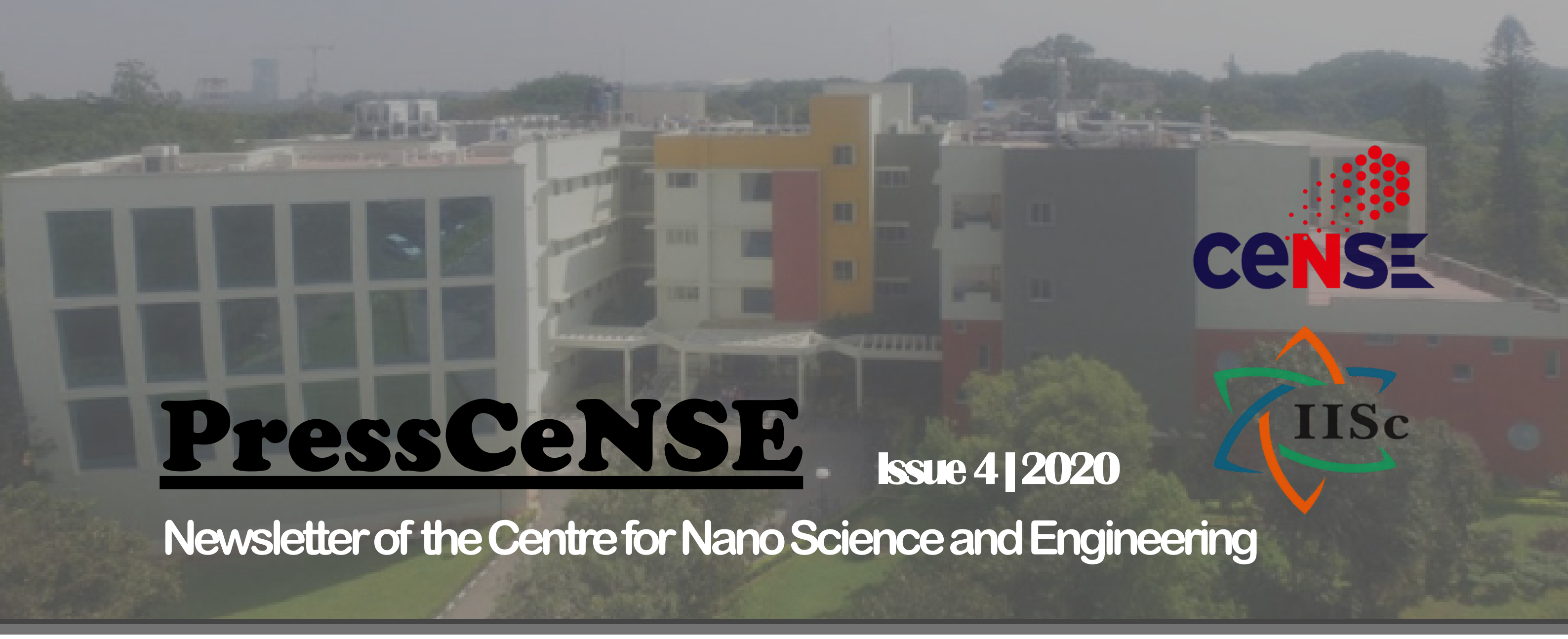


PressCeNSE

Issue 4 | 2020

Newsletter of the Centre for Nano Science and Engineering

Message from the Chair

2020 has been a very challenging year. However, we have coped with the crisis and have emerged stronger. There is always a silver lining and the one to emerge from the current scenario is the ability to work and meet through virtual means. With the advent of the vaccine, it is hoped that normalcy will be restored by the end of 2021.

As the new Chair of CeNSE, I would like to place on record a vote of thanks to the former Chair, Prof. Navakanta Bhat, who has taken over as Dean of the Inter Disciplinary Sciences Division. Right from the inception of the idea of CeNSE in the late 1990s and through its execution, he has been at the forefront of the effort. He, our new Director, Prof. G. Rangarajan, and the new team have had to take over the administrative responsibilities of the Institute under rather difficult conditions. CeNSE wishes them all the very best.

