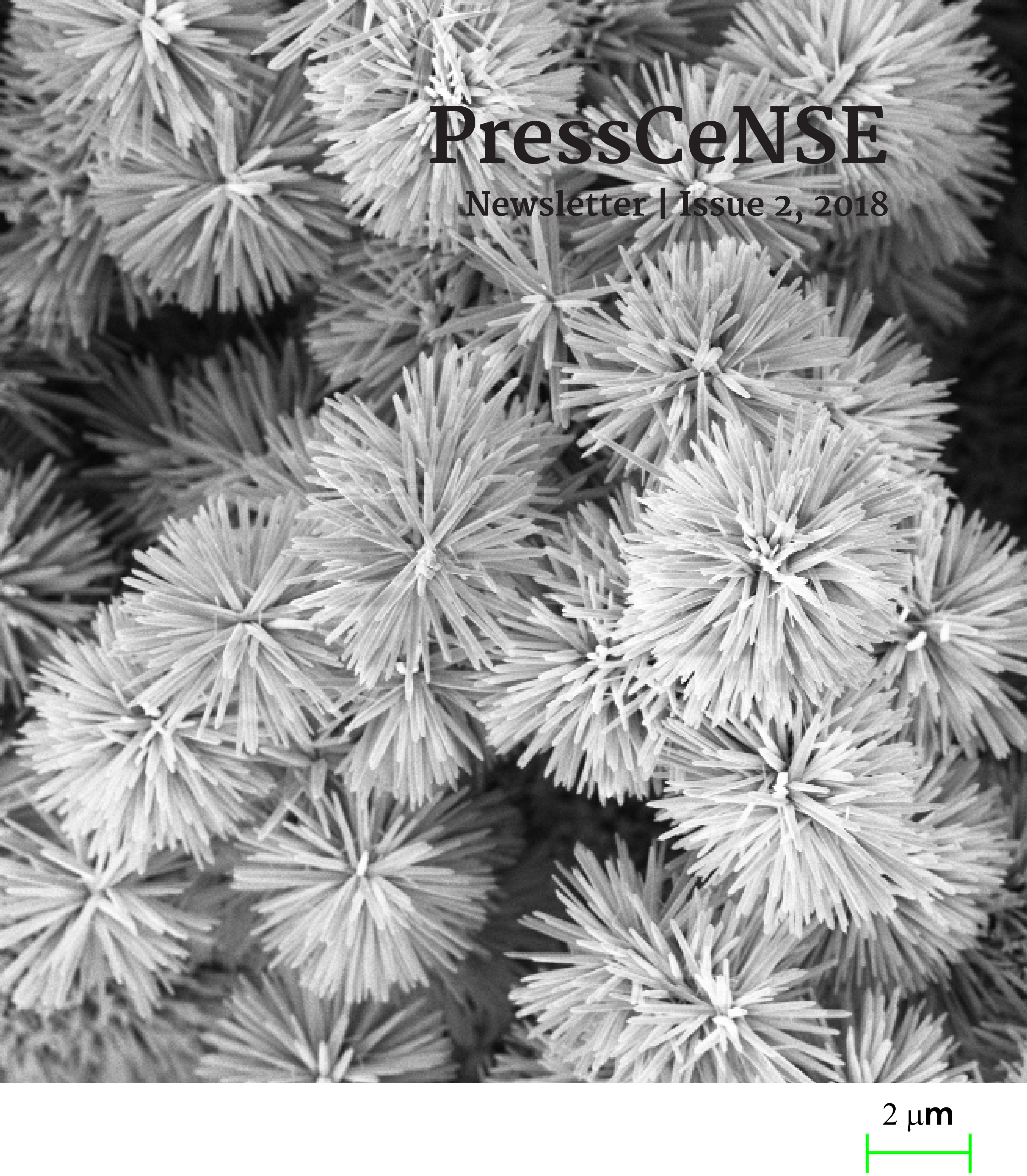
PressCeNSE

Newsletter | Issue 2, 2018



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

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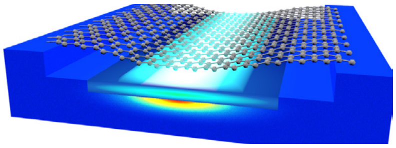

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Cover photo: Bunch of TiO_2 by S. Varadharaja perumal

A WORD FROM THE CHAIRPERSON

I feel privileged to present to you this issue of PressCeNSE, highlighting our recent initiatives and achievements. Through this issue, we also share with you the important events at CeNSE in the last few months.

We were lucky to have a hat-trick of three major initiatives this April. The first was the initiation of "Nanoelectronics Network for Research and Applications (NNetRA)", a major research project funded jointly by the Ministry of Electronics and Information Technology and Department of Science and Technology (DST) Nano Mission, under the Ministry of Science and Technology. There are four other participating Institutes in this national network R&D program. This includes IIT Bombay, IIT Delhi, IIT Madras and IIT Kharagpur. Over the next four years, a synergistic research and technology development will be pursued, by leveraging complementary expertise among these five Institutes. We have identified important and societally relevant thrust areas including (i) Safety (ii) Energy and Environment (iii) Healthcare (iv) Agriculture and (v) Nano devices and systems for other applications. In addition to pursuing cutting edge research in these areas, there will be substantial efforts in developing technologies and products, working with start-ups and industries to commercialize the research outcome. I envision this to be a great opportunity, with multiple stake holders coming together. We also hope to expand this network in future, by bringing in other Institutes to create a hub-and-spoke model for sharing research infrastructure and developing focussed research groups working across multiple Institutes.

The second was launching of a project titled "Indian Science Technology and Engineering facilities Map (I-STEM)", funded by the office of the Principal Scientific Adviser to Govt. of India, in close cooperation with Department of Science and Technology. This initiative is expected to bring a transformational change in the landscape of science and technology research in the country. I-STEM will develop an online web portal listing all the major research equipment available in academic institutes, national laboratories, across the country so that any researcher should eventually be able to access resources in a seamless fashion.

The third one was the MHRD support on "National Initiative on Education and Innovation in Nanotechnology" with an intent to supplement and support the national facilities at CeNSE, through the Institutional grant and help expand the national outreach programs in nanotechnology education and innovation.

Considering the importance of sharing the knowledge on running and maintaining the cleanroom, nanofabrication and characterization facilities, we have started a new platform : Micro and Nano Fabrication AND Characterization Symposium (MNFACS - 2018), a very unique two day event, conducted on 11th and 12th July. The intent was to share best practices in running and maintaining the equipment and facilities.

We hope to continue this as an yearly feature with active involvement of scientists and technical staff in academia, national labs and industries.

Our industry collaboration got a boost with the induction of Park Systems from South Korea. Recognizing the mutual strengths and expertise, Park Systems and CeNSE have joined together to set-up Park Nanoscience Lab,

inaugurated on 22nd July. We are happy to note that Park Systems has donated its NX 20 AFM to CeNSE, which will be used for education and research.

Last summer was also the time to bid adieu to our graduating M.Tech. and Ph.D. students. We were proud to graduate 8 M.Tech. students and 25 Ph.D. students. You will be amazed to read in this issue the breadth of research topics covered by these graduating students, a testimony to the interdisciplinary nature of our centre. We have an article presenting the summary of the graduation day party arranged on 22nd June, to appreciate the contributions made by our students. I wish them all the best in their future endeavours. We are also very happy to share with you that a new batch of 28 students, has just joined CeNSE in August, perpetuating the ever-evolving life-cycle of education and research. In the years to come, these energetic and enthusiastic bright young minds will work with us in realizing our collective dreams for CeNSE.

The CeNSE student chapter of the IEEE Nanotechnology Council and Sensors Council conducted one week summer school on "Nanotechnology: From Science to Systems and beyond". This was very gratifying because our students won a worldwide competitive bid to conduct this summer school. This is just an example to illustrates the capabilities and leadership of our student body.

Finally, on behalf of CeNSE community, I feel very proud to share an important news on the elevation of our faculty colleague, Prof. Rudra Pratap, as the Deputy Director of the Institute, in charge of infrastructure and planning. Please join me in congratulating him and wishing him all the best for his future initiatives in the Institute.

-Navakanta Bhat

WHAT'S NEW IN RESEARCH AT CENSE

MEMS/NEMS LAB & PRL

On-chip Optical Probing of Graphene NEMS: Aneesh Dash, Prof. Shankar Kumar Selvaraja & Prof. Akshay Naik

Graphene is an exciting platform to study the fundamental limits of physics and the mechanics at nanoscale. Recently, tremendous amount of work in carrier transport in Graphene has given insight into understanding the change transport that wasn't possible before. Scaling of Micro-Electro-Mechanical System (MEMS) toward highly sensitive nano-electro-mechanical systems (NEMS) requires the use of ultra-low mass structures like Graphene membrane. The fundamental question is, how would the material behave when the size is scaled to a one or two atomic layers?

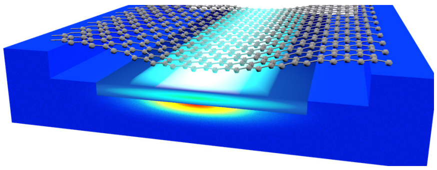
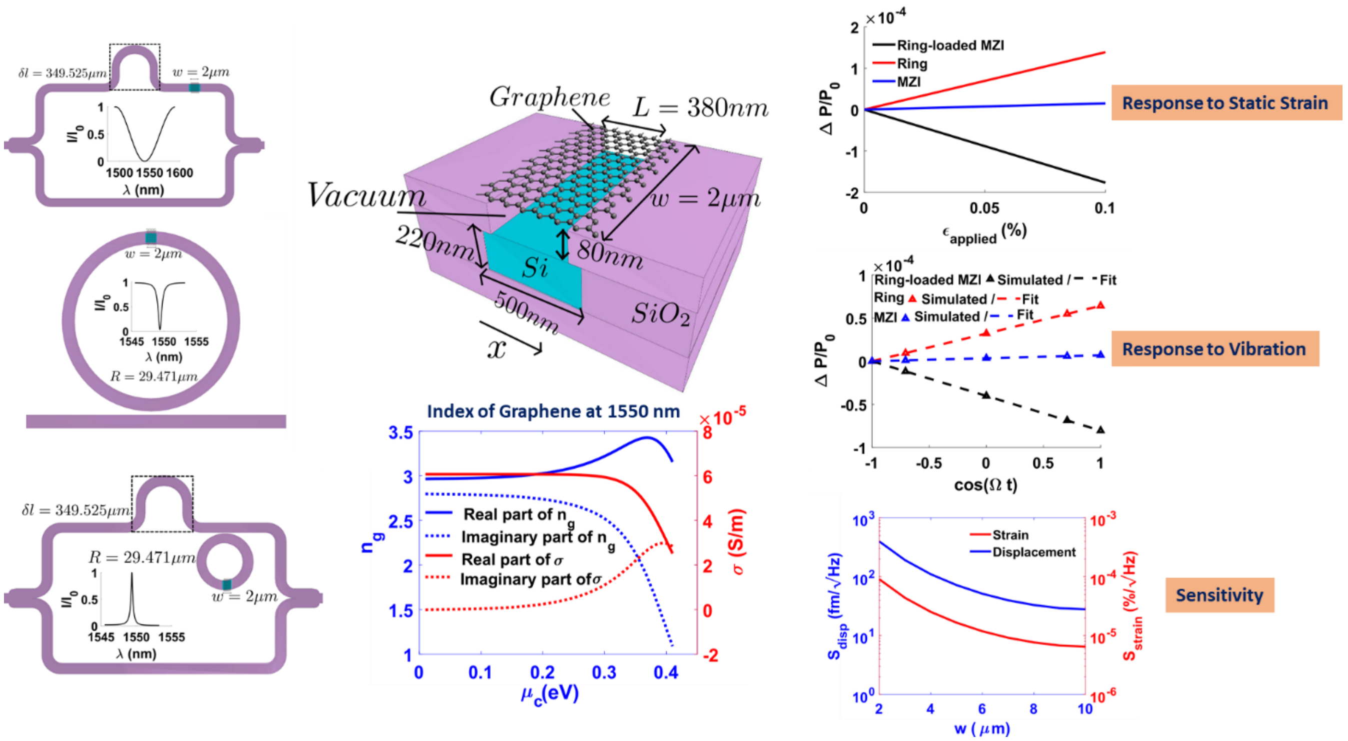


