PressCeNSE

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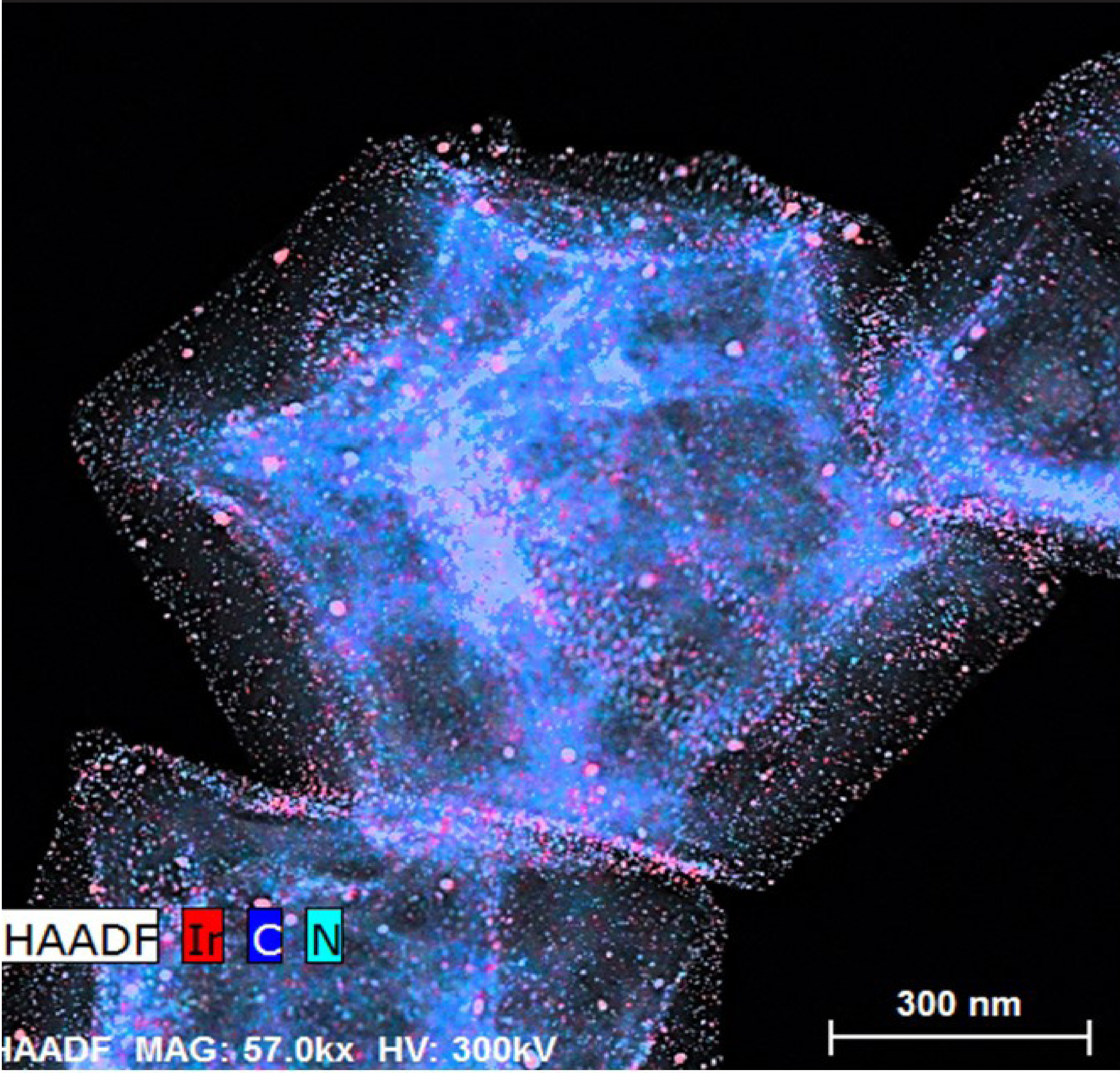


Centre for Nano Science and Engineering (CeNSE)

Indian Institute of Science

CONTENTS

Cover photo: IRC on Carbon Film; EDS Mapping in STEM by Ambresh M. Sample Courtesy: Debanjan Das, MRC.

MESSAGE FROM THE CHAIR

With this issue of PressCeNSE, we present to you recent updates on a variety of topics ranging from research highlights, outreach activities and events conducted during the last quarter.

We have been able to continue our outreach activities under INUP banner, to train research scholars and faculty from academic institutes around the country, thanks to the support provided by MHRD. The program has now become broader to include training and mentoring in all aspects of nanoscience and nanotechnology. Mr. V.L.V.S.S. Subba Rao, Senior Economic Advisor, Department of Higher Education, MHRD, GoI, inaugurated the workshop on 14th May, and stressed the need for building critical mass of well-trained researchers who can then contribute in building technologies for societal impact.

Towards amplifying our efforts to impact healthcare technologies through the intervention of nanoscience, we have now partnered with Rajiv Gandhi University of Health Sciences (RGUHS), to which most of the medical colleges in Karnataka are affiliated. Three workshops have been planned this year, to train clinicians from RGUHS on nanoscience and nanotechnology relevant to medical research. The first such workshop, focussed on clinicians from Ayush stream was a great success, which is now enabling new research interactions between CeNSE and RGUHS.

With a continued focus on internationalization, we have started a new partnership between IISc and TU Dresden, led by CeNSE, with a research focus at the interface between nanoscience and life science. The program supported by DAAD, within the framework of the German government's program on "Internationalization of German Universities", enables exchange of research students and faculty in the next few years. We hope to leverage this program to build new joint research projects between the two institutes.

We also present to you the star employees among our technical and administrative staff members, through a brief update on the annual employee of the year award function. I take this opportunity to congratulate all of them again, for their exceptional performance over the last year. It is only due to such committed and talented staff in the CeNSE family, that we are able to scale greater heights in all our endeavours.

-Navakanta Bhat

What's new in research at CeNSE?

Reversible Defect Engineering in Graphene Grain Boundaries

Krishna Balasubramanian, Tathagatha Biswas, Priyadarshini Ghosh, Swathi Suran, Abhishek Mishra, Rohan Mishra, Ritesh Sachan, Manish Jain, Manoj Varma, Rudra Pratap and Srinivasan Raghavan

The prospect of using graphene as a channel material for RF transistors and interconnects, has recently garnered much attention. Efforts are being made for improvements on the material and device front. Graphene-based devices can be processed in two ways: 1) exfoliation of a monolayer onto a target substrate 2) transfer of large-area CVD graphene onto a dielectric substrate. The graphene flakes or layers obtained by the former method are limited in size and in the yield of the layers. The CVD-based method conditions the presence of carbon atoms from catalytic decomposition of methane on copper surface leads to nucleation of discrete grains comprising a hexagonal lattice of carbon atoms, which coalesce together to form a monolayer of polycrystalline graphene. Hence, grain boundaries and triple junctions that are a part of any polycrystalline material are also present in large area monolayer graphene. These intrinsic defects result in scattering of both electrons and phonons, which results in the reduction of overall