Life does and must go on. We welcome two new and exciting faculty members. Aditya Sadhanala- perovskite solar absorbers and emitters- will bolster our efforts in the area of renewable technologies, while Pavan Nukala adds *in situ* TEM expertise and oxide systems at the edge of chaos to the existing colourful palette. We bid good-bye to Prof. Mohan after many years of association and wish him a happy retirement. As you will read in this letter, our students and faculty have continued to win awards and report exciting research. CeNSE as a whole has started to branch out towards the quantum and biological worlds.

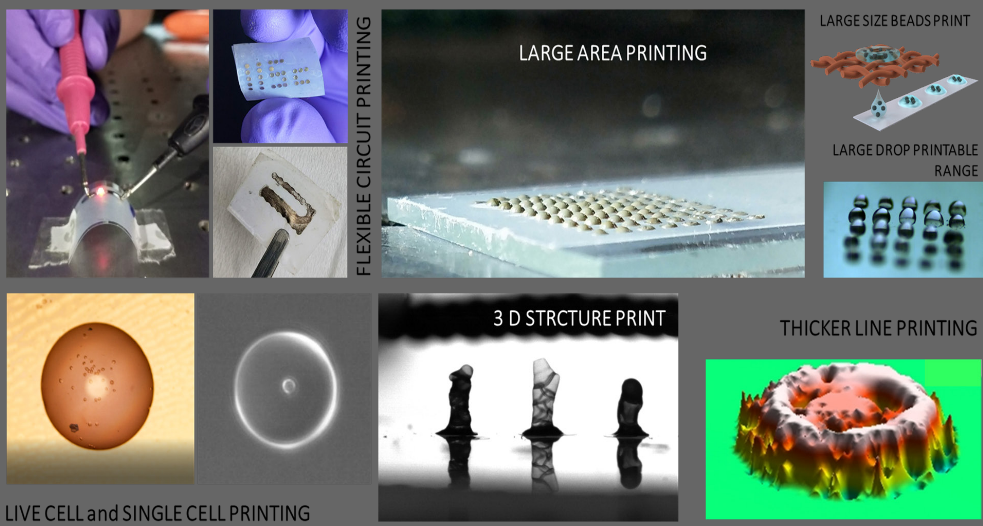
If there is one painful memory from the 2019-2020 timeframe that I will remember in addition to COVID, it is the passing away of a near and dear friend, to me and to CeNSE, Prof. Venkataraman. Venky was selfless in his contributions to CeNSE, especially the INUP program, the Institute, and was a teacher of semiconductor device physics par excellence. He leaves behind rather big shoes to fill.

Wish you all a very happy 2021.

- Srinivasan Raghavan

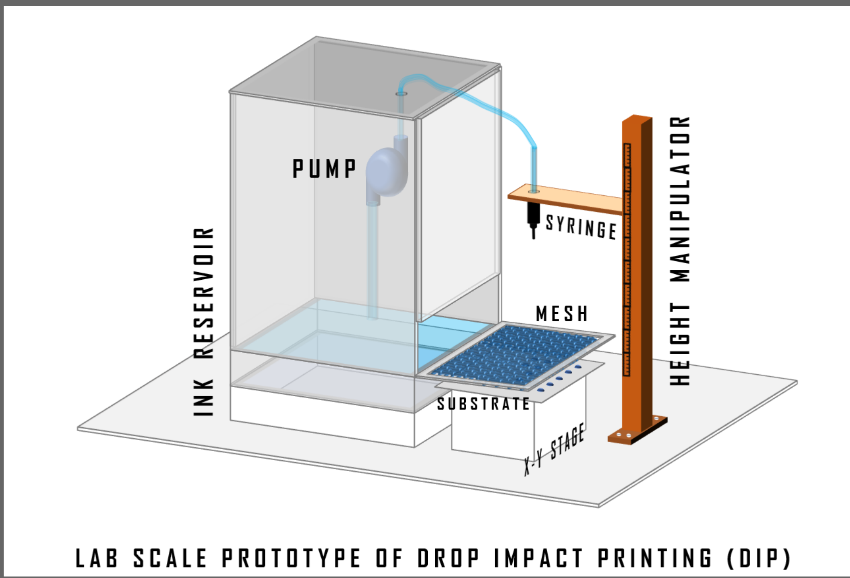
Drop Impact Printing
- clog-free printing with a range of droplet sizes

The pursuit to print microscale droplets accurately is not new. However, with the advent of additive manufacturing and 3D bio-printing research interest in this technology has been renewed. Newer applications demand use of inks which are not well suited for conventional printers. For example, bio-printing requires dispensing live cells. Viability of cells is dramatically reduced by the thermal or piezoelectric actuation used in conventional printers. Further, printing inks with higher mass loading (i.e., a larger number of particles or cells per droplet) is desirable and often necessary. This remains a challenge which has not been addressed till date.