Fig. On-chip Optical Probing of Graphene NEMS

Characterising mechanical property of such materials becomes extremely challenging with the current techniques. A highly sensitive method with ultra-low noise characteristics is essential to probe such a system. Recently, researchers at the Centre for Nano Science and Engineering, IISc proposed a novel method to measure strain and displacement of Graphene. The transduction scheme exploits Silicon Photonics; a versatile photonic integrated circuit platform developed for optical interconnect application. The scheme uses overlap between a guided wave and Graphene to interrogate the changes in the mechanical property. Graphene has both dispersive and dissipative interactions with near-IR wavelengths. Both these interactions change with a static strain in graphene. Vibration alters the overlap of graphene with guided light and affects both the interactions. Thus, the complex effective refractive-index experienced by the guided light carries information about both the strain and the displacement and can be used to realize transduction. Based on detailed calculation based on practical scenarios a sensitivity of 28 fm/√Hz and 6.5×10−6 %/√Hz for displacement and strain, respectively, is predicted. This is the first time such an integrated photonics-based transduction proposal is made and accepted by the community as a viable option for probing materials at such extreme scale.

The proposal and details of research findings were accepted for publication in Optical Society of America (OSA) journal Optics Letters 43, 659-662 (2018). The article was an editor's pick.



MEMS/MOEMS LAB

Grow Epitaxial ZnO Nanorods in Your Kitchen!:

Randhir Kumar & Prof. Rudra Pratap

The epitaxial growth of any thin film requires precise control of process parameters. These parameters are difficult to control in conventional hydrothermal equipment. Usually epitaxial thin films are grown in very expensive growth equipment like Metal-Organic Chemical Vapour Deposition (MOCVD), Pulsed Laser Deposition (PLD) and Molecular Beam Epitaxy (MBE). Zinc oxide is one of the most well-known wide band gap semiconductors (Eg = 3.37eV) with a large exciton binding energy (60 meV). It is one of the most studied oxide semiconductors which has found applications in areas ranging from near-UV emission, transparent conductivity and piezoelectricity. Recently, our lab has demonstrated epitaxial growth of ZnO nanorods on a Sapphire substrate by Microwave Assisted Hydrothermal Method. The equipment used for this growth is shown in Fig. 1 (a). The setup consists of a microwave oven which is very common in a kitchen, modified in a way to accommodate glassware for growth chemistry. Scanning electron microscope image of the nanorods is shown in Fig.1 (b). The X-Ray phi-scan (Fig.2 (a)) on the sample shows six peaks, which confirms the epitaxial nature of material. FWHM of omega scan was found to be 0.640 degrees (Fig.2 (b)) which confirms good crystal quality of the samples.

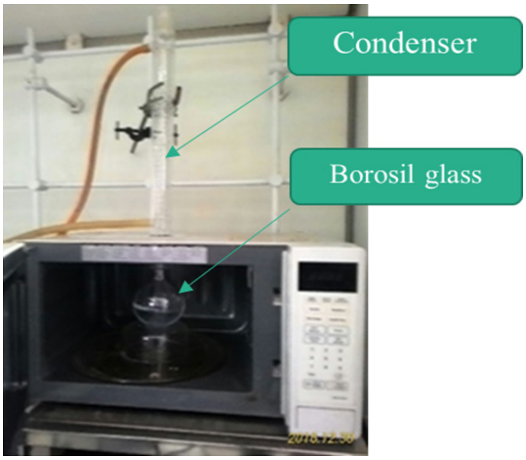


Fig 1(a): Experimental setup for growth of ZnO nanorods.

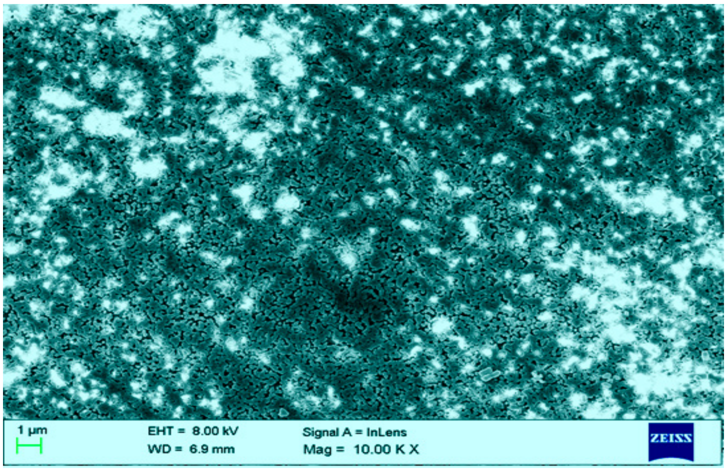


Fig 1(b): SEM Image of ZnO nanorods

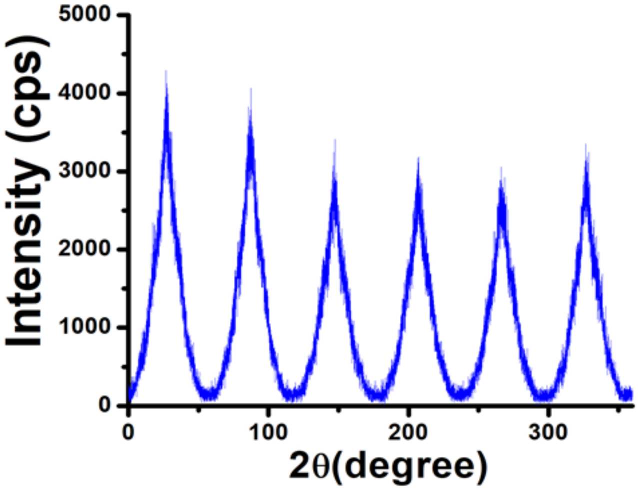


Fig 2(a): Phi-scan of ZnO nanorods showing 6 peaks

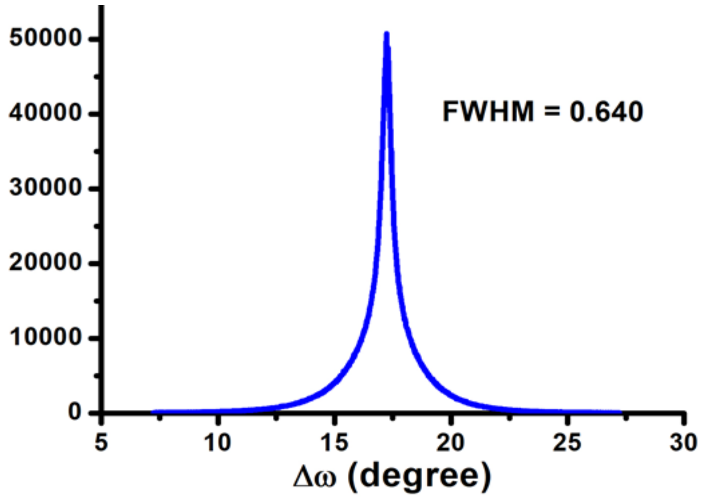
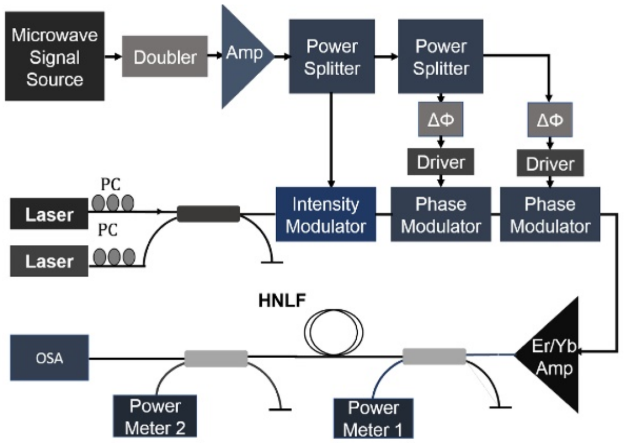


Fig 2(b): Omega scan of the ZnO nanorods showing 0.6400 FWHM.

NONLINEAR PHOTONICS AND LASERS LAB

High Repetition Rate Multiwavelength Source in C-band: B.S. Vikram, Prof. Supradeepa

Demand for bandwidth in optical communications necessitates the development of scalable transceivers that cater to these needs. For this, in DWDM systems with/without Superchannels, the optical source needs to provide a large number of optical carriers. The conventional method of utilizing separate lasers makes the system bulky and inefficient. A multi-wavelength source which spans the entire C-band with sufficient power is needed to replace individual lasers. In addition, multi-wavelength sources at high repetition rates are necessary in various applications such as spectroscopy, astronomical spectrograph calibration, microwave photonics and arbitrary waveform generation. Here, we demonstrate a novel technique for equalized, multi-wavelength source generation which generates over 160 lines at 25GHz repetition rate, spanning the entire C-band with total power >700mW. A 25GHz Comb with 16 lines is generated around 1550nm starting with two individual lasers using a system of directly driven, cascaded intensity and phase modulators. This is then amplified to >1W using an optimized, Erbium-Ytterbium co-doped fiber amplifier. Subsequently, they are passed through highly nonlinear fiber near its zero-dispersion wavelength. Through cascaded four-wave mixing, a ten-fold increase in the number of lines is demonstrated A bandwidth of 4.32 THz (174 lines, SNR>15 dB), covering the entire C-band is generated. Enhanced spectral broadening is enabled by two key aspects - Dual laser input provides the optimal temporal profile for spectral broadening while the comb generation prior to amplification enables greater power scaling by suppression of Brillouin scattering. The multi-wavelength source is agile with tunable center frequency and repetition rate.



