frequency NEMS devices. Optical transduction techniques are preferable for NEMS. A highly sensitive integrated scheme with ultra-low noise characteristics is essential to probe such a system. This thesis discusses:

1) integration of graphene nano-mechanical resonator over integrated-optic platforms operating at near-IR to form an integrated nano-opto-electro-mechanical system (NOEMS).

2) interaction of graphene with near-IR, ultra-sensitive on-chip optical transduction schemes using optical cavities, and optical actuation schemes along with possible applications and implementation challenges.

3) integration of transparent electrodes over waveguides for manipulation of mechanical resonance as well as the optical cavity, for cavity-optomechanical experiments, is discussed.

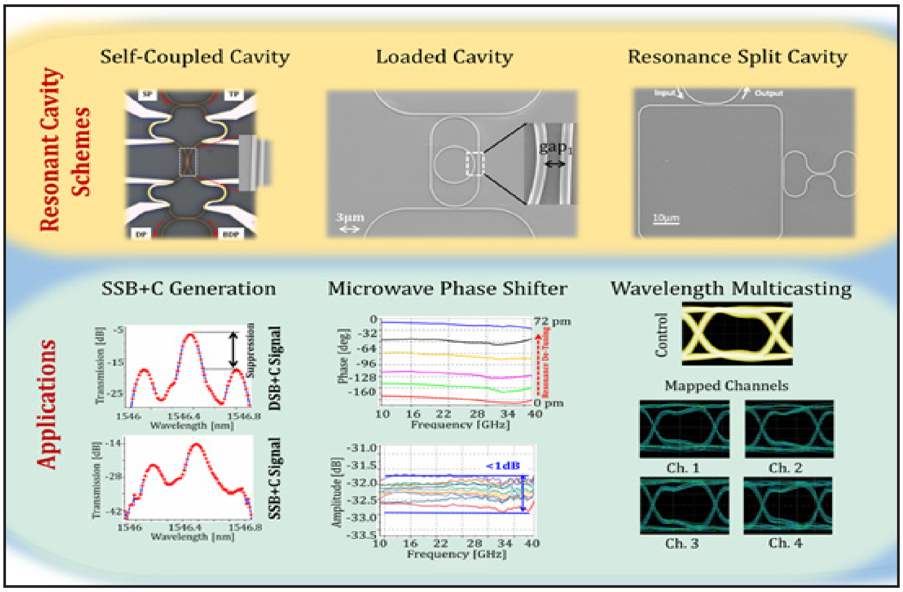
4) complete structure of the system and its fabrication.



## Mode Engineering in Micro Ring Resonators and Their Application

Awanish Pandey

Silicon Photonics (SiP) has emerged as the prominent platform for Photonic Integrated Circuits (PICs). CMOS technology compatible fabrication processes, high index contrast of the waveguide core-cladding leading to sharp bends, and low propagation loss are the key advantageous features of SiP circuits in Silicon on Insulator (SOI). Various functional units are already in their mature stage where Micro Ring Resonators (MRRs) have been widely used to realize wavelength-selective devices in a PIC. Compact design, high Q-Factor, scalable spectral properties, and ability to create complex higher-order signal processing architectures are some of its basic advantages. Due to these benefits, MRR has found wide range of applications ranging from sensors to optical communication to filters. MRRs resonate at particular resonance wavelengths dictated by the interference condition. However, fabrication imperfections and parasitic coupling at various interfaces in MRR excites undesirable degenerate cavity modes that can lead to unpredictable resonance splitting. This work attempts to:




1) Tackle resonance splitting problem by engineering mode interaction within the cavity.

2) Discusses a unique Self-Coupled MRR (SCMRR) that provides predictable and controllable resonance split by regulating the excitation of degenerate cavity modes.

3) Understand multiple cavity systems to gain control over not only the extent of splitting, but also the resonance shape.

Finally, the proposed devices were exploited for applications in the following domains:

1) Optical Communication: four channel multicasting at 48 Gbps (4 x 12 Gbps) by selectively splitting the MRR resonance into four notches was demonstrated. Highest data rate/channel of 12 Gbps using an MRR based device was achieved.

2) Sensing: an on-chip self-calibrated sensor interrogator was demonstrated in a patented technique.