Conventional printers employ a nozzle with small orifice to form droplets. Particles in inks with high mass loading tend to aggregate at the orifice causing the nozzle to clog. The 'Drop Impact Printing' technique, developed by researchers in the Microfluidics and Heterogenous Systems Lab headed by Prof. Prosenjit Sen, addresses these problems by replacing the nozzle with a mesh. "Replacing the nozzle with the mesh also allows for printing relatively large particles without clogging the device", says Chandantaru Modak, graduate student in Prof. Sen's group and first author of the paper published on this work – Modak, C.D., Kumar, A., Tripathy, A., Sen, P. "Drop impact printing", *Nature Communications* 11, 4327 (2020). https://doi.org/10.1038/s41467-020-18103-6.

Currently, different printing techniques are required for different applications. This increases capital investment and reduces convenience of use. Hence, to evaluate applicability of their technique, the team tested drop impact printing for a wide range of applications. Using this technique, it has been possible to print 3D pillar structures of different sizes, an electronic circuit for semiconductor device applications, and bio-based droplet arrays for cell culture. It was observed that this technique could be easily and conveniently used for different applications and can be extended to a wide range of other relevant processes. Capability to print a wide range of droplet sizes while using different kinds of inks for different applications makes this technique unique. Moreover, the setup is extremely simple and cost-effective, which improves its accessibility to a larger community. Further, the mesh costs only a small fraction of the nozzles that it replaces. This significantly reduces operational cost when compared to conventional printing techniques. The development and workings of this method are explained in detail here: https://www.youtube.com/watch?v=TCmkuCFR4Go.



Dwell-time - a means to characterize nanoparticle-pore interactions in sensor applications?

Solid-state nanopores are rapidly emerging as a promising platform for developing various single molecule sensing applications. The modulation of ionic current through the pore due to translocation of the target molecule has been the dominant measurement modality in nanopore sensors. In this work, done in the Complex Systems and Molecular Sensors Lab headed by Prof. Manoj Varma, the focus is on the dwell time, which is the duration taken by the target molecule or particle to traverse the pore, and to study its dependence on the interaction of the target with the pore using single gold nanoparticles as targets interacting with a Silicon Nitride nanopore. The interaction, which is electrostatic in nature, can be controlled by coating the nanoparticles with charged polymers. It was observed that the dwell time is extremely sensitive to the target-pore interaction and the authors believe that this feature can be exploited in emerging nanopore sensor applications.