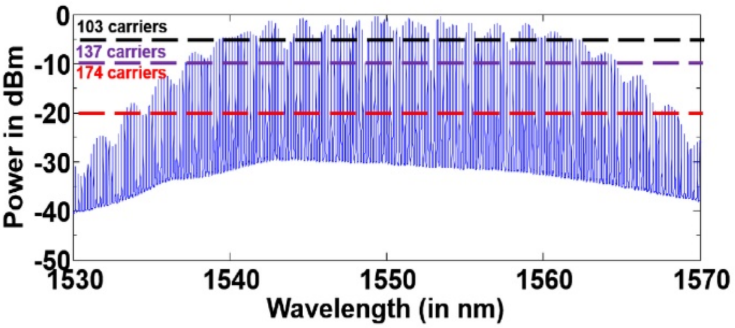


Fig: Set-up and spectrum of the C-band spanning high repetition rate multi-wavelength source

MICROFLUIDICS LAB

Graphene transfer on PDMS using microfluidic channels: Prabhat Vashishth & Prof. Prosenjit Sen

Graphene is said to be material of the future, its extraordinary electrical, mechanical and optical properties has propelled research in all the directions. Researchers all around the world are trying to answer real world problems using graphene e.g. using graphene in flexible electronics. It has been predicted that graphene could replace silicon technology according to ITRS 2011 report. But there are many obstacles in the path. The biggest challenge being production of graphene and fabrication of graphene-based devices. A reliable way to transfer graphene reported by Regan et al where they used direct transfer method in which graphene was directly placed on a substrate with a drop of isopropyl alcohol (IPA) which was then heated to evaporate IPA for better adhesion between graphene and substrate. After this, the stack was inverted and placed in copper etchant to obtain graphene on the substrate. In fact, they have suspended graphene on TEM (transmission electron microscope) grid using this method. This method was investigated in detail by Du et al. In the report the substrate wettability was studied theoretically and experimentally in detail for direct transfer method. They concluded that critical water contact angle of substrate that is necessary to sustain the direct transfer process is 600. The merit of this process is elimination of repeated wetting and drying process. It is a cleaner and gentler process than polymer-based methods. Here, we report a novel method to transfer graphene on Poly Di-Methyl Siloxane (PDMS) using microfluidic channel. The method relies on using PDMS as both substrate and polymer support. In this method graphene/copper stack is pressed on a PDMS surface which is then bonded by another PDMS containing microchannel. Copper etchant (Ammonium Persulphate) is then made to flow through the channels to etch copper and obtain graphene on PDMS substrate. This is a unique method to transfer graphene on a flexible and soft substrate that eliminates the need of any polymer support or any process involving multiple wetting and drying processes. The graphene obtained on PDMS using this process can be used as a platform to make solution gated field effect transistor for sensing.

Graphene is grown on 25 microns thick copper foil using chemical vapor deposition. Graphene copper stack is placed in Copper Etchant-Ammonium Persulphate solution (0.25 M APS-100) for around 2 hours to etch copper and remove graphene from one side. It is then rinsed with water for 15 minutes. The Copper graphene stack is lifted and pressed on PDMS substrate and then heated at 90°C for 15 minutes. Pressing and heating increases adhesion between PDMS and graphene. The other PDMS substrate with microchannels is plasma bonded with the Copper/graphene/PDMS (without microchannels) stack to obtain the device.

The obtained device is PDMS/graphene/copper/PDMS cover stack. Etchant was made to flow in the microchannels of 200um width using syringe pump. The etching process was studied optically and electrically. Electrical connections were made using silver epoxy. Figure 2 shows experimental set-up which has 3 components: device, sourcemeter and camera. Wires attached to copper graphene stack using silver epoxy were connected to sourcemeter (Keithley 2450). Simultaneously, video is recorded using 3.0 usb camera (Edmund Optics) above the device.

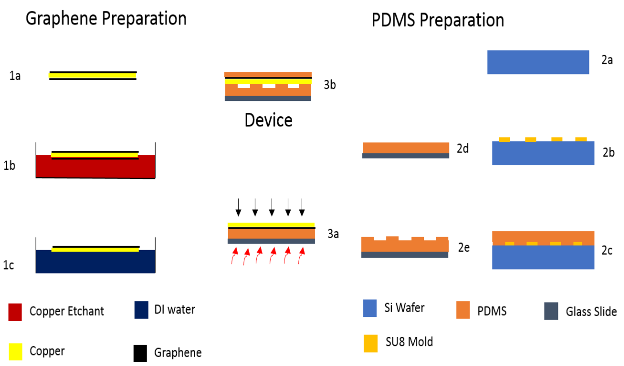


Fig 1: Fabrication process of Device

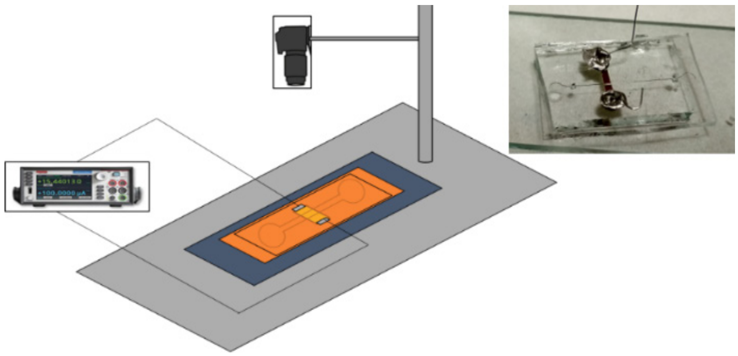


Fig 2: Experimental set-up and device fabricated.

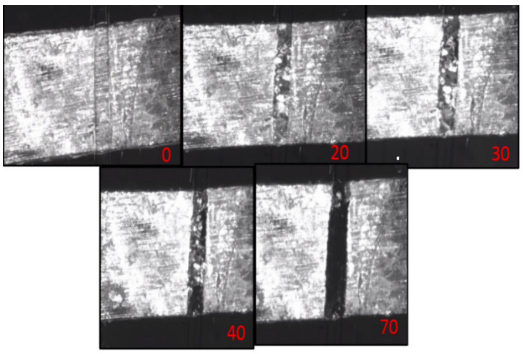


Fig 3: Optical images of graphene etching at different intervals (in minutes) at flow rate of 10ul/min

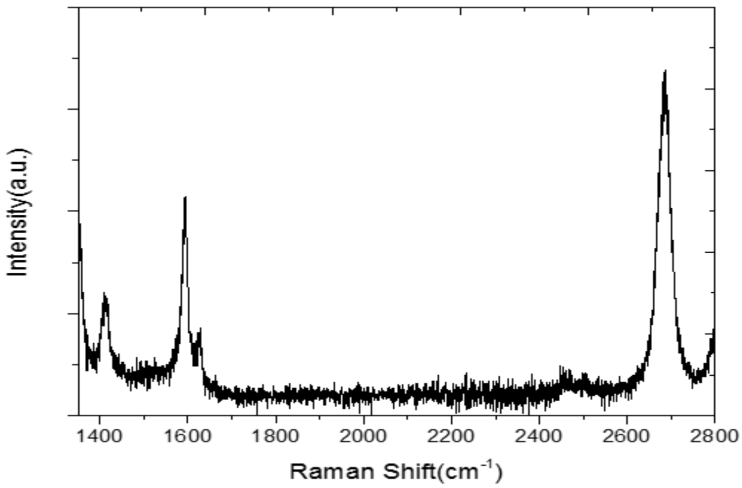


Fig 5: Raman Spectra of graphene transferred.

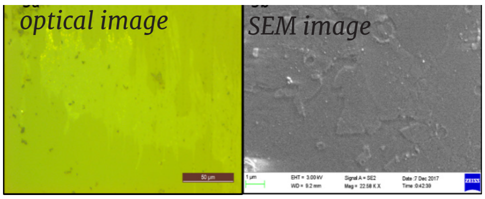


Fig 4: Graphene transferred to PDMS

PHOTONICS RESEARCH LAB

High-Speed Waveguide Integrated Si Photodetector on SiN-SOI Platform: Avijit Chatterjee & Prof. Shankar Kumar Selvaraja

Rapid growth of internet traffic is posing big challenges towards existing data center infrastructure. Some of those challenges are the demand for higher bandwidth interconnects (beyond 400 Gbps), lesser energy consumption, and scaling up the capacity without increasing the cost significantly. In that direction, Silicon photonics at 1550 nm wavelength has emerged as the attractive solution for long haul communication due to low loss, high-speed optical interconnects in Silicon. However, for short reach rack to rack communication inside the data centers, 850 nm VCSEL and Multi-mode fiber (MMF) based technology is more popular mainly because of economic reasons. Current infrastructure mostly relied upon parallel MMF links to scale up the data rate demands. But, such parallel links increase the overall cost and cannot be scaled up after a certain point. Therefore, coarse wavelength division multiplexing (CWDM) at 850 nm wavelength band is regarded as the potential solution. Moreover, CMOS compatible technology can be handy for mass production at affordable cost.

With that view, we present the waveguide integrated Silicon photodetector where we focus on realizing SiN waveguide integration with high speed Silicon photodetector on SOI platform. Silicon inverse tapers are introduced to minimize the coupling loss between SiN waveguide and Silicon PIN photodetector. We obtained the highest responsivity of 0.44 A/W at 25 V bias, and estimated the best 3dB cut off frequency of 15.5 GHz at 10V reverse bias. In future, SiN WDM integrated to Silicon photodetector can be promising for providing high-speed, energy efficient, and cost effective solution for datacenters and supercomputers.