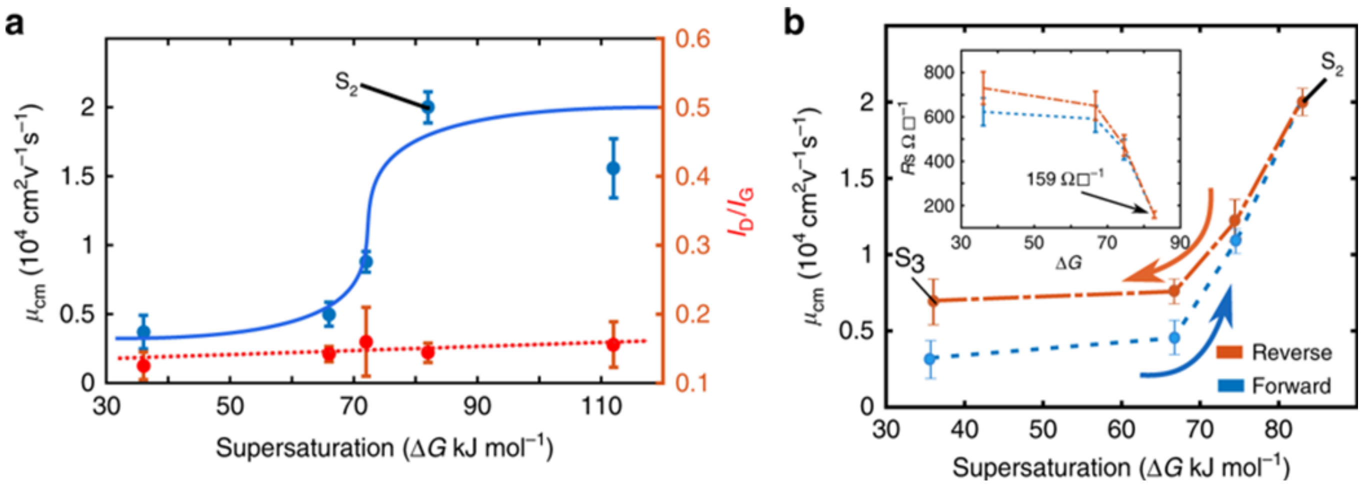


Figure 1: a) Effect of annealing a monolayer of graphene under increasing supersaturation (ΔG) on mobility (μ) and Raman ID/IG ratio. Mobility is seen to increase significantly with supersaturation and then saturate. The averaged defect density as measured by Raman is insensitive to this change b) Reversal of mobility on reversal of supersaturation, indicating that the phenomenon is thermodynamic in origin and not kinetic.

gives a high-yield and technologically feasible way to large-area fabrication. CVD growth of graphene and its subsequent transfer onto a target substrate are two crucial process steps in realizing high-performance and robust technology. After CVD growth of monolayer graphene on copper substrate was invented, a plethora of modifications and improvements on the original technique have been reported. The CVD growth of graphene is carried out by catalytic decomposition of methane over copper at temperature ranging from 1000 to 1070 °C. Under thermodynamically favourable mobility and thermal conductivity. Consequently, large and well stitched grains are required for efficient electrical and thermal transport. The size of the discrete grains is decided by the nucleation density, which in turn is fixed by the partial pressure of methane. Research efforts in large area graphene synthesis have been focused on increasing grain size. Intrigued by the nature of defects in a monolayer of carbon atoms, we decided to explore the possibilities of engineering their properties as per the demands of application. Through a recursive cycle involving material growth, device fabrication and electrical measurements, the existence of a thermodynamic correlation between the vapor phase chemistry and carbon potential at grain boundaries and triple junctions was discovered. The experimental findings were also corroborated by first-principle calculations. Specifically, we found that the configuration of grain boundary defects in graphene monolayers has a thermodynamic relationship with carbon potential in the vapor phase. This relationship allows one to control grain boundary structure. An important implication of the thermodynamic correlation is defect or grain boundary engineering. The control lever provided by thermodynamic parameters can be used to anneal the boundaries or incorporate defects at the boundaries. The defects in a monolayer of graphene, grown at a certain supersaturation, can be healed or created by changing the post-growth supersaturation. The resulting large variation in grain boundary resistance allows the field effect mobility in graphene monolayers to be changed by more than an order of magnitude, from 1000 cm2/V-s to 20,000 cm2/V-s, the best reported yet for such large device sizes. All these improvements on the monolayer happen in a regime in which Raman and SEM characterizations are insensitive to the changes occurring in it. Hence, to supplement the electrical transport measurements, water permeation measurement technique is used to identify and spatially locate the incorporated changes in the monolayer. Water permeation experiments show that changes are localized to grain boundaries. The results highlight the importance of grain boundary closure in obtaining graphene with the best of electronic properties over large areas, in the regime in which the yields of increasing grain size start diminishing. In addition, there are many applications that can benefit from the controlled introduction of defects at graphene boundaries. These include the ability to control molecular permeation and sensitivity to various chemicals. The study also shows that grain boundaries might be as important as, if not more important than, grain size in graphene. Such thermodynamic control is essential to enable consistent growth and control of two-dimensional layer properties over large areas. [*The detailed research-findings have appeared in Nature Communications, volume 10, Article number: 1090 (2019) [https://www.nature.com/articles/s41467-019-09000-8], published by the Nature Publishing Group.*]

NANO-DEVICES AND SENSORS LAB

Tungsten Disulphide Nanosheets for high performance Chemiresistive Ammonia gas sensor

Neha Sakhuja, Ravindra Jha and Navakanta Bhat

With the advent of nanoscience and nanotechnology, numerous gas sensors have been demonstrated to detect ammonia (NH3) for a variety of applications in environment monitoring, industrial safety, and the biomedical sector, to name a few. These sensors are mainly based on electrochemical, optical, and chemiresistive transduction principles. However, electrochemical based sensors are prone to electrode poisoning, whereas optical ones incur

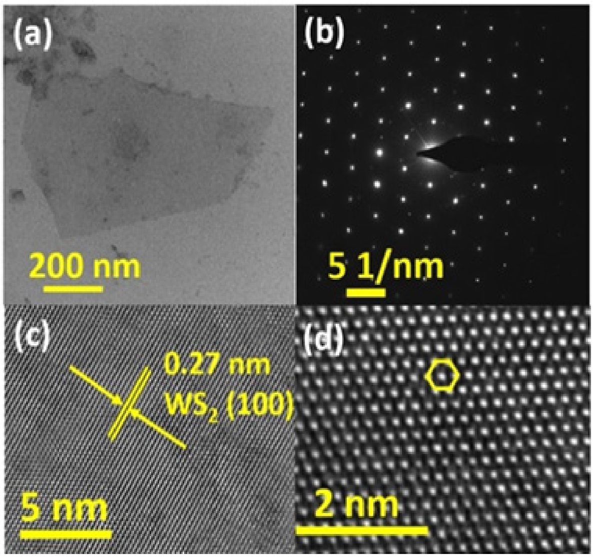


Fig. 1 (a) Low Mag. TEM Image (b) SAED pattern (c) HRTEM (d) Atomic resolution TEM