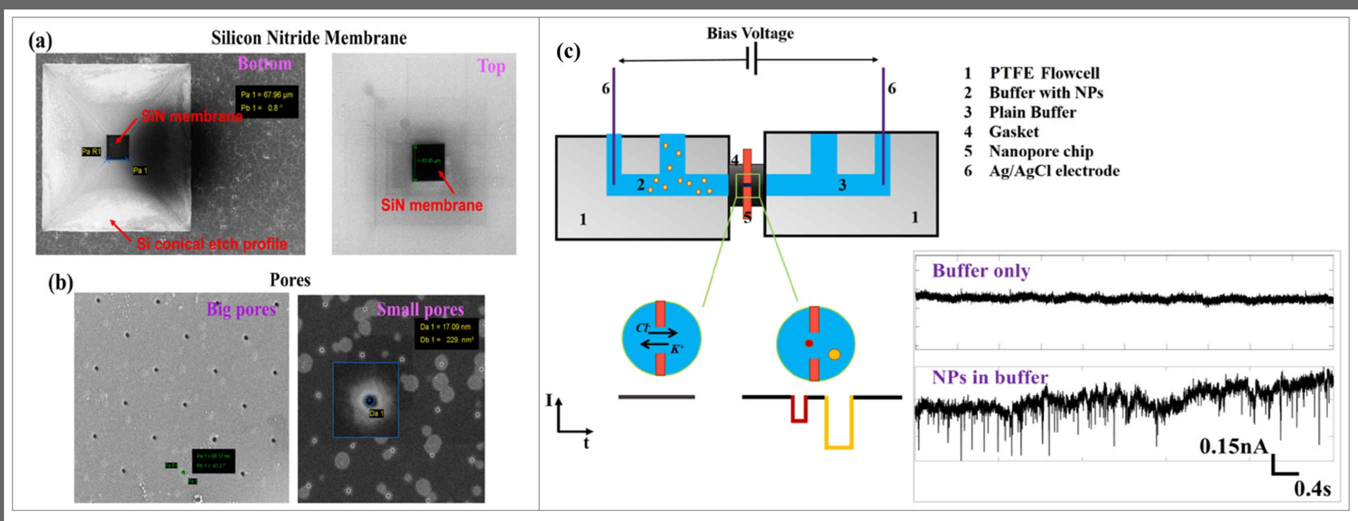


Figure: SEM scan images of silicon nitride (a) membranes and (b) nanopores. (c) Schematic of the experiments.

This work has been published as Pal, S. et al. Effect of single nanoparticle-nanopore interaction strength on ionic current modulation. *Sensors Actuators B Chem.* 325, 128785 (2020). The authors claim that the exponential dependence of dwell-time on the NP-pore interaction strength paves the way for developing highly sensitive sensing techniques based on dwell time of NPs through nanopores. For instance, one could functionalize the NPs with DNA or protein recognition elements and use their dwell-time as a means to characterize the strength of interaction between them and a functionalized nanopore.

Exploring Piezoelectricity in 2D Materials

Growing need for integrated sensing systems with the capability to detect multiple physical parameters for application in wireless sensor networks, IoT (Internet of Things), wearable sensors, bio-implantable devices, etc., has led to an increase in the demand for materials which possess out-of-the-ordinary characteristics. Piezoelectricity in 2D materials is one such property that has evoked interest in them for diverse applications in electromechanical systems. Plenty of materials exhibit piezoelectric property when scaled down to 2D or 1D by different means such as breaking the centrosymmetry, charge delocalization or surface modification. Between the two, 2D materials are of particular interest because they are proved to withstand strains as high as 11%, are highly crystalline, and their processing is compatible with CMOS technology.

As part of her research, Sai Saraswathi - a graduate student in Prof. Akshay Naik's group (MEMS Lab) – attempted to quantitatively measure the in-plane piezoelectric coupling for 2D materials using a novel approach to in-plane field excitation in lateral piezoresponse force microscopy (PFM). PFM, one of the application modules in Atomic Force Microscopy (AFM), is used to characterize the piezoelectric and ferroelectric properties of a given material (Figure 1). "In any AFM-related measurement, the detection scheme involves the extraction of the information from tip-sample interactions. This makes the measurement to have a complex dependency on the applied drive frequency, and the choice of AFM tip plays a significant role. Our technique would be helpful in studying the in-plane piezo-coupling in the emerging 2D-materials for various applications", says Saraswathi.

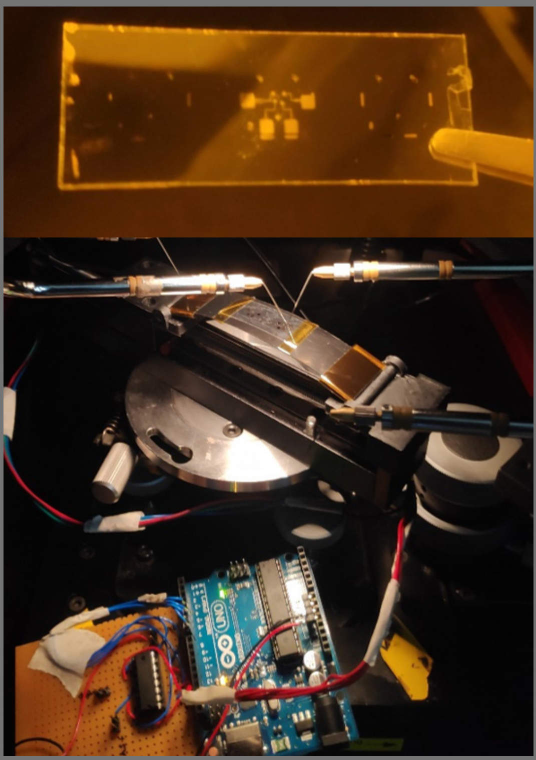


Figure: 2D Material based devices fabricated on flexible substrates and the bending setup for the strain measurements.