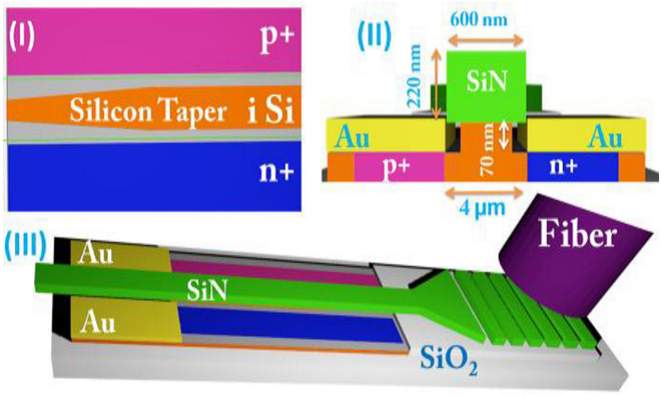


Fig 1: Schematic of the proposed design, (I) top view, (II) cross section

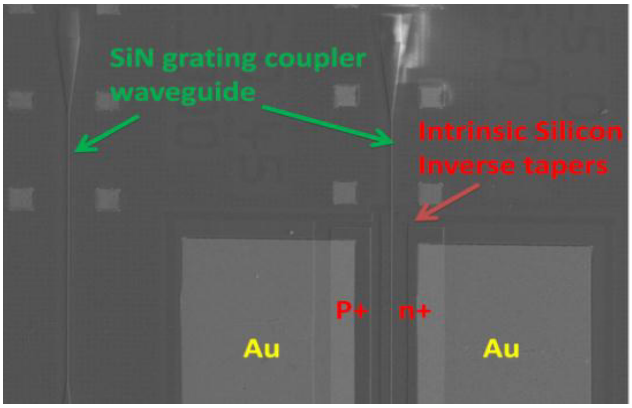


Fig 2: SEM image of the fabricated device

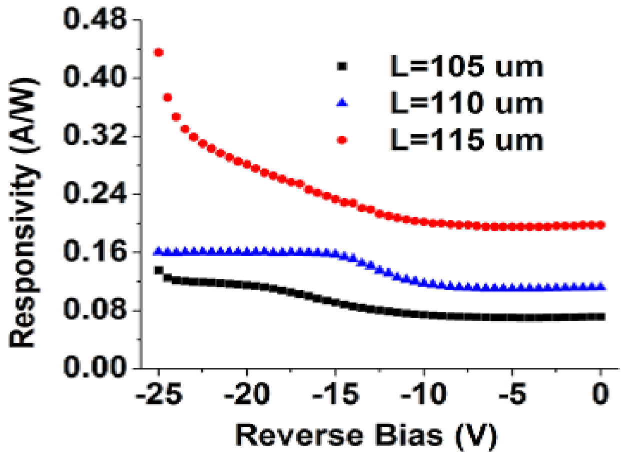


Fig 3: Dark Current Vs. reverse bias for different lengths of photodetectors

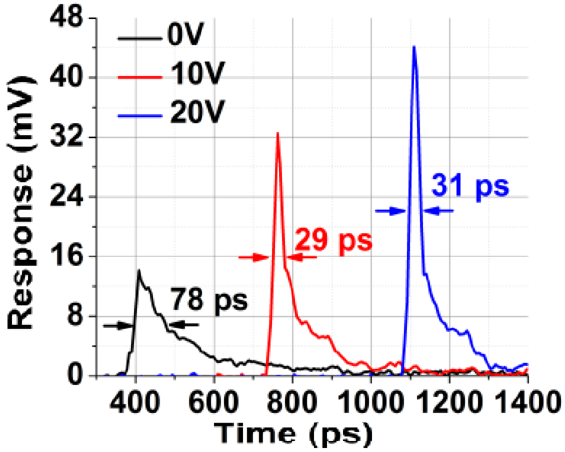


Fig 4: Responsivity verses reverse biases for different length of photodetectors

HETERO-JUNCTION LAB

In-house Developed Chemical Vapor Deposition Reactor: Vivek Singh & Prof. Sushobhan Avasthi

A new chemical vapor deposition (CVD) reactor has been developed under Prof. Sushobhan Avasthi's guidance at CeNSE. CVD is a ubiquitous thin film deposition technique used in the microelectronics industry, where it is used to grow high quality, high performance thin films. Chemical vapor deposition is a synthesis process in which the chemical precursors react in the vapor phase near or on a heated substrate typically in vacuum. The precursor flows are engineered keeping in mind the thermodynamics of their reactions, to achieve high quality films. The reactor has been built to deposit films of metal oxides and sulfides, with a capability to house multiple precursors which supports the deposition of films of multi-cation compounds.

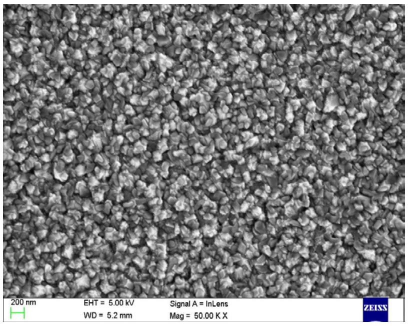


Fig: Left: Pictures of the CVD system built at CeNSE. Top: SEM image of thin film deposited using this CVD reactor

CeNSE Welcomes New Students

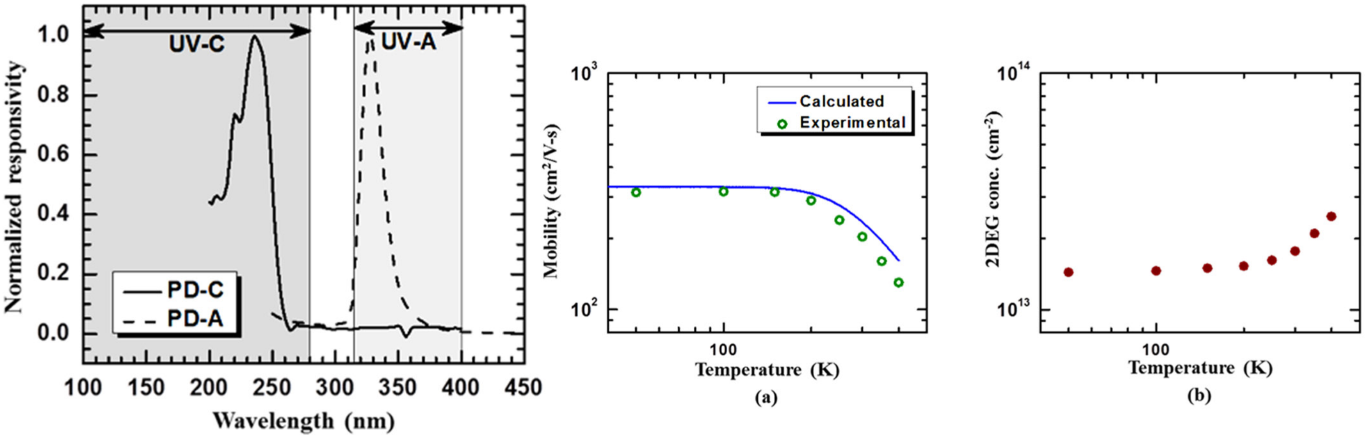
On 1st, August, 2018, CeNSE welcomed a group of 28 students to its M.Tech and PhD programs. Out of these, 4 joined the M.Tech program and the rest joined the PhD program. We wish them a fun, productive time during their academic journey at CeNSE.

WRITE-UPS ON RECENT COLLOQUIUMS

Abheek Bardhan: Integration of AlGaN with (111) Si Substrate by MOCVD

AlGaN is an important semiconductor material for electronic and optoelectronic applications. The change in composition of AlGaN (AlN to GaN) provides a range of bandgaps extending from 6.01 eV, far ultraviolet, to 3.4 eV. This higher bandgap results in a higher breakdown voltage, than GaN one of the current materials of choice, in the devices made out of it. Carrier transport is also less sensitive to temperature variation. Hence, AlGaN with high Al fraction is a suitable candidate for power transistor technology. For optoelectronic applications like UV-photodetectors and UV-emitters, the full range of AlGaN provides the tunability in wavelength ranging from 206 nm (AlN) to 360 nm (GaN). As the solar spectrum ranges from about 250 nm to 2500 nm, AlGaN with high Al fraction is useful for solar-blind UV applications. AlGaN UV emitters on the other hand can be used in water purification.

Till date all these developments have been carried out by growing AlGaNs on expensive substrates like SiC, sapphire or freestanding AlN. But the growth of AlGaN on Si (111) substrates is desirable as opposed to commonly used substrates such as sapphire, SiC or AlN owing to its higher thermal conductivity (except SiC), low cost and availability in large area. Integration with Si opens up the possibility to integrate the multifarious applications of AlGaN with the economic viability of Si (111) substrates. The present work focuses on the integration of AlGaN on Si (111) substrates by MOCVD. The bounds placed on the competing requirements thickness, composition, stress, defect density and surface roughness due to the physico-chemical aspects of AlGaN growth have been identified. Using such understanding an AlGaN/AlGaN high electron mobility transistor and a UV detector have been demonstrated.

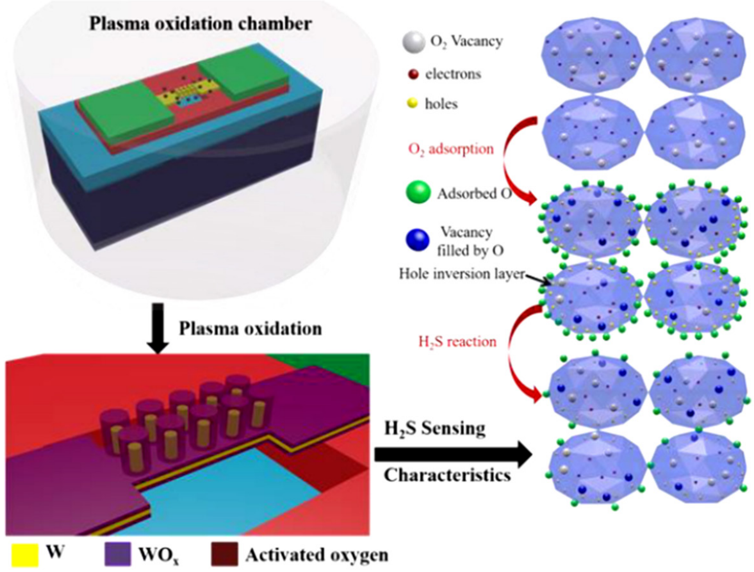


(a) Normalized responsivities of PD-A (24% Al fraction) and PD-C (66% Al fraction). (b) Calculated total mobility and measured Hall mobility of 2DEG as a function of temperature at the $Al_{0.13}Ga_{0.87}N/Al_{0.35}Ga_{0.65}N$ interface. (c) 2DEG carrier concentration as a function of temperature, obtained from Hall measurement.

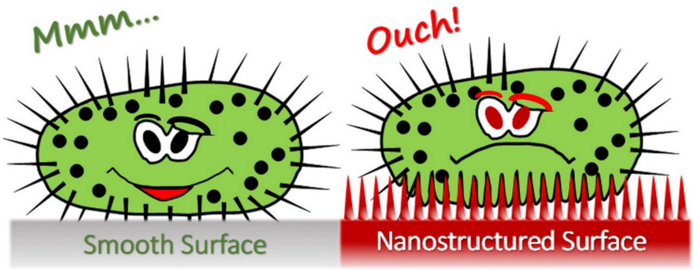
Samatha Benedict: Nanostructured metal oxide semiconductor gas sensors

Gas sensors play a vital role in today's world; be it in pollution monitoring, breath analysis, food quality monitoring or in agriculture. Chemical gas sensors based on conductometric change of semiconducting metal oxides are gaining much attention due to their simplicity, easy fabrication and low cost. The scope of my work at CeNSE was to explore different fabrication methods for developing nano-dimensional gas sensors which meet the figures of merit namely sensitivity, selectivity and stability (SSS). Furthermore, an effort was also made to develop a low cost and low power sensor array platform on a flexible substrate, using CMOS processes. In this work, plasma oxidation of different metallic structures to form metal/metal oxide core-shell sensors is investigated for achieving a reliable hydrogen sulfide sensor. Platinum, widely known for its catalytic nature, is plasma oxidized at optimum conditions to fabricate Pt-PtO_x core-shell nanowire sensor. The Pt-PtO_x sensor shows degradation in response when used for H_2S sensing, which is due to surface contamination by the sulphur species. To recover the sensor, deep ultra-violet light (UV) treatment is studied as a promising recovery method for sulphur contaminated sensor surfaces. Further, plasma oxidation of tungsten nanodiscs decorated nanowire is carried out to achieve highly sensitive H_2S sensor with fast response and recovery times and good response repeatability over a study span of 6 months with detection limit as low as 0.5 ppb, one of the lowest reported in literature. The tungsten nanodiscs are patterned using electron beam lithography process which is known to be expensive and time consuming. Thus, an effort is also made to integrate an inexpensive process such as colloidal lithography to pattern the nanostructures on the metal nanowires, later plasma oxidized to form the core shell sensor. Colloidal lithography assisted nanostructure-based palladium/palladium oxide sensor is fabricated and tested for sensing of H_2S gas. We also explored a low cost and low temperature process for synthesizing nanostructured metal oxide through microwave radiation. Microwave synthesis of NiO is optimized for detection of NO_2 resulting in room temperature response all the way down to 200 ppb.