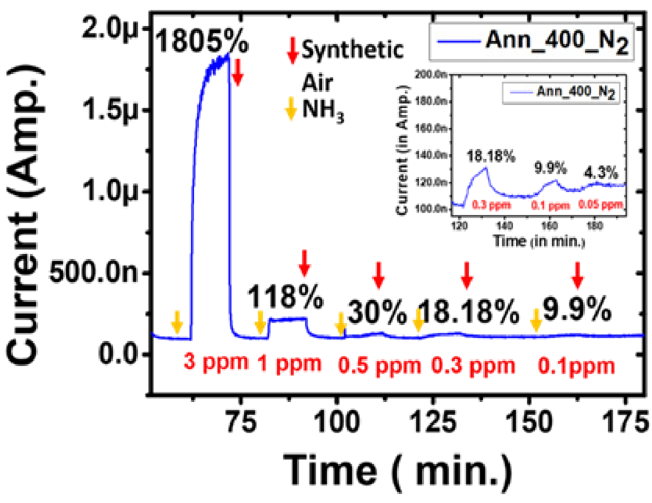


Fig. 2 Transient gas sensing response towards the concentration range of 50 ppb to 3 ppm of Ammonia (NH3)

huge manufacturing costs, along with zero miniaturization potential. Commercially available table-top equipment like GC-MS can span the lower concentration range, but are bulky, expensive, and cannot be used for in situ detection, which is very desirable from the biomedical perspective. Over the last few decades, metal oxide chemiresistive gas sensors have been extensively exploited due to their simplicity, ease of use, ruggedness and cost effectiveness. However, the quest for gas sensing material alternative to these established classes of materials is still on. Recently, a new class of 2D materials, i.e., transition metal dichalcogenides (TMDs) have gained attention for developing gas sensors owing to their high surface-to-volume ratio and tuneable band gap of around 1-3 eV. These TMDs being layered in nature, can be exfoliated into high aspect ratio nanosheets.

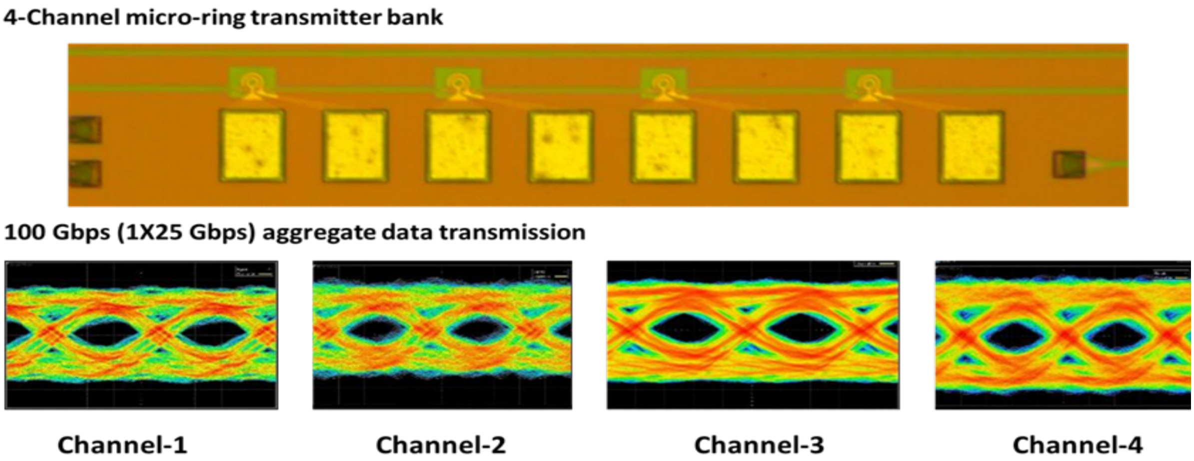
We have demonstrated liquid-exfoliated WS_2 nanosheets as receptor in chemiresistive sensors with Ti/Pt interdigitated electrodes (IDEs) as transducers. Successful exfoliation is evidenced by the low mag. TEM micrograph [fig 1(a)]. The atomic-resolution image [fig. 1(d)] stands testimony to the unaffected lattice symmetry of the WS_2 hexagonal crystal. The sensor fabricated exhibits a remarkable response of 1805% towards 3 ppm of NH_3 and can be used to span a concentration range from 50 ppb to 3 ppm at an operating temperature of 250 °C, as evident from the experimental results shown [fig. 2]. The limit of detection (50 ppb) for NH_3 achieved experimentally makes it a probable candidate for use in disease diagnostics.

PHOTONICS RESEARCH LAB

Photonics integrated circuit for next-generation wireless communication

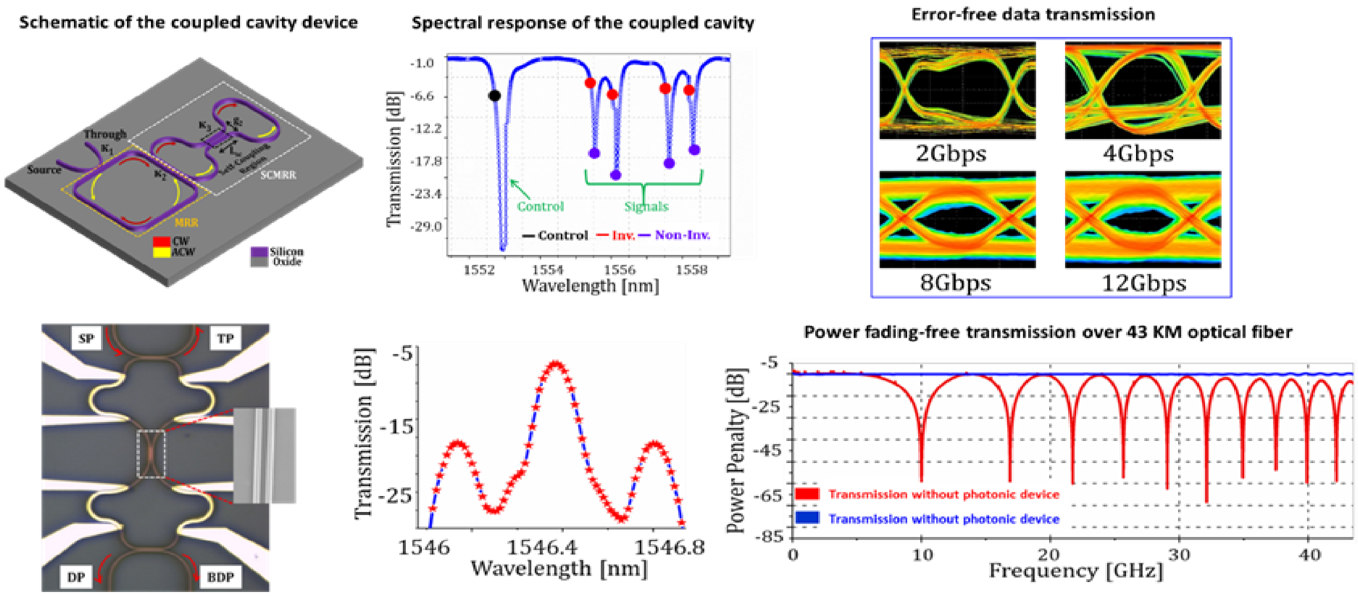
Awanish Pandey and Shankar Kumar Selvaraja

Demand for data and information transfer is growing exponentially, particularly, with the increase in mobile devices. Optical fibre communication has been meeting the demand at the network backbone; however, the last-mile distribution is primarily done through the wireless network. The need for higher data rates at the user end is achieved by updating wireless technology generations: 2G to 4G. Wireless technology of the future (5G and beyond) requires fundamentally different architecture and higher frequency to meet the rising demand. The technology would essentially use smaller cell/coverage size with high capacity; theoretically 300 Mbps per LTE-device. To achieve the desired quality of service, coverage and capacity, a fundamental change in network infrastructure is inevitable. The traditional microwave signal transmission is done either through co-axial cables or antennas. In both cases, increasing frequency would result in very high signal attenuation. An alternative approach is to use optical fibres to directly transmit upconverted high-frequency signal through optical fibre for signal distribution to individual cell towers. Transmitting radio-frequency-over-fibre (RoF) is an emerging area of technology to



meet future communication needs.