Furthermore, 2D materials which are semiconducting and piezoelectric are potential candidates for piezotronics. The researchers have fabricated 2D-material-based piezotronic devices on flexible substrates. Despite the many challenges involved in fabrication on these substrates – because of low-temperature processing, poor adhesion, film stress-related issues, etc. -- efforts were made to encapsulate these devices with a suitable top dielectric medium to improve reliability. Such devices are of great interest in attaining different mechanisms in wearable/flexible piezotronic sensors.

New faculty profile

Two new faculty members have joined us in the year 2020 and we are delighted to welcome them to CeNSE. PressCeNSE sat down (virtually) with them to chat about their academic interests and research vision.

Aditya Sadhanala comes to CeNSE from Clarendon Laboratory (Department of Physics), University of Oxford, where he did his post-doctoral training from 2018 to 2019. Prior to this, he worked at the KAVLI Energy and Nanoscience Institute and Department of Chemistry, UC Berkeley (Winton Cambridge-Berkeley Fellow 2018) and the Cavendish Laboratory (Department of Physics), University of Cambridge (Post-doctoral Research Associate, 2015 – 2018). He completed his PhD in Physics from the University of Cambrigde, UK, in 2015. He obtained his Master's (MSc in Nanoelectronics, 2010) from the University of Manchester, UK, and Bachelor's (B.E. in Electronics. 2009) from the University of Mumbai.

From his research work over the years, Dr. Sadhanala has several academic publications (Google Scholar Profile) and has presented his research findings at universities and conferences across the world.

1) Have you always been in your current field of study or did you start in another area of research?

I have switched my field of study consistently – from Electronics Engineering to Nanoelectronics Engineering, to Physics.

2) What are your research interests? What projects are you currently working on?

I would classify them into three categories.

a) NanoEngineered/NanoStructured Optoelectronics: Microfabricated optoelectronic devices have been around for a long time and their performance has also grown leaps and bounds. However, to achieve the next leg of big advance in performance we need to look at nanofabrication. Although the concepts of nanofabrication have been around since more than a decade, we have not managed to translate the advances into realising efficient optoelectronic applications/devices that can replace real-life microfabricated optoelectronics. One of the aims of the research done in my lab is to deliver the next-generation of efficient and high-performing optoelectronics by realising efficient Nanostructured Solar Photovoltaic (PV) devices, Nanostructured Light Emitting Devices (LEDs), novel nanoelectronic devices and hybrid optoelectronic devices.