Motivated by the need for low cost sensors we developed a sensor array platform with integrated microheater on flexible and low-cost plastic substrate using CMOS compatible fabrication processes. The sensor array consisted of four sensors with individually controlled microheater deposited on nanogap created using electromigration process. Due to flexible nature of substrate, the bending angle dependent microheater characteristics and sensing performance show the potential of the sensor platform in low power wearable electronics.



A schematic of the fabrication process for the nano-structured metal oxide gas sensors



Abinash Tripathy: Superhydrophobic surfaces for anti-bacterial properties

Bacterial antibiotic resistance is becoming more wide spread due to the excessive use of antibiotics in healthcare and agriculture. At the same time the development of new antibiotics has effectively ground to a hold. Chemical modifications of material surfaces have poor long-term performance in preventing bacterial build-up and hence approaches for realising antibacterial action through physical surface topography have become increasingly important in recent years. The complex nature of the bacterial cell wall interactions with nanostructured surfaces represents many challenges while the design of nanostructured antibacterial surfaces is concerned.

In nature several insects such as cicada wing, dragonfly wing, dronefly wing possess sharp nanostructures on their wing which kill bacteria by contact killing mechanism i.e. when a bacterium sits on such surfaces, they get stretched and deformed while trying to settle on maximum anchoring points and when the threshold of stretching is reached, cell lysis takes place. In this work a range of surfaces with distinct surface topography and chemistry has been studied. Initially, inspired from dragonfly wing, high-aspect ratio silicon nanostructured surface (NSS) was fabricated using a single-step deep reactive ion etching (DRIE) technique. The nanostructures were found to be random in both size (300-1100 nm) and spatial distribution (300-500 nm). Post fabrication the surfaces were coated with a thin layer of copper (NSS_Cu) and silver (NSS_Ag). The bactericidal efficacy of the NSS_Cu, NSS_Ag and NSS surfaces were tested and compared against Gram-negative bacterium E. coli. NSS_Cu was found to have the highest bactericidal efficacy killing 97% of the bacteria in just 90 minutes. The results from this study suggests that the addition of a surface chemistry to the physical nanostructures enhances the bactericidal efficacy. However, copper is not stable when exposed to environment and reacts to the ambient and forms certain compounds such as CuO, Cu_2O etc. To overcome this problem, we replaced copper with a stable biocompatible polymer “Chitosan (CHI)”. Unlike copper coating where sputtering tool was used, CHI can be coated on any substrate by a simple dip coating technique making the process simpler and cost-effective. CHI was coated on flat silicon (Si_CHI) and NSS surfaces (NSS_CHI). The bactericidal efficacy of the surfaces was tested against Gram-negative E. coli and Gram-positive S. aureus. NSS_CHI surface was found to be the most efficient in killing bacteria as compared to the Si_CHI and NSS surfaces. Also, the antibiofilm characteristics of these surfaces was studied. NSS_CHI surface was found to have the least amount of bacterial bio mass on its surface after a period of 5 days of bacterial incubation in Luria Broth (LB) medium for both E. coli and S. aureus. Also, the CHI coating was found to be very stable when exposed to PBS for 7 days showing its durability for a longer period.

CHI coating was cost-effective and easy as compared to the sputtering technique. However, fabrication of NSS using DRIE still comes with a cost. To overcome this issue, we fabricated ZnO nanostructured surface using simple chemical synthesis method at near room temperature (~20O C). Neither sophisticated tool like DRIE nor clean room environment was required for this process. Sharp ZnO nanostructured surface was fabricated in an alkaline solution containing zinc nitrate hexahydrate and potassium hydroxide. The synthesis time was kept to be 12 hours (h). The ZnO nanostructures possess a length of 1.5-2 m, tip diameter ~20 nm, tip angle ~ 10°. Also, this technique was used to grow the ZnO nanostructures on a variety of substrates such as copper sheet, glass, polydimethylsiloxane (PDMS) showing the versatility of the fabrication technique. The antibacterial performance of the ZnO nanostructured surface was evaluated against Gram-negative E. coli. Flat silicon surface and silicon surface coated with 20 nm of ZnO thin film were taken as controls. Bacterial attachment was seen on the flat silicon and flat ZnO substrates after a 24 h of incubation. In contrary no bacterial colony was observed on the nanostructured ZnO surface showing its bacteriophobic behaviour. The simplicity and cost effectiveness of this process makes it possible for this surface to be used in practical applications. Also, large scale fabrication is possible using this technique. Despite several advances in this area, it is well understood that the micro/nano structures are mechanically fragile. This reduces their reliability and hence increases the cost of use.

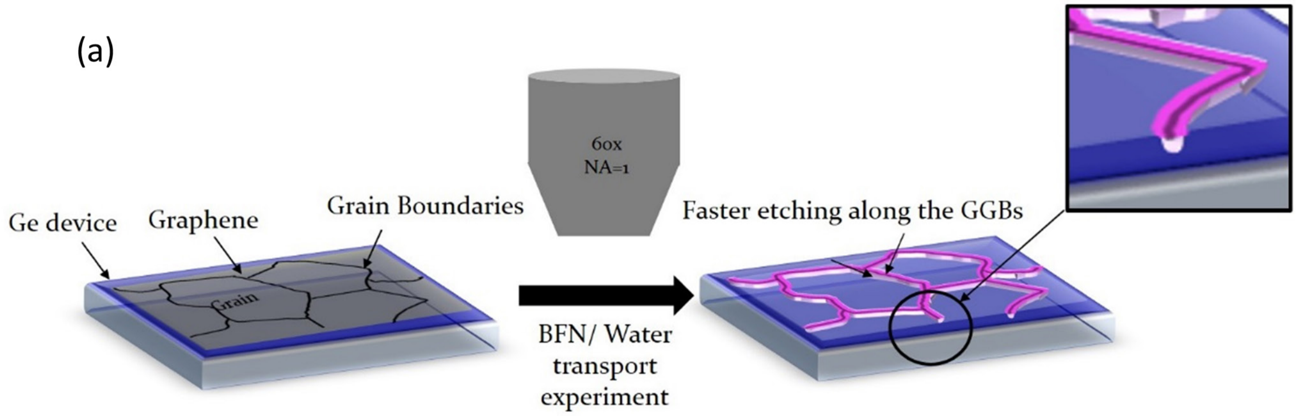
Moreover, several applications such as aprons, gloves, temporary mats etc. require these surfaces to be flexible. The above requirements call for the development of flexible antibacterial surfaces with mechanical reliability. In addition, the surfaces should be lowcost so that they can be periodically replaced to address the issues with reliability. To achieve this, transferring of copper hydroxide nanostructures onto a curable silicone polymer, polydimethylsiloxane (PDMS), was carried out by a two-step process: (i) copper etching to form nanostructures and (ii) transfer of the copper based nanostructures onto the PDMS surface by mechanical tearing. This PDMS surface decorated with the copper nanostructures (PDMS_Cu) is unique in displaying two functionalities; superhydrophobicity preventing bacterial adhesion and a potent bactericidal effect from the copper nanowires as copper has been regarded as a very good antimicrobial agent from centuries. This process was scaled for large area fabrication for real world applications. Absence of a microfabricated template makes this process significantly cheaper and easily scalable as it is not limited by the size of the template. In addition, as the cured polymer strongly holds these nanowires in place, these surfaces showed reliability against abrasion, tape peel and solid weight impact. Also, the surface was superhydrophobic after dry heat, moist heat and UV exposure. The fabricated PDMS_Cu surface was tested against drug resistant E. coli, S. aureus and K. pneumoniae. The surface exhibited excellent antibacterial behaviour against all the drug resistant bacteria. Also, the PDMS_Cu surfaces were kept at several infectious places in the hospital. The flora count on the PDMS_Cu was lesser than the control surfaces showing its superior antibacterial property. The ability of the PDMS_Cu surface to support RAW Macrophage and HeLA cells proliferation was also evaluated using confocal microscopy by staining the cells with DAPI and tubulin. Both the Macrophage and HeLa cells attachment was found to be higher on the coverslip and PDMS substrates as compared to the PDMS_Cu surface which can be attributed to the superhydrophobic property of the PDMS_Cu surface. MTT assay method was also used to assess the cell metabolic activity. ~50% RAW macrophage and ~71% HeLa cells were found to be viable after an incubation period of 5 h. Taken together, these data confirm that the PDMS_Cu surface was not cytotoxic to the RAW macrophage and the HeLa cells. To demonstrate its application in healthcare, heartbeat sound recording was carried out via the PDMS_Cu surface. Good quality heart beat sound was recorded showing its plausible use as a thin covering on the stethoscope diaphragm to prevent the transmission of pathogenic flora from one person to another in the hospital.

Every surface studied in this work exhibits unique topography and surface chemistry and they can be used in several applications such as photovoltaic, high efficiency photo detector and sensors, water treatment, food packaging, health care etc.

Swathi Suran: Bright-field Nanoscopy

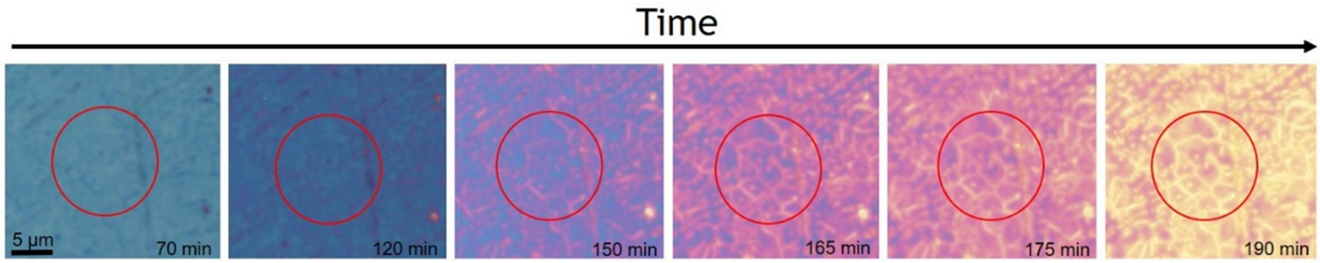
We present a technique which allows the visualization of nanoscale structures using a regular optical microscope without the need of any additional fluorescent tags. We refer to this technique as Bright-field Nanoscopy (BFN). The mechanism involves a device which works on the phenomenon of interference producing strong thickness dependent color response of ultra-thin films of Germanium on an optically thick Gold film. The Ge films get etched due to the dissolution of its oxide, GeO_2 in water. Any nanoscale object placed on the Ge device, impedes the transport of water to the Ge film resulting in a differential etch rates and consequently giving rise to a local color difference. The generated color contrast was significant enough to be picked up by any conventional optical microscope. Using this technique, we were able to directly image grain boundaries in single layer graphene and single metal nanoparticles. Additionally, this technique allows spatially resolved direct visualization of water transport through nanomembranes. For the first time, the odd-even effect known in polyelectrolyte multilayers (PEMs) was directly visualized. Further, we used this technique to directly image the nanoscale organization of the interpenetrating networks in polymer thin films.