3) RF signal processing using photonics: RF Phase Shifter (PS) and generation of on-chip Single Side Band with Carrier (SSB+C) for Radio over Fiber (RoF)-based applications was proposed. In PS, continuous tuning of RF phase was achieved from $0^{o}$ to $180^{o}$ with a record low power penalty of sub-1 dB over a considerable bandwidth RF (8 GHz-43 GHz).

## Multiscale modelling of quantum transport in 2D material-based MOS transistors - Madhuchhanda Brahma

The emergence of beyond-graphene 2D materials has opened up the possibility of using them as alternative channel material for metal oxide semiconductor (MOS)-based transistors. Since such atomically thin devices offer excellent electrostatic integrity, 2D materials pave the way for downscaling the transistor channel length below decananometer, where the wave nature of electron gets manifested. In order to explore the plethora of 2D materials one needs to develop a multi-scale modeling methodology, which enables estimation of intrinsic performance of MOS transistors from the crystallographic information of the materials. This thesis discusses the development of such a modeling framework for two different types of transistors (MOSFET and tunnel-FET) involving three different 2D materials.

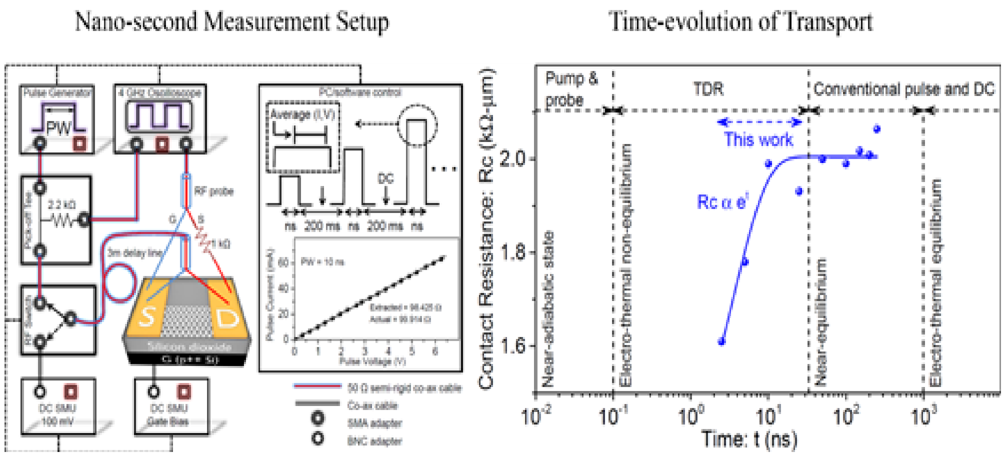
First, the ballistic transport in monolayer Germanane MOSFETs is investigated for high-performance applications. The approach is based on a self-consistent quantum ballistic transport model within the framework of the nonequilibrium Green's function formalism and relies on DFT (density functional theory) calibrated single-band and a two-band $\mathbf{k} \cdot \mathbf{p}$ Hamiltonian for n and p-type channels respectively. It was found that, even for a gate length scaled down to 3 nm, the ON current ($I_{ON}$) in n- and p-MOSFETs for a fixed OFF current $I_{OFF}$ = 100 nA/µm is as high as 890 and 700 µA/µm, respectively. For longer channel lengths, the p-MOSFET can outperform the n-MOSFET in terms of $I_{ON}$ requirements, as the direct source-to-drain tunneling gets suppressed.

Second, the same methodology was employed to assess the intrinsic performance limit of monolayer GeSe-based TFET for low-power applications. This work finds that the complex band wraps itself within the conduction band and valence band edges and thus signifies efficient band-to-band tunneling (BTBT) mechanism. The study shows that monolayer GeSe-TFET is scalable till 8 nm while preserving ON/OFF current ratio higher than $10^4$.

Third, the anisotropic dissipative quantum transport in Phosphorene-based MOSFET in armchair and zigzag directions was studied. Here the transport equations rely on DFT-calibrated two-band $\mathbf{k} \cdot \mathbf{p}$ Hamiltonian and the treatment of electron phonon scattering is done under the Self-Consistent Born approximation (SCBA). The effect of different acoustic and optical phonon modes on the drain current of n and p channel device was investigated.