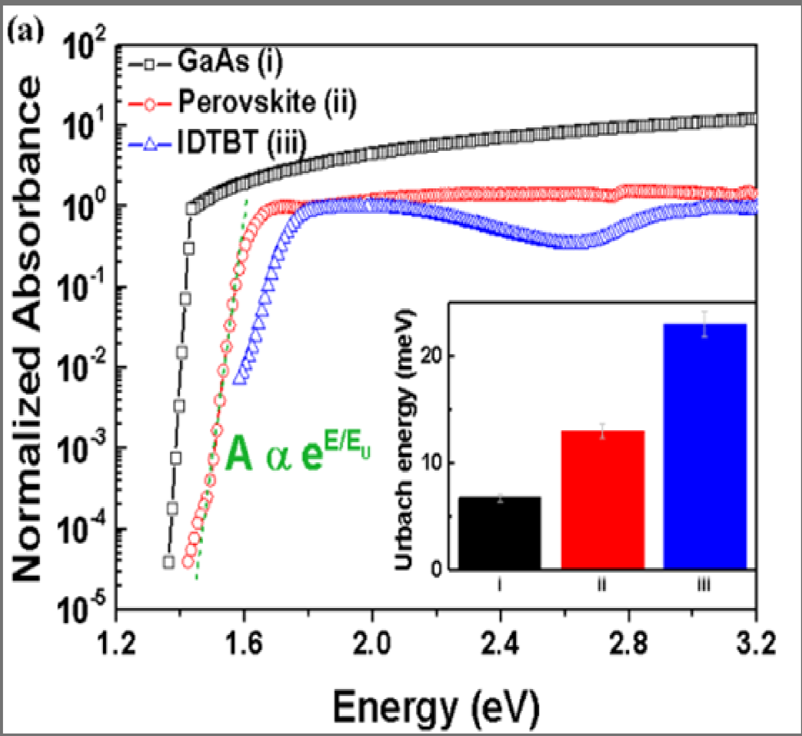
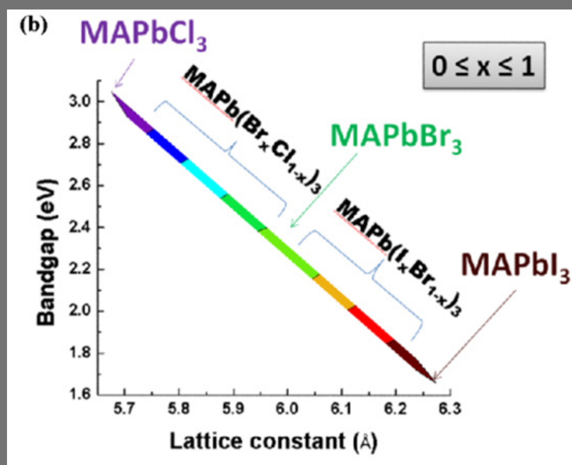


Figure (a) PDS spectra showing sharp band edge of $MAPbI_3$ perovskite compared to GaAs and low disorder polymer - indacenodithiophene-co-benzothiadiazole (IDTBT) and the inset shows their energetic disorder in terms of Urbach energy (EU).

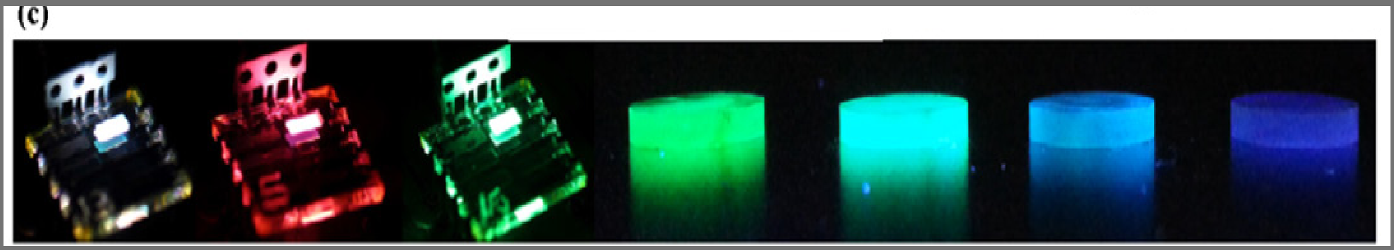
b) Advanced Spectroscopy: Understanding thin-film semiconductors starts with understanding their material and optical properties. Our approach is to study their photophysical properties by using advanced steady state and time resolved optical and electrical measurements. On this front we are developing a highly sensitive optical absorption spectroscopy tool - Photothermal Deflection Spectroscopy (PDS) technique that enables direct defect measurement and acts as a rapid semiconductor quality screening tool. The PDS technique has the capability to measure absorption data with 4-5 orders of magnitude dynamic range of sensitivity making it one of the most sensitive absorption measurement spectrometers. We also focus on time resolved photoluminescence measurements to study the charge carrier dynamics and will combine this with various electrical characterisation tools to study them in-situ. This will help us unravel the properties of materials while in active working mode in devices thus helping in gaining a complete understanding of the materials and devices that we intend to fabricate.



Figure(b) Bandgap tuning by changing the halide composition as indicated. MA indicates CH_3NH_3 cation.

c) Novel Hybrid Semiconducting Materials: We also work on inventing/synthesizing new semiconducting materials that can be used in efficient optoelectronic devices, charge selective/

blocking contact layers/interlayers, etc. The aim is to achieve hybrid properties to realize artificial synaptic memory devices to be used in Neuromorphic Computing Applications.