(a)



1. Suran, S. *et al.* Bright-field Nanoscopy: Visualizing Nano-structures with Localized Optical Contrast Using a Conventional Microscope. *Sci. Rep.* **6**, 25011,(2016)
2. Suran, S et. al, Spatially resolved observation of water transport across nanomembranes using bright-field nanoscopy, Appl. Phys. Lett. 113, 043701 (2018)

(b)



(a) Schematic of the imaging mechanism (b) Evolution of the appearance of GGBs with time.

Velpula Balaswamy: Tunable, cascaded Raman fiber laser

Rare-earth doped fiber lasers are limited in terms of wavelength coverage and power scalability. Wavelength coverage is limited to the emission spectra of different rare-earth dopants around 1, 1.5 and 2µm wavelength regions based on Ytterbium, Erbium or Thulium/Holmium fibers. Power scalability is limited to only Ytterbium (Yb) emission window. However, there are numerous applications like LIDAR, free space optical communications etc. which require high power fiber lasers outside the rare-earth emission bandwidths. Currently, cascaded Raman fiber lasers is the only proven power scalable technology which offers wavelength diversity [1]. However, conventional systems lack wavelength flexibility due to the use of wavelength selective fiber Bragg gratings (FBGs) for wavelength conversion. Cascaded Raman fiber lasers based on random distributed feedback (RDFB) offer wavelength flexibility due to the broadband nature of both Raman gain based on SRS and RDFB due to Rayleigh backscattering. Recently, Raman fiber lasers based on random distributed feedback (RDFB) have been demonstrated [2]. In these systems, not just the Raman gain, but RDFB due to Rayleigh back scattering is also available at any arbitrary wavelengths, making them grating-free and wavelength-agile. However, the tunable lasers reported in these systems has been limited to a maximum output power of ~10W [3]. The primarily limitation is that, because the distributed feedback used is broadband, the cascaded Raman conversion cannot be terminated at the required wavelength at higher powers.

Recently, we have addressed this issue with the use of specialty Raman filter fiber (RFF) which terminates the Raman cascade at a fixed wavelength band as we reported in [4]. Here, we report a novel system, which can provide termination of the Raman cascade at any specific Stokes order and, coupled with a tunable input source with a range of at-least one Raman shift, enables power scaling at any arbitrary wavelength. We have used the standard grating free Raman laser architecture [10], but instead of a filter fiber for termination, a novel filtering scheme in the backward port is used.

With this system, we demonstrate high power, a continuously tunable cascaded Raman fiber laser, over a wide-bandwidth of >450nm, from 1118nm to 1575nm. Pump-limited output powers ranging from 8W at lower wavelengths to 33W at longer wavelengths have been achieved. This laser achieves the bridging of the Ytterbium to Erbium wavelength gap.

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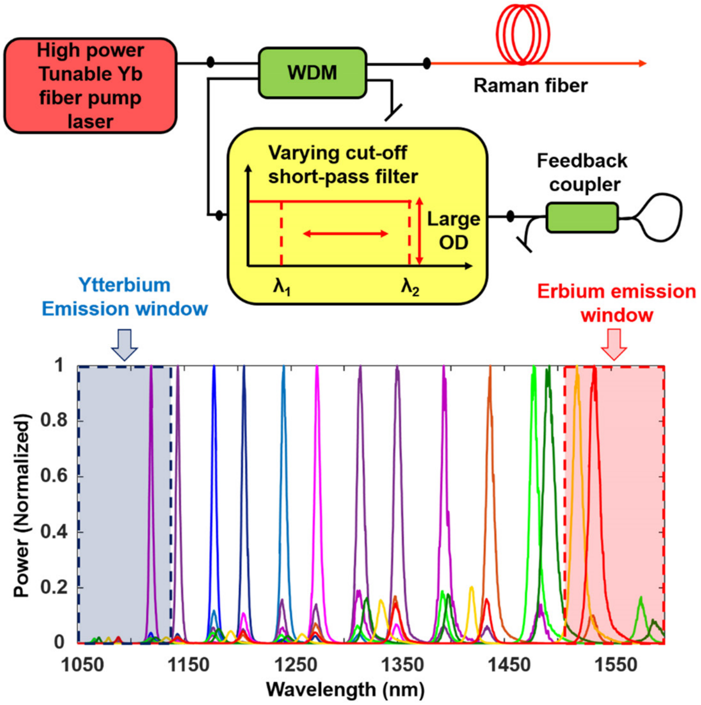

Graduation Day Ceremony: 2018

Namratha Nayak

As it happens at the end of every academic year, numerous students graduated from the Indian Institute of Science. CeNSE also had its fair share of graduating students this year. Although CeNSE is a commonplace for the most happening events on campus, it is the Graduation Day that everybody holds very close to their hearts. CeNSE has always proudly celebrated the graduation of its students. This year the event was to be held on the evening of 22nd June, 2018, following the Institute Convocation Ceremony in the morning.

CeNSE was decorated with colourful lights. The seating arrangements were made in the CeNSE backyard, under a huge, elegantly decorated makeshift tent. The aroma of piping hot delicious platter filled the area. The mementos, to be awarded to the achievers, were lined up next to the stage, overlooking the round tables where the guests were to be seated.

The CeNSE memento is considered a prized possession, as each memento consists of an in-house custom-fabricated SOI wafer, with the name of the graduating student alongside the iconic logos of IISc and CeNSE, etched on it. A write-up regarding the student's work is framed along with this SOI wafer and awarded to the graduates.

What enhances the glory of this day is that the students are provided a stage to share their journey, express gratitude, and provide valuable feedback to the department. The mentor professors in-turn say a few words about their experience with their students. These are indeed moments that will be cherished for a lifetime.

The graduating students, professors, and their respective families were welcomed to a beautifully lit department. The parents and spouses were eager to meet and greet the professors; the children running around, were having a gala time. There was excitement in the air.

CeNSE awarded a total of 8 students, with M.Tech degree. Krutikesh Sahoo, Jadhav Shubham Avinash, Rahul Goyal, Venkatanaga Prashanti, Sachin Kumar, Saravanakumar, Himanshu Kumar, and Amandeep Singh were conferred with the M.Tech degree.

CeNSE saw a total of 25 Ph.D. students graduate this year. All these students have achieved exceptional results in diverse topics under the umbrella of nanoscience.

Dr. G P Raghavendra Yasasvi has systematically tackled some of the long-standing problems in using CNT as a transistor beyond 10nm node technology, such as Schottky barriers at CNT-metal junction and n-type CNTFETs that are suitable for large scale fabrication. His work has major implications on CNT based logic circuits as well as on various applications using flexible electronics.

Dr. Prashanth has achieved significant performance improvements in silicon photonic resonators for biosensing, by extending the dynamic range and improving measurement resolution using a double ring configuration and dual harmonic detection of optical resonance. He also utilized on-chip temperature compensation, targeting drifts. His work allows for low-cost measurements using intensity-based measurements, as opposed to those using spectral interrogation.

Dr. Chandan Samanta has explored various aspects of nonlinearities in atomically thin resonators. This meticulous investigation of the phenomenon of internal resonance, resulting from interaction between the device vibrational modes, has been one of the main topics of his thesis.



Dr. Suman Pahal has demonstrated a technique which enables fluorescence imaging for the measurement of molecular transport in ultra-thin polymer films of the order of a few hundred nanometres. She used thickness dependent modulation of fluorescence intensity close to metal surface to extend these techniques into the nano-domain.

Dr. Debadrita describes a new strategy for integration of graphene onto gold and silver nano-antennas for highly sensitive photodetection of UV, visible and IR wavelengths. This method of integration allows tremendously strong concentration of light within the atomic layer. Apart from technology potential, this new device strategy can answer long standing fundamental questions in quantum plasmonics.

Dr. Emil M Joseph has conducted experimental research on quantum fluids, where he also devised a non-destructive method for trapping and probing multielectron bubbles. These objects allow tuning of electron interactions from non-interacting gaseous state, all the way to the strongly interacting Fermi liquid state. His work opens new avenues in the discovery of new electronic phases and phase transitions. This thesis is one of the first examples of experimental research in quantum fluids in India.



Dr. Pranay Mandal demonstrates independent control and self-propulsion of magnetic nano-swimmers. His system provides a new platform to answer fundamental questions in non-equilibrium physics and may lead to new control strategies for magnetic swimmers in biomedical applications.

Dr. Prasanna Kumar has developed a new strategy to design efficient membranes in terms of chemical resistance, cost and manufacturability; by blending two immiscible polymers like polyethylene (PE) and polyethylene oxide (PEO). One of the phases of the resulting morphologies can be selectively etched to fabricate porous structures. He has proposed different strategies to render the membrane surface antibacterial and to resist bio-fouling.

Dr. Shubhadeep has addressed the issue of limitations in scaling MOSFETs by demonstrating for the first time, an adaptable transport transistor architecture on MoS2, to beat the Boltzmann limit. This steep slope, high performance, sub-thermionic transistor, operating down to a voltage of 10mV, has opened up new vistas for future nano-electronic technologies.


Dr. Amiya Banerjee's research involving a combination of equipment development, thermodynamic modelling and challenging crystal growth research is a big step towards enabling the epitaxial integration of functional oxide materials with Si substrates.

Dr. Jayaprakash Reddy presents the first successful development of a MEMS gyroscope in India. He has fulfilled the dream of the strategic sector by carrying out hundreds of fabrication-runs for perfecting this indigenous technology.



Dr. Kranthi Kumar showed how to deposit MoS_2 over large areas by a true CVD method. The control over microstructure and stoichiometry described in his thesis is unprecedented and is expected to be a major step in the realization of MoS_2 device quality materials technology.

Dr. Abheek Bardhan showed that there are some empirical limitations to obtaining films with a combination of high Al-content, low surface roughness, zero cracking density and low dislocation density, due to the nature of the AlN-Si interface, all of which are requisites for enabling technology. His research is expected to play a key enabling role in the realization of UV detectors and power electronics both of which rely on AlGaN and its heteroepitaxial integration.

Dr. Ajay Dangi reports a complete development of PMUTs from design, simulation, material development, process development, device fabrication, to application development. His effort has led to first working PMUT devices from India.

Dr. Priyadarshini Ghosh has demonstrated methods of combining growth techniques of 2D materials and nano-particles, to result in performance enhancements in low dimensional materials that would impact the fields of plasmonics and thermo-electrics.

CeNSE also encourages students to actively interact with other departments by admitting them under its interdisciplinary research programme, in collaboration with departments such as materials engineering, aerospace engineering, chemical engineering, electrical communication engineering, etc. A couple of students from the interdisciplinary category who graduated this year include Dr. Ramesh Chintala and Dr. Saptarsi Das, who worked on architectures of different kinds of accelerators for computational applications, Dr. Ipsita Biswas who targeted accelerated pre-silicon verification of very large designs thorough a novel algorithm-architecture co-designed reconfigurable hardware system, Dr. Ashish Kumar Pradhan who designed an energy efficient, and dynamically reconfigurable baseband processing system for mobile and cognitive radios, Dr. Krishna who has applied specialized techniques for the development of novel nano-materials for the treatment of antibiotics and bacteria simultaneously in waste water, Dr. Janeni Natarajan who has developed a variety of biodegradable polyesters with tunable properties from affordable and renewable sources for drug delivery and tissue engineering, Dr. Anuj Bisht who provides crucial experimental and simulation inputs on energy being the basis for defect nucleation in materials subjected to shock waves, in contrast to the strain accommodation, Dr. Neeraj whose work brought out numerical robustness to systems/models exhibiting nonlinear parameter dependence with non-affine system matrices and excitations, Dr. Sherine Alex who worked on material and thin-film synthesis for solar applications and, Dr. Jagadish who has used a combination of experiments and numerical simulations to understand optoelectronic phenomena resulting in increased light absorption and electro-thermal mechanisms resulting in catastrophic damage in organic electronic devices, thus addressing the major issues dealing with performance enhancement and robust design of these devices.