## **Electro-thermal Transport through Graphene & CNT at Nano-second Time scale and its Implications on Device Reliability** – Abhishek Mishra

The possibility of using Graphene and MWCNTs as channel material for RF transistors and interconnects, respectively, has recently garnered much attention. Efforts are being made for improvements on both the material and the device fronts. For a comprehensive evaluation and for improving the robustness of the technology based on these materials, it is imperative that the reliability of the devices be evaluated for short-term and long-term catastrophic failures. The deterministic operation of the device requires investigation and understanding of dynamics and transients associated with the electro-thermal transport, which eventually leads to oxidative breakdown of the devices. Given the low-dimensional nature of the materials chosen for this thesis and their extraordinary electrical and thermal properties, the devices so fabricated demand deployment of novel techniques for the investigation of high electric-field transport and assessment of reliability. In this work, a comprehensive investigation of electro-thermal transport through graphene and MWCNTs is presented. Phenomena occurring at the time-scale of the order of a few nano-seconds, the thermal diffusion time, have been studied. A novel characterization setup which involves synergetic use of a transmission line pulse tester and Raman spectrometer to inflict controlled defects and study their temporal and spatial evolution, was developed and used to investigate the effect of electro-thermal transport.




This work investigated the mechanism behind electro-thermal transport through graphene and CNTs, and its manifestation as a potential reliability and aging issue has been explored. It is found that the electrical transport is a time-function of intrinsic heating (scattering) of the device. A maximum change of 50% in metal-graphene contact resistance was captured over a time-span of 8 ns. Further, it is found that the low-dimensional nature of 1D and 2D materials amplifies the effect of various interfaces and defects on the electro-thermal transport through the devices based on these materials. Consequently, their reliable operation demands engineered interfaces and low-defect density, for efficient phonon transport across the interface and delayed oxidation of the lattice, respectively. Contrary to bulk semiconductors, which break only above a critical field, the time-dependent failure behaviour of graphene has been discovered, which precludes the existence of failure threshold and manifests as a potential defect-assisted aging issue for graphene and other 2D material-based devices.

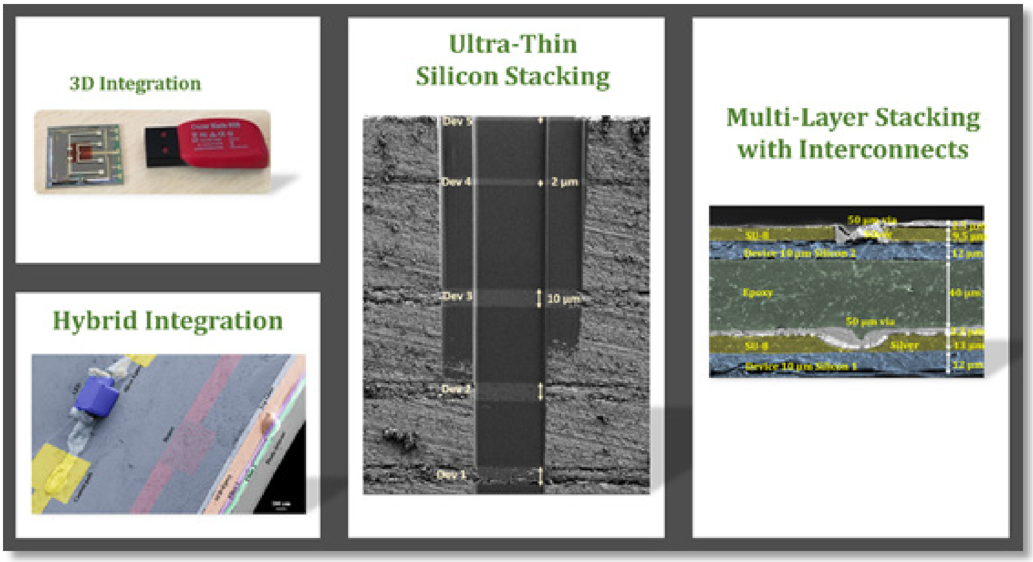
## 3D Packaging for Integration of Heterogenous Systems

Pavani Vamsi Krishna Nittala

With several new applications getting developed around wearable technologies for Internet of Things (IoT), there has been a growing need for the development of miniaturized systems. These emerging applications in healthcare, structural monitoring, consumer accessories, etc. are fuelling the need for these miniaturized hybrid systems. Such micro-nano systems will be enabled through the development of heterogeneous integration technologies that will allow co-packaging of several chips with different functionalities in a single vertical 3D stack. Therefore, the consumer electronics industry has initiated development of 3-D integration of CMOS devices in vertical stacks which are electrically interconnected using thru-silicon-via (TSV) technology. This technology is however not suitable for stacks having a complex combination of GaN-HEMT's, MEMS, microfluidics, optical devices and CMOS. To address these issues, the researchers have developed innovative processing technologies that would allow 3D packaging by post fab vertical stacking technique, suitable for the packaging industry.