Communication through optical fibre offers many advantages, including, low loss transmission over kilometres, scalable bandwidth, low cost of ownership and immunity to electromagnetic interference. Though RoF provides many advantages over direct RF transmission, there are a few challenges. A team of researchers from the Photonics Research Lab at CeNSE is developing a cutting-edge solution to address these problems. The core of the technology is the use of silicon photonic integrated circuits to implement optical signal processing of the RF signal.



Three key elements in an RoF are a transmitter, an optical signal processor and the receiver. In a fully integrated circuit, all three components are fabricated and combined in a single photonic IC. Signal transmitters essentially do electric to optical conversion (E/O) whereas the receiver does the optical-to-electric conversion (O/E), which is achieved by using an on-chip high-speed electro-optic modulator as a transmitter and high-speed photodetector as a receiver. We have demonstrated an electro-optic bandwidth of 50 GHz for both transmitter and detector. The technology offers a scalable solution for the next generation wireless technology, which is still evolving in frequency band allocation (3.3 GHz, 3.4 GHz, 24-40 GHz). While signal generation and detection is one part of the integrated photonic solution, transmission and signal processing play an important role in establishing the desired system performance.

The optical carrier with RF signal is transmitted through an optical fibre between nodes that might be separated by a km or tens of km. One of the issues with such transmission is frequency dependent power fading along the length of the fibre due to chromatic dispersion. By using on-chip optical filters, we generate a single-sideband signal that evades the power fading problem. We have developed a novel filter with a tunable bandwidth of over 400 GHz for fading free signal transmission over any length and at any frequency. Furthermore, in addition to routing of signals to the desired coverage area, control and network management communication strategies are essential. To establish such a management scheme, identical signals should be communicated to the desired number of coverage areas. Using silicon photonic coupled cavity device, we have demonstrated wavelength multicasting architecture capable of copying a control signal onto four optical carriers with an aggregate data rate of 48 Gbps.

Integrated photonics offers an energy efficient and scalable solution for next-generation wireless communication. The ability to construct and integrate various optical function on-chip is exploited as a powerful tool. These demonstrations make an encouraging trend towards photonics-enabled next-generation wireless communication.

FACILITY UPDATES

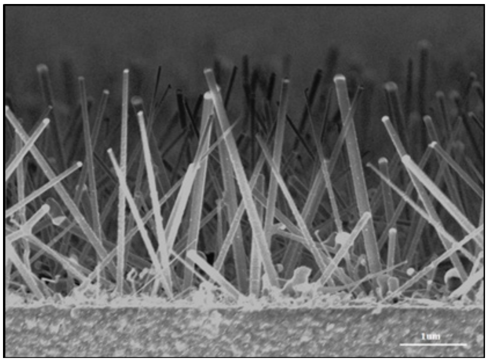
NATIONAL NANOFABRICATION CENTER

Savitha P

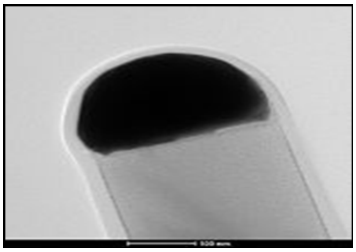
The National Nanofabrication Centre at CeNSE is a CMOS/MEMS/NEMS- capable facility, fully equipped with tools needed for the development of micro- and nano-scale devices with novel properties. Technology development is a major thrust area for the centre and new processes are constantly being developed deploying a full spectrum of capabilities. The following provides an overview of the fabrication processes and features recently added to NNfC's repertoire.

Vertical Silicon Nanowires

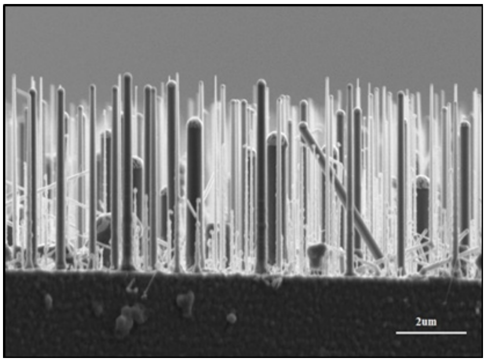
Undoped and doped (p- & n-) SiNWs were grown via VLS mechanism by LPCVD using Au as catalyst and diborane and phosphine as dopant gases. Long nanowires (10-26 µm) with well controlled diameters were obtained uniformly over 100-mm wafers.



Cross sectional SEM micrographs of undoped SiNWs

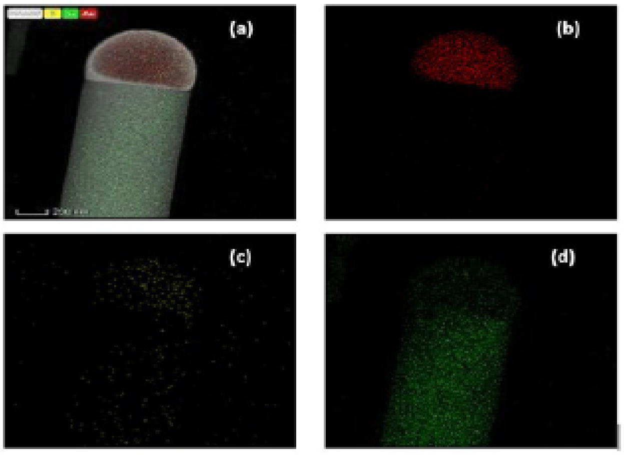


TEM image of a single p-doped silicon nanowire



Cross sectional SEM micrographs of p- doped SiNWs

The p-doped silicon nanowire consists of a thick crystalline Si core with (111) growth direction and an amorphous silicon outer shell of approximate thickness of 30 nm. The distribution of silicon, Au, and boron in the nanowire can be seen clearly from STEM HAADF images. It is also evident from the image that the content and distribution of boron is uniform in the SiNW.



STEM HAADF images of boron doped SiNW for B2H6 flow of 10sccm (a) color mapping image of single doped nanowire and its elements distribution on the nanowire (b) gold nanoparticles (c) Boron (d) Silicon

Large area patterning using E-beam Lithography

EBL is key contributor in nanotechnology research and development owing to flexibility available with maskless, direct writing of features down to 50nm. However, writing strategy still involves stitching fields together, which results in stitching errors at each intersection of a writing field. These errors pose challenges in specific applications, such as in photonics, where stitching errors introduce losses in optical waveguides.