As the cheery faced and teary eyed graduates shared their bittersweet memories of how they took challenges head on and achieved their successes, and how they would really miss the atmosphere at CeNSE and IISc; their peers and families proudly recorded these moments. These students left their mark in nano-science academia, while taking back a part of CeNSE with them. CeNSE indeed stands proud.

It so happened that Prof. Rudra Pratap's birthday was also on the very same day. The event culminated with the sweet taste of cake, as we gathered along with his family to celebrate his birthday.

CeNSE looks forward to celebrating its next graduation day with just as much cheer, along with a fresh set of bright graduates.

ISTEM: A POWERFUL NEW INITIATIVE

The Origin:

One day in October 2017, Prof. Navakanta Bhat, the Chair of our Centre, received a phone call from Dr. R. Chidambaram, Principal Scientific Advisor (PSA) to the Govt. of India (GoI). He said, "I would like you to take up an important national project, our office will support it". The answer could only be "Yes"! "Please tell me, Sir, what this project would be about". The PSA described how he had come to know of the initiative taken by the INUP office at CeNSE, under which the INUP web portal displayed a database of hundreds of pieces of equipment and facilities procured and installed at the home institutions of INUP participants from around the country. All such equipment had been obtained through funding from agencies of the GoI. So, the PSA thought that a natural extension of the idea would be to have a National Web Portal listing all public-funded equipment and facilities at all institutions/organization in the country, so that any interested and qualified Researcher/User could have access to them, through the portal.

The Indian Nanoelectronics Users Program (INUP) has been a highly successful outreach program of CeNSE. Funded by the Ministry of Electronics and Information Technology (MeitY, GoI), INUP has been "on" for a decade now, with thousands of aspiring researchers trained at CeNSE in workshops held regularly, many of whom have conducted ambitious research projects using the state-of-the-art facilities at CeNSE. During one of the workshops in 2016, Dr. Sanjeev Shrivastava, then the INUP Coordinator, began gathering data from the participants on the R&D equipment running in their respective institutions, explaining to them that they could think of forming "regional facility networks" that could benefit everyone. The participants shared the data eagerly, which was displayed on the INUP web portal in mid-2017, catching the attention of the PSA.

Thus was born the Project funded by the Office of the PSA, with the name I-STEM chosen by Prof. Bhat standing for Indian Science, Technology and Engineering facilities Map. The very ambitious goal of the three-year project is to set up a web portal that lists all functioning, publicly funded R&D equipment and facilities in institutions and organizations – public and private – around the country, so that access to them would be available to researchers and other professionals needing to use them, in a transparent manner through a secure Web Portal (https://www.i-stem.ac.in/).

The Motivation: To Shift the Paradigm

It has always been the basic tenet of the Government of India, in generously funding R&D efforts at academic institutions over the decades, that facilities established through such support be made available to those needing them and qualified to make use of them for their own research work. However, this has never been easy or straightforward for, among other reasons, there was no ready source of information of what facility was available and where. Thanks to the Web, it is much easier today to have a national and regional "inventory of resources", so as to match Users with the resources they need, and to do all this in an efficient and transparent manner. This can lead to a leap in R&D productivity and greatly enhance the effectiveness of public investment. This is the motivation behind I-STEM. Hence the I-STEM motto, "Linking Researchers with Resources".

The Mechanism:

The I-STEM Web Portal is the gateway through which Users would be able to locate the specific facility(ties) they need for their R&D work and identify the one that is either located closest to them or available to them the soonest. Through recent directives of the GoI (UGC, MHRD, DST, MeitY, ICAR), institutions that have procured and installed R&D facilities with funding from the agencies of the GoI are now required to list them on the I-STEM Portal (which will be regularly updated). More than 3000 eqpt./facilities at some 70 institutions are already listed on the Portal. Either through the I-STEM Portal or the web site of the organization which is the custodian of the desired facility, a User will be able to make a reservation for using it, as per a mutually convenient schedule. To enable the running and maintenance of the resources, the organization may prescribe a User Fee, which depends on whether the User is from the academia, a public institution, or from industry. A Panel of Experts will be formed over time to help Users (via the Web) to make the most informed use of resources made available through I-STEM, by seeking answers, clarifications, and learning of best practices.

The Goal and the Prospects:

It is the goal and the expectation of the I-STEM project that ALL public-funded and functioning eqpt. and facilities in institutions and organizations (open to the public) would be listed on the I-STEM Portal and that All of them would be made available by their custodians to Users needing them, in a mutually convenient manner, through reservations made via the Portal. The "Pay and

Use" model that will be implemented is intended to help in meeting at least part of the cost of operating and maintaining the facilities.
The sharing of facilities through I-STEM is expected to increase their utilization, thus enhancing the effectiveness of the considerable public investment in them. Over time, therefore, the approach can result in minimizing duplication of equipment and facilities, which occurs now not only within institutions, but even within departments. The Portal would be able to gather usage statistics which, in turn, can aid funding/investment decisions. In addition, the Portal would, for the first time, contain an up to date inventory of facilities funded by the various agencies of the Govt.
Even more importantly, the I-STEM has the potential to inculcate a culture of collaboration among researchers, regionally and nationally. Over time, such collaboration can contribute greatly to technological development in the country by enabling scientists and engineers from even the remotest and the smallest institutions to pursue their ideas and bring them to fruition, as they would now have access to all the facilities they need.
Recognising the importance and potential impact of the "idea of I-STEM", articles have appeared in the national news media (e.g., https://www.hindustantimes.com/lucknow/coming-soon-online-national-network-to-help-researchers/story-91dRjESq4pCkurb7nGpPWI.html). It is hoped that, in a few years' time, the "culture of sharing" will sweep through the country's R&D community, benefiting the nation as a whole.

Relevant articles:

The Hindustan Times on 13th April 2018
https://www.hindustantimes.com/lucknow/coming-soon-online-national-network-to-help-researchers/story-91dRjESq4pCkurb7nGpPWI.html

The Hindu on 19th April 2018
http://www.thehindu.com/todays-paper/tp-national/national-portal-to-share-research-facilities-soon/article23597100.ece

Science Chronicle
https://journosdiary.com/2018/04/19/portal-research-equipment-facility/

Aspirant World
http://aspirantworld.in/2018/04/20/national-portal-to-share-research-facilities-soon/

The Bangalore First
http://www.bangalorefirst.in/?p=29291

New Tools and Facilities at MNCF

Dr. Suresha

In the month of July, 2018, a new Atomic Force Microscope was introduced to Mechanical Bay of MNCF, CeNSE.

Park Systems, South Korea was very generous to kindly donate an AFM - Park Systems NX20 - to MNCF housed at CeNSE.

Park Nanoscience Lab was inaugurated on 25th July, 2018 by Dr. Sang-Joon Cho, the Chief Scientist and Director of R&D department at Park Systems, Korea and Prof. Navakanta Bhat, Chairperson, CeNSE.

The Park Nanoscience lab was declared as a National facility.

A seminar was conducted on 'Recent Advances in Park AFM Technology and its applications' where Dr. Sang - Joon Cho and T.K Chin delivered talks on various advances in AFM technology. The event was attended by various delegates from Park Systems - Korea, Icon Analytical India Pvt. Ltd, Faculty, MNCF committee members and researchers from various departments at IISc. A demonstration of the AFM instrument was also conducted by experts from Park Systems, Korea.

In the photo, mementos being awarded to delagates from Park Systems by Prof. Navakant Bhat (left) and Prof. Akshay Naik (right)

Capabilities of Park NX20 housed at MNCF

- Contact, true Non-Contact, and dynamic force modes used for surface roughness and topography measurements.
- Electrostatic Force Microscopy (EFM) , Piezo Force Microscopy (PFM), Scanning Kelvin Probe Microscopy (SKPM) for Electrical Measurements
- Force Modulation Microscopy (FMM), Force Distance Spectroscopy (F-d), Lateral Force Microscopy (LFM), Pinpoint spectroscopy for Mechanical Characterization.

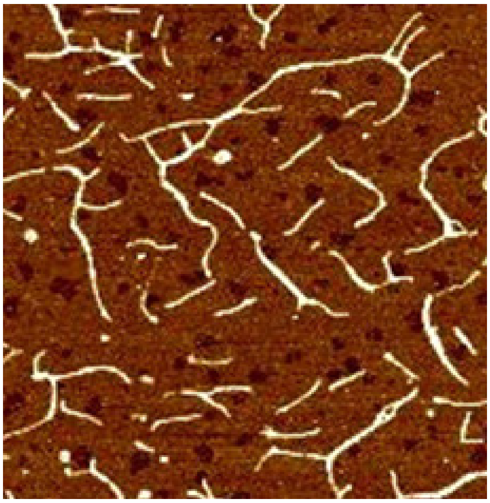

Figure 2. DNA Bundles on Mica (Top)

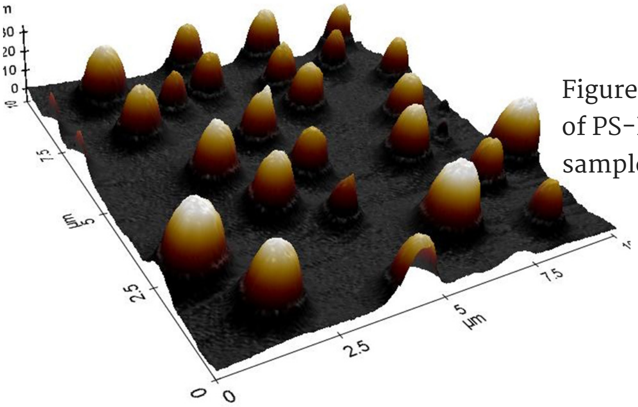

Figure 3. 3D rendering of PS-LDPE composite sample(Left)

"Park Systems AFM boasts of its capability in very high accuracy in measurements. The initial scans look very promising."

New Tools and Facilities at NNFC

Dr. Vijayraghavan

Leybold , UNIVEX 400 housed at NNfC Thin films bay

UNIVEX 400 is an E-Beam multi-purpose experimentation system by LEYBOLD for research and development.

Features include:
A Six pocket hearth of 20 cc to evaporate different materials (Metals and Oxides) individually or as stack without braking vacuum usually at 3×10^{-6} Torr. Also, the tool is equipped with an Ion source for ion assisted depositions. A 6 inch substrate holder which could hold samples of smaller size to max of 6 inch substrate with heating capability of 300 C with/without rotation for uniform film depositions. It comes with a single electron source which can be controlled to yield point beam heating and distributed beam pattern heating helps in controlling deposition rate as low as 1A/Sec, monitored with the help of Quartz crystal monitors.