Figure(c) Emission profiles achieved using bandgap tuning in LEDs based on these perovskite thin-films.

3) Will you be teaching any courses at CeNSE?

None as of now. However, I would be initiating a Basic and Advanced course on Spectroscopy in the semesters to come.

4) What brought you to CeNSE?

The refreshingly dynamic, energetic, truly open and cohesive, translation-focused interdisciplinary research atmosphere is one of the main reasons that attracted me to CeNSE.

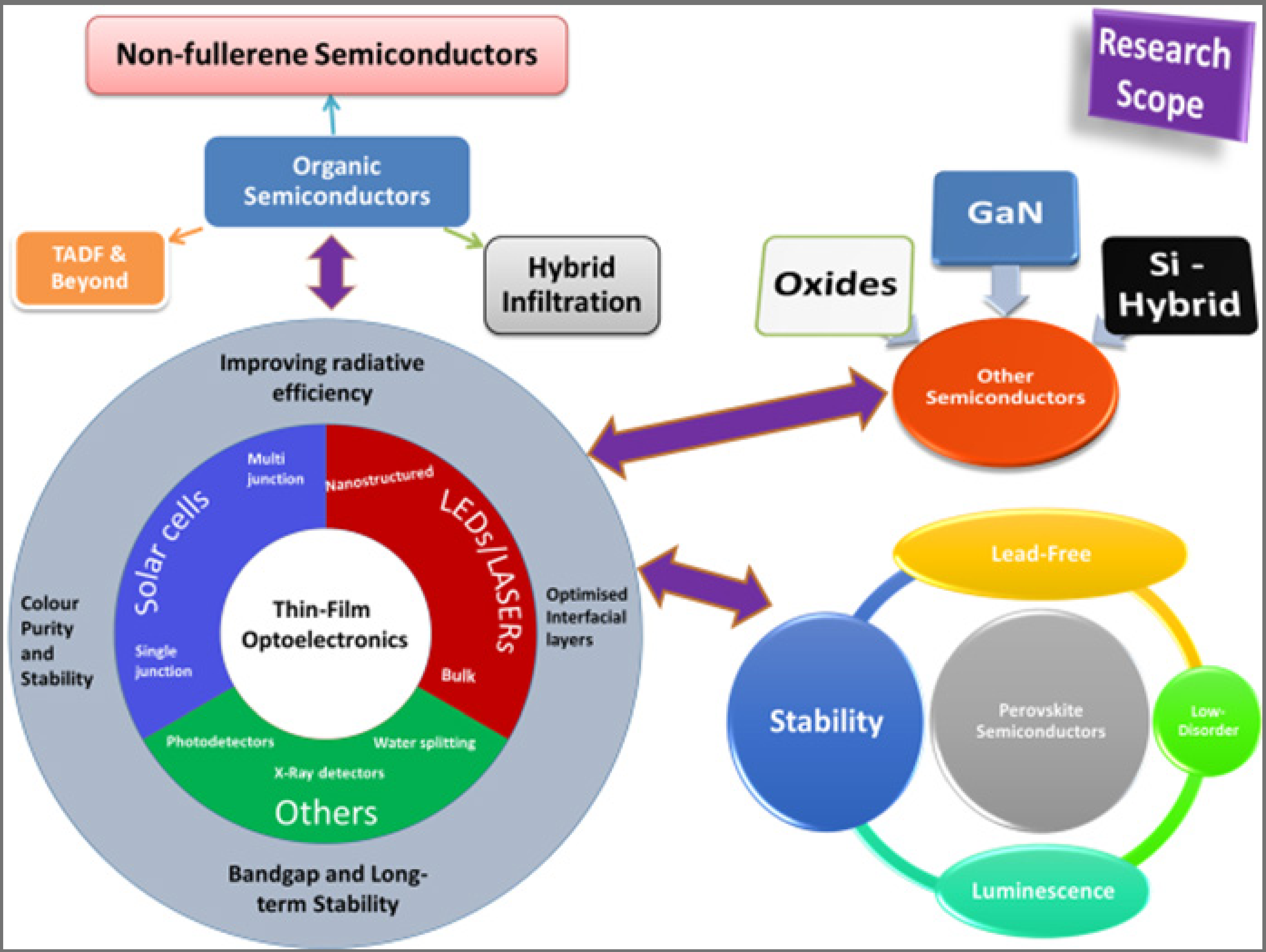


Figure: Aditya's research scope for what is planned at CeNSE.