Among several methods used to reduce stitching errors, FBMS or Fixed Beam Moving stage (now named as Traxx) is one method where the stage is moved with respect to set design, while the e-beam is deflected in a circular motion. This method allows the user to fabricate millimetre-long photonic wires and circular paths without stitching error. Further enhancing on the same modulation of beam during stage movement, beam deflection is not restricted to circular motion, but the beam path can be as per the design pattern fed to the Raith Nano Suite software. Using this, a large area of uniformly pitched gratings can be exposed with very high accuracy over millimeters. [Images 1, 2]. With further optimization of user defined pattern definition, it has been possible at NNfC to expose periodic structures well below 100nm in extent. [Image 3]

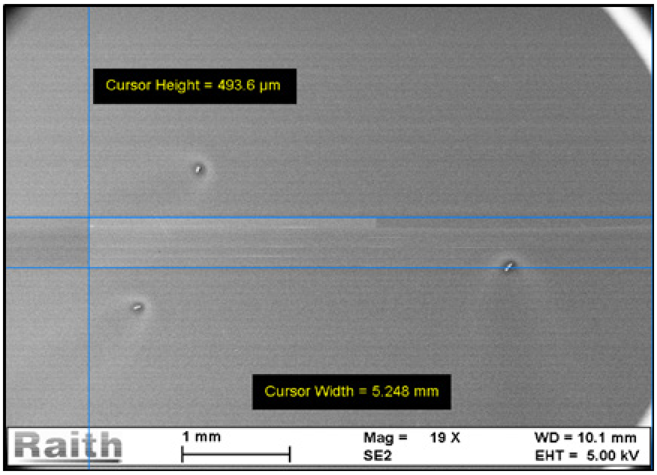


Image 1: Magnified image of the gratings section, showing Line/ spacing of 100nm/200nm.

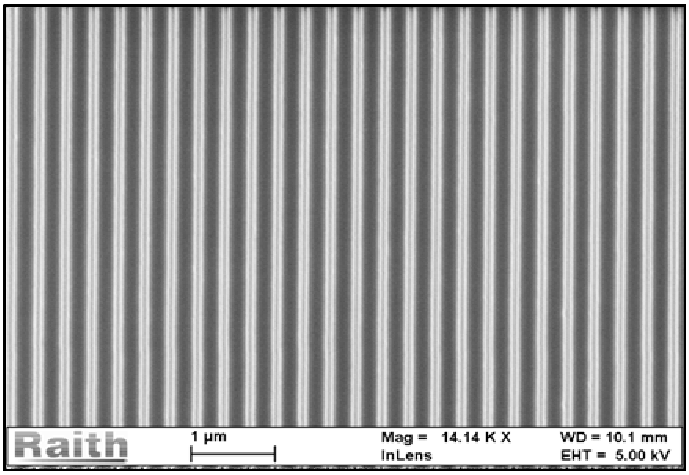


Image 2: SEM micrograph of large area gratings patterned using UDPD.

Fabrication of deep trenches by DRIE: Processes for High-aspect-ratio etching

High-aspect-ratio trenches with minimum feature size were targeted, to understand the through-silicon-via (TSV) etch capability at NNFC. In DRIE, high-aspect-ratio structure fabrication with minimum feature size has always been a challenge, because of the complex "recipe algorithm". When

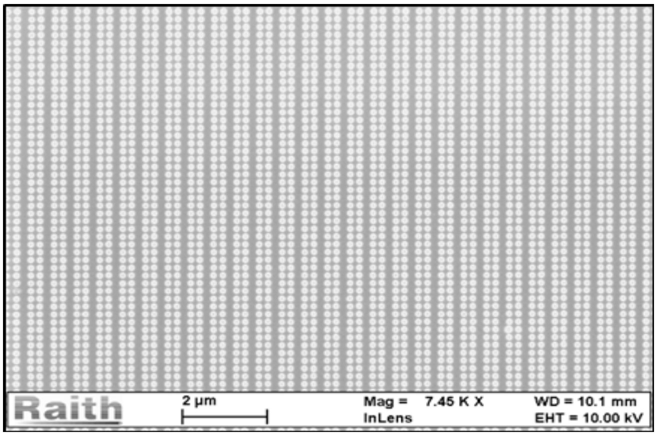
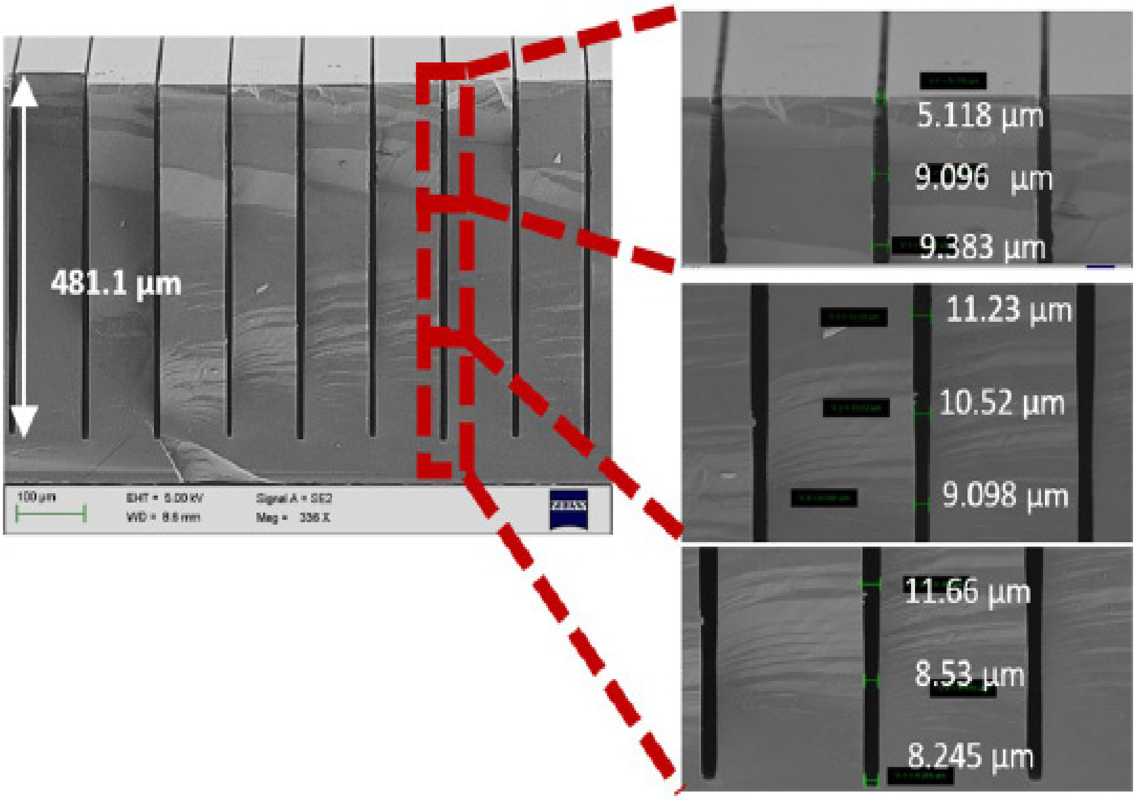


Image 3: SEM micrograph of Periodic pattern exposed using UDPD of 125nm circles. Magnified image of large area exposure which was $12mm^2$.

the normal etch recipe is used, the diffusion of ions into the deep trench of smaller features is difficult, resulting in the termination of etching. To overcome this, the "recipe algorithm" was modified by breaking the complete etch process into various steps, resulting in the high aspect ratio of 1:94 for a feature size of 5 µm. This TSV-grade etching process can be applicable for 3D CMOS integration and the fabrication of a wide range of MEMS devices.



SEM images of the 5 µm trenches with High Aspect ratio of 1:94 achieved in SPTS DRIE at NNfC.