The first part of this thesis demonstrates a 3D integration method for miniaturisation of hybrid systems. Several fabrication challenges of planarization, stacking and interconnection of these divergent chips have been resolved. The second part disusses development of processing technologies for 3D stacking of homogenous silicon systems. Using these, a low temperature process to transfer MOS devices on ultra-thin silicon layers (1.5 μm) from a parent substrate to a foreign substrate or stack has been demonstrated. Furthermore, three-layer stacking of the ultra-thin silicon layers with functional MOSFETs in each layer was demonstrated.

The third part of the work demonstrates an approach for stacking of the III-nitride-on-Si HEMTs and Si-MOSFETs on to a copper substrate. The developed process flow offers a significant improvement in the device behaviour due to the transfer to a thermally conducting substrate like copper.




Finally, the thesis demonstrates interconnection methodologies using the unconventional inkjet printing technique for via-filling that would enable identical die size stacking.

# EVENTS

## ITEC COURSE ON SCIENCE, TECHNOLOGY, AND INNOVATION POLICY
13 – 20 November

The Course on STIP is a significant new initiative of our Centre funded by the Ministry of External Affairs (MEA) through its Indian Technical and Economic Cooperation (ITEC) program. The Course provides a forum for discussion and development of public policy to promote Science, Technology, and Innovation. As is well recognised, S&T and the stream of innovations emerging incessantly from these two enterprises influence lives everywhere profoundly, and their impact is only growing. Governments, the academia, and public institutions are acutely aware of this, especially in the developing world. However, often, they find themselves only reacting and adjusting to the disruptions emanating from far away. Yet, these institutions have the power and autonomy to formulate policies and take action on their own. In this context, the aim

of the course was to impart training to participants on how S&T policies are important and are evolved, and what the role of the government and public institutions is and should be in the “STI” system.

The course dwelt on how S&T policies are formulated when government and the society look increasingly to experts to do more for the society than conduct research and produce knowledge. Such expectations include protecting society from misuse or unintended consequences of S&T. The Course was therefore designed to impart sufficient knowledge to participants so that they can contribute to decision making related to S & T issues in public, private, and civic settings in their own countries.

The course had nearly 35 participants from thirteen countries, including those in the neighbourhood, such as Sri Lanka, the Middle-East, Africa, Southeast Asia, Mongolia, and the Caribbean. Participants included senior academics, senior officials in policy-making positions in Government, students in S&T policy studies, and even a sitting Member of Parliament.

The Course was inaugurated by Dr. VK Aatre, formerly the Scientific Advisor to the Raksha Mantri, GoI, who recounted his experiences in policy making. Other distinguished policy makers to address the participants included Dr. R. Chidambaram, the former Principal Scientific Advisor (PSA) to GoI, Dr. Arabinda Mitra, Scientific Secretary to the Office of the PSA. Domain experts also discussed issues of intellectual property, sustainable agriculture, Healthcare (clinical registry), the ethical aspects of S&T policy, and the policy framework developed by the Karnataka Govt. to promote start-ups and entrepreneurship. The proceedings included a lively panel discussion moderated by Prof. Rudra Pratap and Prof. Navakanta Bhat of CeNSE, in which the MEA was represented by Shri Rajesh Naik of the Regional Passport Office, Bengaluru.

The Course was organized by Dr. Sanjeev Kumar Shrivastava, National Coordinator, I-STEM, and Coordinator of ITEC Courses @IISc, and by Prof. SA Shivashankar, CeNSE. Dr. Chagun Basha of the DST Policy Centre, IISc campus, played a key role in arranging the Course Program and in working with the participants to prepare and present reports on aspects of S&T policy. During the feedback session at the end of the course, participants said unanimously that the objectives of the Course were clear and that the content was relevant and beneficial to them.