All the above parameters are run sequential/steps (recipes) are controlled and monitored using a GUI.
Materials that can be deposited: Al, Ni, Ti, Au

Micro and Nano Fabrication and Characterization Conference

Dr. Savitha

Recent years have seen a serge in Micro and Nanofabrication and Characterization facilities across the country under various government umbrella programmes. There is therefore a need to identify a forum to share experience catering specifically to the management of such facilities. CeNSE, being in the forefront of such activity, has initiated and conducted the first Micro and Nanofabrication and Characterization Symposium which aims to bring together expertise in the operations and management of cleanroom and characterization facilities across educational institutions, strategic sector labs and industrial facilities. The symposium endeavours to be a platform to discuss best practices, maintenance protocols, workforce development, facility management, and resolving issues in running these specialized facilities. Conducted on the 11th and 12th of July 2018 at IISc, the symposium is attended by 60 invited members from across the country. The symposium was inaugurated by Dr. Milind Kulkarni, Head, Swarna Jayanti Fellowship Cell, DST. Prof. Anil Kumar from Physics Department, IISc, started the session by elaborating on the painstaking exercise that it took to realize CeNSE cleanroom. Very insightful talk on utilities management was delivered by Dr. Vikas Trikha from Semi-Conductor Laboratory (SCL) Chandigarh. Over two days a broad range of facility related topics like Building management systems, Utilities management, user safety, equipment maintenance and tool vendor interactions were discussed. Networking in smaller groups was organized to discuss in-detail on specific issues like tool maintenance, stocking of spares and consumables and vendor service experience. The symposium was very well received by participants and all agreed that this symposium should continue annually. Everyone expressed a need to establish user community network across the country to share facility related issues. The symposium concluded with panel discussion stressing on continuing the efforts and taking the forum forward.

IEEE Nanotechnology Summer School

Prabhat Vashishth

A 5-day Nanotechnology Summer School ***"Nanotechnology: From Science to Systems and beyond"*** was organised by the IEEE Nanotechnology Council- Sensors Council Joint Student Chapter (IEEE NC SC JSC) at Centre for Nano Science and Engineering (CeNSE), Indian Institute of Science (IISc) Bangalore, India from June 16-20, 2018. Over 90 people, from across the world, participated in the event comprising of 25 academicians and 67 students. The summer school successfully provided a platform for interested students/professionals to interact and learn about the latest developments in the field of nanotechnology. With over 24 invited talks, each day of the Summer school was dedicated to a unique field of research buzzing with innovations. Hands-on training session were also organized each day to acquaint the participants to the state-of-the-art nanofabrication and nano characterization facilities at our centre. The participants gained knowledge through seminar talks from scientists pioneering in the said field of research and through intricately designed hands-on sessions for better understanding of the topics discussed. IEEE NTC Summer School 2018 started with a grand ceremony with inauguration speech from Prof. Rudra Pratap representing IEEE Bangalore section, Dr. M.N.Kumar representing IEEE Nanotechnology Bangalore Section, Prof. Navakanta Bhat and Prabhat Vashishth representing IEEE NC SC JSC. The importance of Nanotechnology in today's world was emphasised with special mention about IEEE Nanotechnology activities in India and abroad.

Day 1 was dedicated to Nanoelectronics with the first talk by Prof. Navakanta Bhat on "Tunable Steep Slope MoS2 Transistors", followed by Prof Digbijoy Nath's talk on "GaN based High electron Mobility devices". Prof. Ayushman Sen from The Pennsylvania State University gave an enriching, interactive and enthusiastic talk on nanoscale machines and their applications. Final talk of the day was by Dr. Vinay Kumar, a CeNSE alumnus and co-founder and CEO of Pathshodh Healthcare, a start-up incubated at IISc., about his PhD work and how it got translated into a product. With question and answer sessions after each talk all the participants actively participated in all the sessions.

Dr.Meyya Meyappan, NASA Ames Research Centre, had the first talk on second day of Summer School on "Beyond Moore's Law". He described about the Roadmap for beyond Moore's law era with discussion on two emerging area: nanoscale vacuum electronics and printed electronics.

Then Prof. Masahiro Yamaguchi,

Tohuku University spoke about "Soft Magnetic Thin Film Applications based on Nanotechnology". This lecture began with a review of nano-structure controlled soft magnetic material covering nano particles and sputter-deposited thin films. Then thin film applications at radio frequencies was discussed for future system-in-package (SiP) and system-on-chip (SoC) technologies. The stage was then handed over to our next speakers from Russia, Dr. Victor Koledov and Dr. Svetlana Gratowski. They gave an amazing talk on new functional materials and shape memory alloy nano-gripper. The day ended with a talk on "Moore's Law and beyond" by Dr. M.N. Kumar, Aquantia.

Third day was dedicated to Nano-Photonics and started with an enthusiastic talk by Prof. Gururaj Naik from Rice University on hot Nano-Photonics. It was followed by Dr. Varun Raghunathan's interactive talk on non-linear optical microscopy. Next were lectures by Prof. Shankar Selvaraja and Prof. V.R. Supradeepa from CeNSE, IISc on Photonics Integrated Circuits and High Power Lasers respectively. The day Ended with an industrial talk by Dr. Vasan Sambandamurthy from Biocon on Anti-Microbial Resistance. We also had a special lecture by Prof. Rudra Pratap focussing on how to choose a career path in research and the students thoroughly enjoyed the vivacious and zealous interaction with Prof. Pratap.

Fourth Day was dedicated to NEMS/MEMS with lectures from CeNSE faculty members. Prof. Srinivasan Raghavan had an interactive session on nanomaterials, followed by Prof. Rudra Pratap's talk on cricket-inspired MEMS speakers. Then Prof. Prosenjit Sen gave a talk on antibacterial super-hydrophobic devices and cell squeezing using air-liquid interface followed by Prof. Sourabh Chandorkar's talk on dissipative mechanisms in MEMS devices. Final talk of the day was by Prof. M.M. Nayak on Advanced MEMS Sensors for Aerospace Applications. Final Day was dedicated to Nano-Biotechnology and started with a talk by Prof. Thomas Thundat from SUNY Buffalo on Recent Advances in Nano-Mechanical Biosensors. Then Prof. Ambarish Ghosh, IISc gave a different perspective on the subject through his talk on Magnetic Nano-Swimmers for Biological Applications, followed by Prof. Manoj Varma and Prof Akshay Naik's talk on Biosensors in NEMS. Lastly, Hands-on sessions everyday included demonstration of fabrication techniques and hands-on experience on high end characterisation tools.

The sessions comprised of sessions on microwave synthesis of nanomaterial and characterisation of Gallium Oxide (Ga_2O_3) using SEM and XRD, 2D transistor fabrication and characterisation, design, fabrication and characterisation of micro-ring resonators, MEMS Cantilever fabrication and characterisation using LDV and superhydrophobic surface fabrication and drop impact characterisation using high Speed camera.

The summer school received great feedback from all the participants and the organization as well as the content was appreciated by one and all. The participants found the five-day event refreshing and inspiring. The delegates were impressed by the highly successful research in nanotechnology and were delighted to have a first-hand experience of it.

VISITORS TO CENSE

Mr N Chandrasekaran, Chairman, Tata Sons (13th April 2018)

Parliamentary Committee on Science and Technology (3rd July 2018)

Mr V L V S S Subba Rao, Senior Economic Advisor, MHRD (23rd July 2018)

Mr K J George, Minister of Industry, IT, BT, Science and Technology, Government of Karnataka (6th August 2018)

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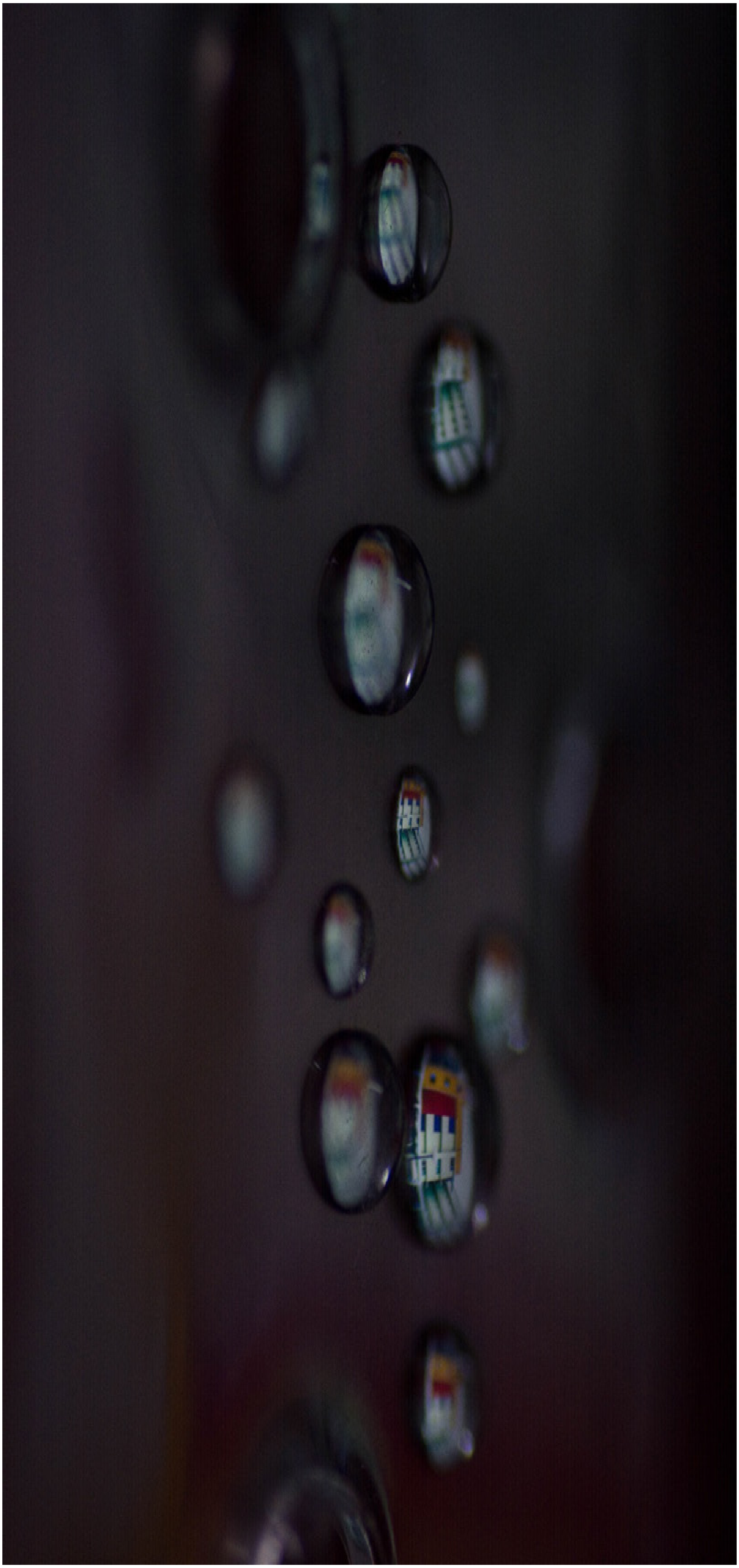

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