OUTREACH

INDIAN NANOELECTRONICS USERS PROGRAM (INUP)

INUP is an outreach program that is conducted by CeNSE. INUP designs its training programs to explain the integration of physics, biology, chemistry and engineering at the nano scale, and tops this with hands-on training sessions to ensure that the trainees acquire know-how of practical implementations of nanotechnology in multiple avenues. The training programs enable radical development of the human resources in the area of nanoscience and engineering by providing unhindered access to the state-of-the-art nanofabrication and characterization facilities available at CeNSE. INUP is a three-tiered program with initial emphasis on overview in the area of nanoscience, followed by rigorous hands-on training on the tools, and the final stage facilitates the execution of the research projects by the users at CeNSE. The program has been running since the inception of CeNSE and has trained more than 4000 scientists from around the country.

Ministry of Human Resource and Development (MHRD), Government of India (GoI), has recognized the importance of the INUP program for the country and provided resources to support the program. The first of these training programs under the aegis of MHRD began on May 14, 2019, with the Basic Training Program in Nanoscience and Technology.

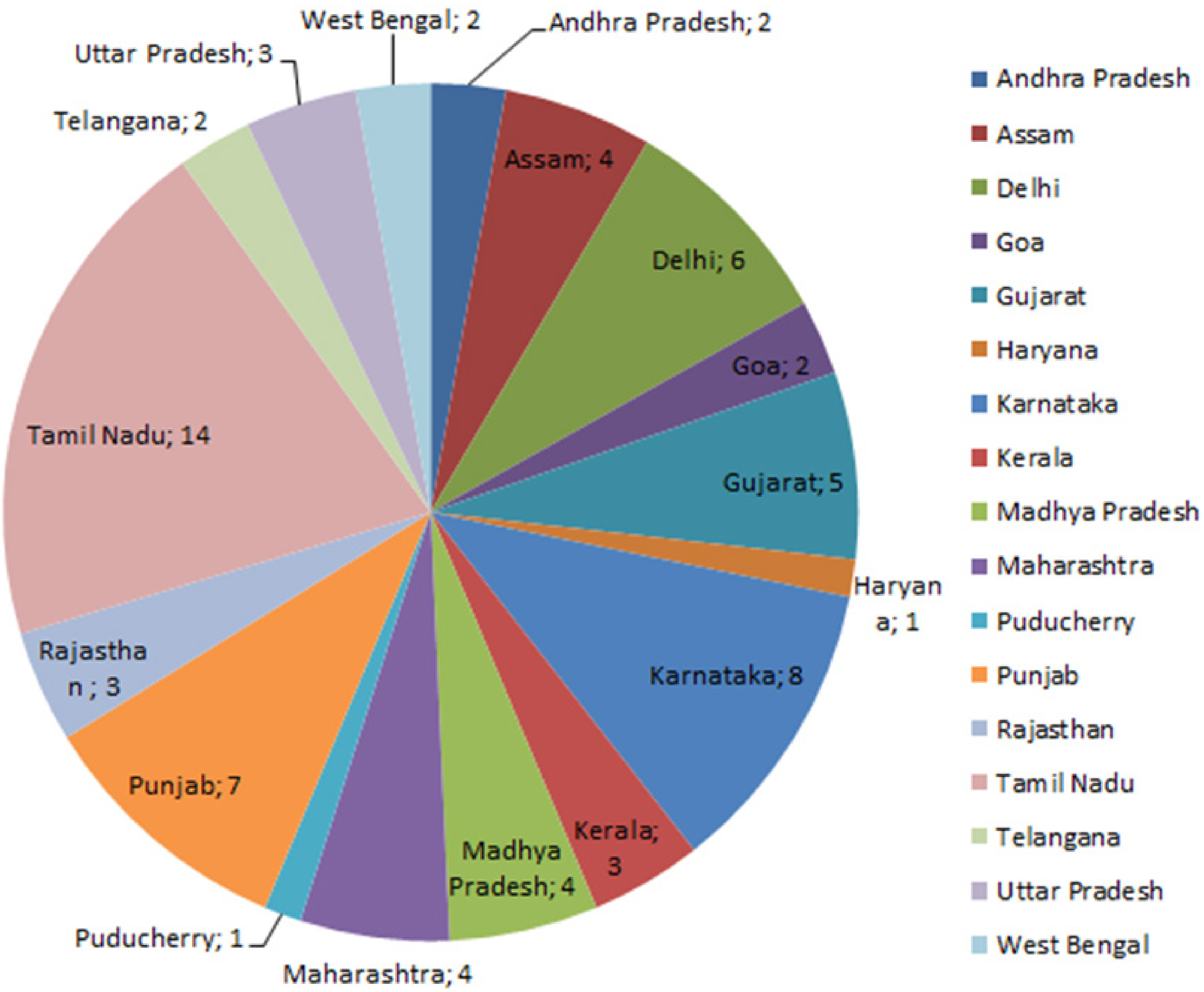
Program and team

The training program, conducted from May 14 to 16, 2019, was inaugurated by Shri. VLVSS Subba Rao, Senior Economic Advisor, Dept. of Higher Education, MHRD, GoI, and Ms. B. Shwetha Rao, Deputy Director, Dept. of Higher Education, MHRD, GoI. Prof. Rudra Pratap, Deputy Director, Indian Institute of Science (IISc) Bangalore also graced the occasion.

This was followed by a talk by Prof. Navakanta Bhat, during which he welcomed the participants and introduced them to the academic and research activities at CeNSE. He provided a vision for how the nanotech landscape in the country can be drastically improved by providing the users unhindered access to national resources. The training team at CeNSE comprises faculty members and technical staff from NNfC and MNCF.

Participants

The program was attended by 71 participants from 48 institutions across the country. Participants included research students and faculty members.



Program aim and methodology

The program is aimed to give participants a broad view of nanoscience and technology and various fabrication processes. Covering the entire gamut from theory to application from different perspectives, the program covers a finite syllabus through lectures and practical training sessions conducted by the training team. The program provides the users with:

- A holistic view of nanoscience and its role in Physics, Engineering and Biotechnology.
- Information about nanomaterials, growth and possible manipulation of their properties.
- Basic knowledge about diverse set of devices and their possible applications.
- Information about tools for nanofabrication and characterization of nanomaterials, devices, and packaged systems.

The series of lectures, over 3 days, from faculty and technical staff covered diverse areas such as materials growth, nanoelectronics, biosensors, photonics, microelectromechanical systems and packaging. Participants were also provided tour of NNfC and MNCF. Highly qualified technical staff at these facilities provided an overview of the tool capabilities that are available at CeNSE.

The program also provided an opportunity to the participants to articulate their research ideas in the form of posters. These poster sessions were a fantastic opportunity for the participants to interact not only with the faculty and the technical staff of CeNSE but also with other participants.

Participants' role

Typically, the inauguration is followed by a session where the participants are encouraged to introduce themselves and their academic/research background. They are expected to attend all lectures and training sessions spread over a time frame of 2 days to 2 weeks, depending on the training level of the program for which they are enrolled. On the last day of the training period INUP provides the participants with an opportunity to share their feedback, which over the years has served a major role in tweaking and tuning the program to improve the learning outcomes of the users.

The next two advanced training programs of INUP where the users are provided hands-on training on the tools are scheduled for 16 - 26, July and 20 - 30, August, 2019.