## INUP HANDS-ON TRAINING
26 November – 06 December

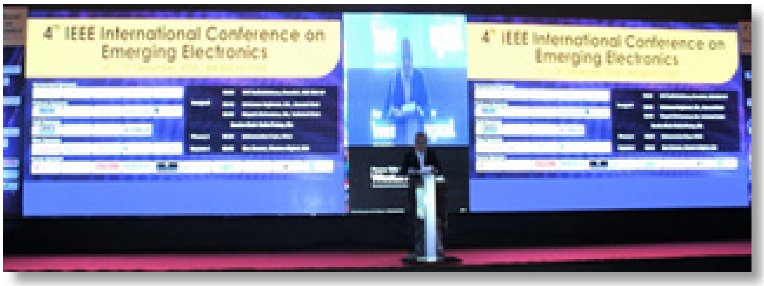
## ICEE 2018
16 – 19 December

The fourth International Conference on Emerging Electronics, sponsored by IEEE Electron Devices Society, was held in Bengaluru in the month of December, 2018. The flagship conference for electron devices was hosted by IEEE-EDS Bengaluru chapter.



The conference philosophy and format covered all aspects from materials for devices to integration in systems. Contributions came not only within the broad thematic area but also from outside of the focus areas, which were accommodated in active poster sessions, invited and contributed talks and focussed workshops. The conference had around 600 participants from industry and academia, eight plenary and four keynote lectures, 220 contributed talks and posters, and a special session on start-up stories.


***ICON Analytical stall at the conference***




***Plenary Talk by Siva Sivaram, Western Digital***

***Odissi dance performance by Rudrakshya Foundation***

# VISITORS TO CeNSE

In the last quarter, we have had many distinguished guests visit our Center and provide encouraging feedback.

Shri R. Subrahmanyam, Secretary, Department of higher education, MHRD, who visited in October 2018 said, "CeNSE is the pride of the country" during his visit in October 2018.


Dr. Arabinda Mitra, Scientific Secretary to PSA, visited CeNSE during the week of STIP course in November 2018.

In January 2019, Prof. Anthony Forster, Vice Chancellor, University of Essex, UK, visited our center. He said, "CeNSE is an amazing World Class Facility".

Profs. Robert Crane, Vincent Crespi, Nitin Samarth, Akhlesh Lakhtakia, John Badding, Jainendra Jain – all faculty members at Penn State University, USA, visited CeNSE and were given tours of NNfC and MNCF.

# AWARDS

**The Shanti Swarup Bhatnagar Prize for Science and Technology** is given annually by the CSIR to recognize outstanding research, applied or fundamental, in biology, chemistry, environmental science, engineering, mathematics, medicine and physics.

In 2018, the apex agency of Government of India for Scientific Research awarded the Bhatnagar Prize to **Prof. Ambarish Ghosh** for his contributions to physical sciences.

**The Infosys Prize** is given annually to honor remarkable achievements of contemporary researchers and scientists across six categories: Engineering and Computer Sciences, Humanities, Life Sciences, Mathematical Sciences, Pysical Sciences and Social Sciences.

The Infosys Prize 2018 in Engineering and Computer Science has been awarded to **Prof. Navakanta Bhat**. Prof. Pradeep K. Khosla, the jury chair said Prof. Bhat was chosen "because of his excellent impactful work ... and how it inspired him to build novel bio-sensors ... building infrastructure for talent training and research in nanoscale science and engineering ... and the impact on building applications for national defense and security ".

# IN CONVERSATION WITH...

## Excerpts from an interview with Prof. Rudra Pratap

***1) How did your journey with IISc start?***

I did not know anything about IISc when I applied for a job here, but a very good friend of mine who was here – Prof. Kumaran in Chemical Engineering – encouraged me to apply to IISc because it was the best place (for research) in India. So, it was on his recommendation that I applied and I got the job. I came straight from the US and joined the institute in 1996.

***Was the institute close to your expectations?***

No, it wasn't. Firstly, since I hadn't visited IISc earlier I did not know what to expect, but when I came here, I had mixed feelings. People I had interacted with were very good and gave me confidence; they were like me in the respect that they had done their PhDs from universities outside India and were working here. The facilities were disappointing, though. The labs spaces looked like they were much behind their time. That's the kind of feeling I got from the first impressions.

***Which building was your lab in?***

Mechanical Engineering.