FEATURE

DAAD Partnership between IISc and TU Dresden

A new cooperation agreement has been forged recently between Technische Universität Dresden (TUD) and IISc. The agreement is within the framework of the German government's program-- "Internationalization of German Universities". It is financed by the Federal Ministry of Education and Research and administrated by the German Academic Exchange Service (DAAD). This long-term partnership program is titled "India – Germany: A New Passage to India". The proposal made by IISC and TUD – and approved – is focused on establishing a program of exchange and collaboration in areas of interest and benefit to both institutions, with primary focus being on cooperation in micro- and nanotechnological research at the interface between life sciences and nanosciences. Priority areas for research have been identified and include topics from:

• Active and Soft matter, including physical, nanotechnological and materials-related research

• Biosensors based on electrical or optical detection.

The duration of the grant is 4 years, from March 1, 2019 to February 28, 2023. The activities of the program have started with a kick-off meeting at TUD on June 27, 2019.

The interdisciplinary team from IISc includes scientists from CeNSE, Bio Systems Science and Engineering (Prof. Vaishnavi Anathanarayanan), the Department of Physics (Profs. Prerna Sharma and Sriram Ramaswamy), and the Division of Biological Sciences (Prof. Sachin Kotan). The IISc team is coordinated by Prof. Ambarish Ghosh, CeNSE.

The German counterpart related to TUD includes a number of research institutions in nanosciences, molecular biotechnology, and materials science. These are either part of TUD or German governmental research institutions – such as Fraunhofer, Leibniz, Max Planck Society – which are organized in a local framework called the "Dresden Concept". The German activities, as well as the overall program, are coordinated by Dr. Hans-Georg Braun who is affiliated with the Leibniz Institute of Polymer Research and the Biotechnological Center of TUD (BIOTEC).

This successful initiative was born out of a long-lasting cooperation of five years (so far) between A. Ghosh and H.G. Braun, including regular lectures on Soft Matter which have been provided within a DAAD-sponsored lectureship program. The provisions of the agreement were formulated after numerous discussions between CeNSE and TUD to identify common interests for inclusion in this initiative. It has been decided that the program will allow the partners:

• to exchange PhD students to stay in Dresden or Bengaluru for doing joint research.

• to exchange post docs (for the preparation of joint proposals or papers).

• to let Master's students do part of their thesis work at a collaborators lab in Dresden or Bengaluru.

• to organize topical workshops or training courses with experts from the participating institutions.

• to exchange technical staff for hands-on training courses.

• to organize or participate in joint outreach activities.

The program does not focus on a specific research goal but is aimed at establishing future cooperation between the institutions through individual contacts between researchers. Although the program is financed and administrated exclusively by DAAD, the exchange would be balanced between IISc and

German research institutions.

Successful exchange of resources and demonstration of cooperation through joint educational initiatives will be the key criteria for evaluation of the program and for the renewal of the agreement and the consideration of future proposals. A positive evaluation at the end will offer the great prospect of extending the cooperation into new interdisciplinary research areas which might include human – machine interfacing, neurosciences etc.

Prof. Ambarish Ghosh introducing IISc and CeNSE at the kickoff meeting at the Bio Innovations Zentrum, Dresden, Germany.

EVENTS

RESIDENTIAL TRAINING PROGRAM ON NANOTECHNOLOGY RELEVANT TO MEDICAL RESEARCH

22 April – 03 May

A training program on Nanotechnology for medical professionals was organized by our Center, supported by the Rajiv Gandhi University of Health Sciences (RGUHS). This course had 29 participants from various medical colleges across Karnataka, particularly from Ayush stream. The event was inaugurated by Shri Shivanand Kapashi, the Registrar, RGUHS and Dr. G. S. Venkatesh, Research Director, RGUHS. Prof. Navakanta Bhat, Chair, CeNSE, presented welcome address and gave an overview of the research and facilities at CeNSE.

The course discussed the tremendous scope for nanotechnology in the medical field with thorough introductory lectures presented by CeNSE faculty members and technical staff on the fabrication and characterization of nanoscale materials, and their application in bio and medical technology. Excellent hands-on training sessions were organized by the staff of the NNfC and MNCF. The Course was coordinated by Dr. Uma Reddy and Prof. Ambarish Ghosh, and able assistance was provided by the other staff. During the feedback session at the end of the course, participants said that the course exposed them to new dimensions in nanotechnology-related research, and that they saw many avenues for collaborating with researchers at CeNSE.

ANNUAL EMPLOYEE AWARDS

08 May

The technical and administrative staff at CeNSE have been contributing very substantially towards the achievements of the Center. The CeNSE Annual Employee Awards event provides the opportunity to recognise and appreciate the Center's most valued employees publicly. While Veera Pandi N and Manjunatha NS received the "Employee of the Year" award, the distinguished "Anand Seshadri Award" was given to Fakirappa Mirji.

VISITORS TO CeNSE

During the last quarter, CeNSE had many distinguished visitors, who provided encouraging feedback.

Sunil Bhaskaran, of Air Asia visited the Center. After a tour of the facilities he said, "Delighted to see the kind of work being done at CeNSE. I am sure it will support some of the world's best innovative solutions in many areas. Hoping industry would make the best use of this!"

Prof. Vladimir Bermanec, Faculty of Natural Sciences, University of Zagreb, Croatia, visited CeNSE and said, "I am impressed with a lot of work in these labs and I will propose further cooperation between scientists from Croatia and India".

Prof. Ivica Smojver, Faculty of Mechanical Engineering, University of Zagreb, Croatia, said, "… very impressive technology used and results. Congratulations and all the best".

Prof. P M Ajayan, Founding Chair of Materials Science and Nano Engineering, and Prof. Reginald DesRoches, Professor of Civil and Environmental Engineering, both from Rice University, Houston, Texas, said that CeNSE is an "excellent facility".

Shri Rajiv Mehrishi, Comptroller and Auditor General of India, as well as his team of deputy Directors, visited CeNSE in June. They were given a tour of NNfC, MNCF and other facilities of the Center.

IN CONVERSATION WITH...

Excerpts from an interview with Prof. Navakanta Bhat

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

I was familiar with IISc and the kind of research done here even during my undergraduate days. My dream was to be a faculty in a research institute like IISc. I always knew that I wanted to come back to India after completing my PhD in the US. This idea was further strengthened during my interactions with Prof. V.U.Reddy (Department of Electrical Communication Engineering, IISc) who frequently visited the Electrical Engineering department at Stanford University, where I was doing my PhD. He encouraged me to apply to IISc and I did. Since the institute policy required me to have some post PhD experience, I decided to work for a couple of years and re-apply. I took up a job with the Advanced Products R & D Laboratory at Motorola, Austin, Texas, with the clear intention to quit after a couple years and head back to India. Later, when I applied to the ECE Department with all the required experience, the committee was convinced that I would be a good fit. That is how I joined as an Assistant Professor in the ECE department at IISc, in 1999.

2) **During your time at Motorola, did anything about the industry attract you enough to change your mind about going to academics?**

I consciously decided to join Motorola to garner the very important industry experience. The reason I joined industry was to get a perspective of how industry functions – and in particular understand how the research outcome gets converted into products. During my industry stint, I got a great opportunity to pursue applied research, develop 250nm CMOS technology and transfer it to manufacturing for the production of PowerPC microprocessors. Thus, I could appreciate how the outcome of long term academic research gets translated into short term applied research in industry, finally resulting in productization of an idea. I could also recognize how strict timelines are important in this endeavour. This has been extremely valuable for me even in my academic career. The industry experience did not really digress me and pivot my long term goals, since I was very sure why I was joining industry and I had clarity on my long term goal to be in academics.

Do you see the line between industrial R&D and academics getting blurred more and more?

Yes, they must overlap very well. When you need to translate any academic research idea or result, especially in any branch of engineering, there are two possibilities – one is working with an established industry, the other way is through startups. At CeNSE we do both. During the last two decades I have been at IISc, I have worked with established industries where in the definition of the project was such that there is an outcome that is of immediate interest to industry. I have also worked with startups, where the gestation time is much longer and there is some risk involved. For instance at PathShodh, we have worked on a very novel idea, which has now resulted into one of its kind product, through sustained research and technology development efforts over few years. From my experience, I think industrial R&D and academics are certainly not disjoint.

3) **Was there a defining moment in your graduate school days at which you decided to go the academic route?**

I always enjoyed teaching even during my undergraduate days. I used to develop deeper understand in the subject through teaching my classmates before examinations. Another turning point was during my Masters days at IIT Bombay, where I had a privilege of learning from a great teacher, Prof. Juzer M. Vasi who had set up Microelectronics program at IITB and had built a group with the sole aim of creating indigenous technology. He is one of the best teacher I have ever had! I also appreciated the fact that even after having worked at the best places around the world, he chose to come back to India and take up teaching as a career. His personality reinforced my decision to continue in academics.

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

There are two major thrust areas of research in my group – one is traditional scaling of electronics where we work towards making transistors smaller and more efficient so that we can make chips that are of high performance; the other area is sensors for various physical parameters.

My interest in electronics started way back, perhaps from my high school days. My fascination for electronics gadgets like the radio and tape recorder back then, made me specialize in this field. I could also appreciate the impact of electronics on the way people live because everybody adopts these gadgets into their daily lives. So, I elected electronics as my major in BTech and pursued it further and delve into Microelectronics during my MTech and PhD. Today we are into nanoelectronics where we craft transistors into smaller and smaller dimensions. The research in my group looks beyond Silicon electronics, which is the workhorse for all electronic gadgets as of today. We explore other new materials to build transistors and make them more powerful, which will be necessary in the next couple of decades.

My interest in sensors started only after joining IISc. When I joined IISc back in 1999, and was thinking through my future research agenda, it became evident very quickly that the semiconductor technology used in building electronics, will have big impact in a variety of sensor applications– health care, defense, aerospace, agriculture and environment to name a few. I then decided to start my research in this emerging area. I already had expertise in the base semiconductor technology and I needed to decide on the application part. After some deliberation I thought that health care and air quality are going to be extremely important going forward, which has turned out to be true today, and we decided to focus on building bio sensors and gas sensors. Thus, my interest in sensors continues even after two decades.

5) **How much of what you studied in your PhD is directly related to what you are working on now?**

Often when I meet young students, the question that I get the most is this – What does it mean to do a PhD? I tell them that PhD is a journey during which you unravel your capabilities. You choose a topic that is unknown to you till then and see if you can master that topic. So, no matter which area one chooses if he/she does their PhD with the right intent and perspective, by the end of it they would be able to investigate any research problem. PhD equips you with the skill set to do research.

I worked on flat panel displays for my PhD. These are the displays you see today on laptops, flat screen TVs, etc. At that time, it was an emerging area. I investigated the possibility of building transistors on glass and new techniques to reduce the processing temperature and build reliable transistors which can then perhaps be adopted by industry to make flat panel displays. The title of my PhD thesis was "Reliability of deposited gate oxides for polycrystalline silicon thin film transistors". Am I doing anything related to that now? Nothing really! But the learning that I got, I use it almost every day in everything I do.

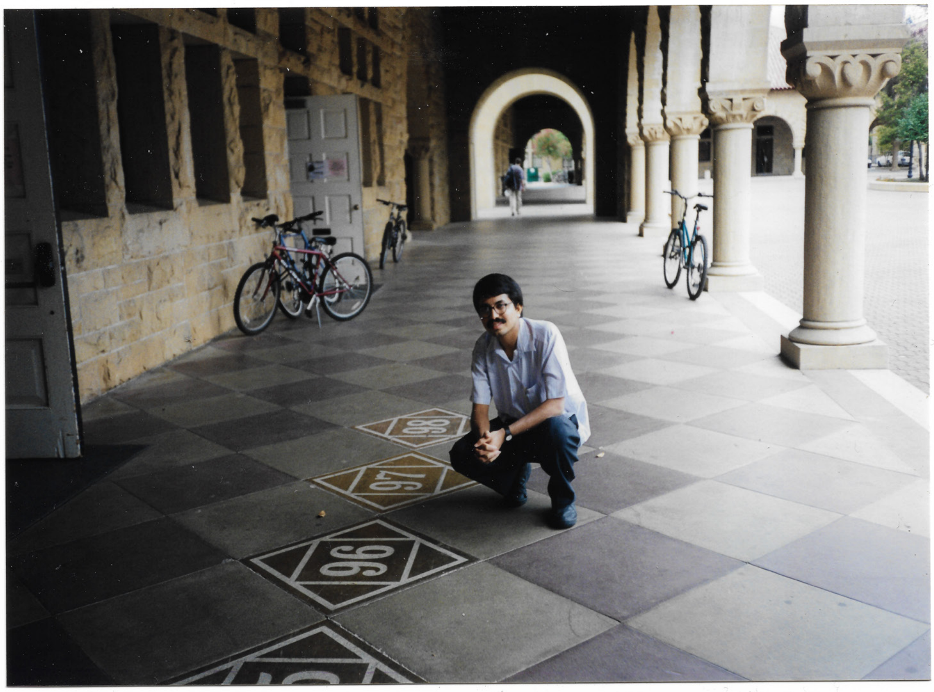
6) **Having worked extensively in industry and academics, what kind of environment do you think is most conducive to working successfully in science?**

There should be a lot of freedom for researchers to pursue their interests in an unconstrained manner. My philosophy for research, particularly for students, is that you should allow room for discovery without setting unreasonably short-term goals and deadlines. Of course, there should be an understanding of responsibility and accountability, but one should really explore their area of study, come up with new ideas which come not only from reading but also from discussions with advisers and peers, doing experiments, failing in experiments and learning from the failures. The environment should allow the student to develop the right kind of aptitude for research. This is what we stress at CeNSE. We should also encourage our students to collaborate with others either from within or outside their discipline, because today science does not happen in isolation.

7) What do you do when you are not thinking about research?

Well, in the last few years getting any leisure time has become difficult, so much so that the research work continues even after going home, on weekends and holidays. But in the little time I can afford to take off work, I try to read creative literature; I have read quite a few works in Kannada literature which has the highest number of Jnanpeeth awardees (eight till date). I also do a bit of creative writing – I have written a few essays and technical articles in Kannada and English. I enjoy listening to classical music. Unfortunately, I do not get much time these days to attend concerts, but Malleshwaram is a great place for these programs. I enjoy spending time in wilderness for which I hope to get more time in future!

Prof. Bhat, then an MTech student, in the Microelectronics lab at IIT Bombay, 1990–92.



Prof. Bhat during his visit to Stanford, December 1998.

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