(Prof. Rudra Pratap shared an interesting story about how he was allotted his lab space. After being dissatisfied with all the other options the chairman has shown him over a period of about 18 months, RP finally decided to take the last option given to him – the building's terrace! This is where he eventually built his lab and office. Once he moved to CeNSE, the lab was handed over to the department. One can still go and visit the lab).

***2) Was there a defining moment in your graduate school days at which you decided to go to academics?***

I was always inclined towards academics. I used to teach even in high school and very well enjoyed it. That love for teaching grew further in grad school. If I were to pick a defining moment, it would be the point at which I started interacting with Andy Ruina (Professor of Mechanical Engineering, Cornell University); I was a Teaching Assistant (TA) for his course. Our partnership was very enjoyable – there was absolutely no hierarchy, he used to learn things from me and I, of course, learned a lot from him. That collaboration with Andy convinced me that I want to be in academics ...to interact with people like him! He had a huge role to play in my decision. I had an industrial job offer in the US after I finished my PhD, but Andy refused to let me go to industry. He forced me not to take up that job and I am glad that he did.

***RP during his time at Cornell University.***

***3) How did you start working in your field of study?***

In my PhD I did not do anything even remotely connected to what I do now. My PhD thesis was about non-linear dynamical systems; it was theory and purely mathematical. It was only after I started teaching at Cornell that I came in contact with another professor – Noel MacDonald – who was then heading Cornell's Nano Fabrication facility; he asked me for some help in modelling. Through meetings with him I got introduced to this field of MEMS. That was the first time I learnt anything about MEMS. At the end of that same year I got an offer from IISc and once I got here, I was surprised to realize that nobody at IISc was working in this field despite this being a premier institute and MEMS a hot field of research then. After some internal deliberation and a discussion with the chairman I decided to start working on MEMS. That's how I got started in this field of work. Starting with one or two graduate students and after working for about three years to get an idea about what kind of work we would like to do, I figured that there was plenty of scope for me to contribute to this area. And just when I had begun doing some work and getting stuck at moments of doubt, particularly in electronics, I met a guy called Navakanta Bhat; he had joined ECE department. I went and talked to Navakanta and we found a partnership -- he was not working in this area either. Once we started working together and having fun, we realized that we cannot go far by just designing our devices here and getting them fabricated in the US. When we realized the need to have a fabrication facility here, we understood that it was going to be a huge challenge in terms of raising money, expertise and infrastructure. But then, our enthusiasm and energy kept us going and we started forming groups of people who shared our ideas and came together to form what is CeNSE today.

***4) What kind of environment is most conducive to working successfully in science?***

I think we still need to create an environment where a lot of time is available to scientists to think. What is troublesome here is that your time gets split into many small parts; you're doing several things that are not necessarily scientific. It is mostly administrative work. The system is not very efficient in our country and IISc is no exception. Therefore, a researcher's time which should ideally be dedicated to thinking about ideas, gets split because of all the little irritants which are usually taken care by a system that is in place. Unfortunately, that is not how our system is. I find that 'dwell time', which is the most essential for a scientist, is lacking. How much of such time is really available to scientists? That level of engagement is missing because you get interrupted so much. I think that is the single most important ingredient we are missing.

***Do you see this situation changing anytime soon?***

Well, I am certainly trying to do my part. Now that I am a senior professor, I find that it is my job to remove such obstacles from the path of my junior colleagues and provide them the kind of environment I would have loved to have. So, with given administrative responsibilities it is up to me to do this. Things are improving, but at a much slower rate than I would like. It would be faster if the administrative staff at the department and institute level takes the full load of administration and deliver services without any interference from faculty members. Their time is best utilized thinking about research, working on new ideas, guiding students, teaching, etc. That is the change I would love to see.

***5) What do you do when you are not thinking about your research?***

I like to think about using scientific thought for social problems. I like to use scientific methods and techniques for analysing social problems because in India we are beseeched with so many social issues. I am trained as an engineer and to an engineer everything is a system: society is a system, family is a system... For a certain input there is a particular output, there is a relationship between the input and output which is modulated by the system parameters. So, how do you identify these parameters for social systems? How do you tweak them so that you get the right output?

Other than that, I love sports and I like playing badminton every weekend. I like to keep fit and I push every student in my group to maintain physical fitness.

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