Pavan Nukala comes to CeNSE from the University of Groningen, The Netherlands, where he did his post-doctoral training in the Nanostructures of Functional Oxides Group (Marie-Sklodowska-Curie Individual Fellow, 2018-2020). Prior to this, he worked as a postdoctoral researcher (2015-2018) in the Advanced Ferroics Group at the University Paris Saclay, France. He completed his PhD in Materials Science and Engineering from the University of Pennsylvania, USA in 2015. He obtained his Bachelor's and Master's in Metallurgical and Materials Engineering (2009) from IIT Madras.

From his research work over the years, Dr. Nukala has several academic publications (Google Scholar Profile) and has presented his research findings at universities and conferences across the world.

1) Walk us through your academic/research journey. Have you, and if yes, how did you switch between different fields of study?

I did my Bachelors and Masters in Metallurgical and Materials Engineering from IIT Madras. During PhD, although I was associated with the department of Materials Engineering, my own research involved learning a lot about solid-state devices and physics. I worked on phase-change materials (nanowires), their device physics and understanding their structure-property correlations through *in situ* electron microscopy. During both my postdoctoral stints in Europe I was associated with Physics departments, although I interacted and worked closely with both physicists and chemists. I was mostly working on various oxide materials with rich correlated physics, and redox chemistry. Especially when trying to understand the behaviour of devices in these materials, and predict material design principles, there is no escape from either of the fields. I was growing thin films of them, studying their device properties (ferroelectric/memristive) and investigated them through various means including *in situ* aberration corrected microscopy and spectroscopy, and X-ray diffraction. This way, for most part of my research career, I've flirted with and floated between physics, chemistry and materials science for nanoelectronics, and was quite blind to any arbitrary boundaries between them. On a lighter note, I hide my ignorance by pretending to be a physicist to chemists and vice versa. In the one case where I found a person with dual PhD (one in physics, one in chemistry) I used my material scientist trump card.

2) What are your research interests? What projects are you currently working on?

My research interests involve working on various types of electronic materials and devices from a structure-property point of view. In the past I have worked on phase-change materials (chalcogenides) for memory applications. Recently, I have been working on various functional oxide thin-films with rich correlated physics very much connected to the symmetry and structure. I am particularly fascinated by defects/imperfections in crystalline materials that can be suitably engineered to enhance the requisite electrical properties. Conversely, if we think of a desired property, can we design materials from experimental principles and guidelines that satisfy these. This is, according to me, the real definition of materials engineering.

<u>One example of the research I've been doing</u>: the idea of ferroelectricity has been recently discovered in doped hafnium dioxide-based thin-films. Conventional ferroelectric materials such as barium titanate and lead titanate are generally very CMOS (Complementary Metal–Oxide–Semiconductor)-incompatible, and their ferroelectric property disappears with miniaturization. For instance, 3 nm-thick barium titanate does not show any ferroelectricity. So, utilizing the nice properties of ferroelectricity in real devices (FeRAMs, FeFETs, FE tunnel junctions) is a tricky proposition. Enter crystalline doped-hafnium dioxide in 2011, which showed robust ferroelectricity macroscopically. Now, this is a CMOS-compatible material, and unlike conventional ferroelectrics, ferroelectricity in doped hafnia is enhanced by miniaturizing it. Ever since, the idea of ferroelectricity in real microelectronics is back.

But the question is - What is this new type of ferroelectricity, and can we understand its basic principles, and replicate it in other systems? So far from my investigations, using techniques such as *in situ* TEM, and *in situ* nanobeam XRD, it turns out that ferroelectricity is very much related to migration of oxygen vacancies (point defects that carry charge) in these materials, an extrinsic mechanism, unlike in conventional ones which require a lack of centrosymmetry (intrinsic mechanism). However, macroscopic measurements do not distinguish between the intrinsic and extrinsic nature of it, and it turns out the extrinsic ferroelectricity is more useful for microelectronics. Hafnia and its sister compounds are well known for their oxygen conducting properties, but that the same property can be used to engineer new type of ferroelectricity is really exciting.

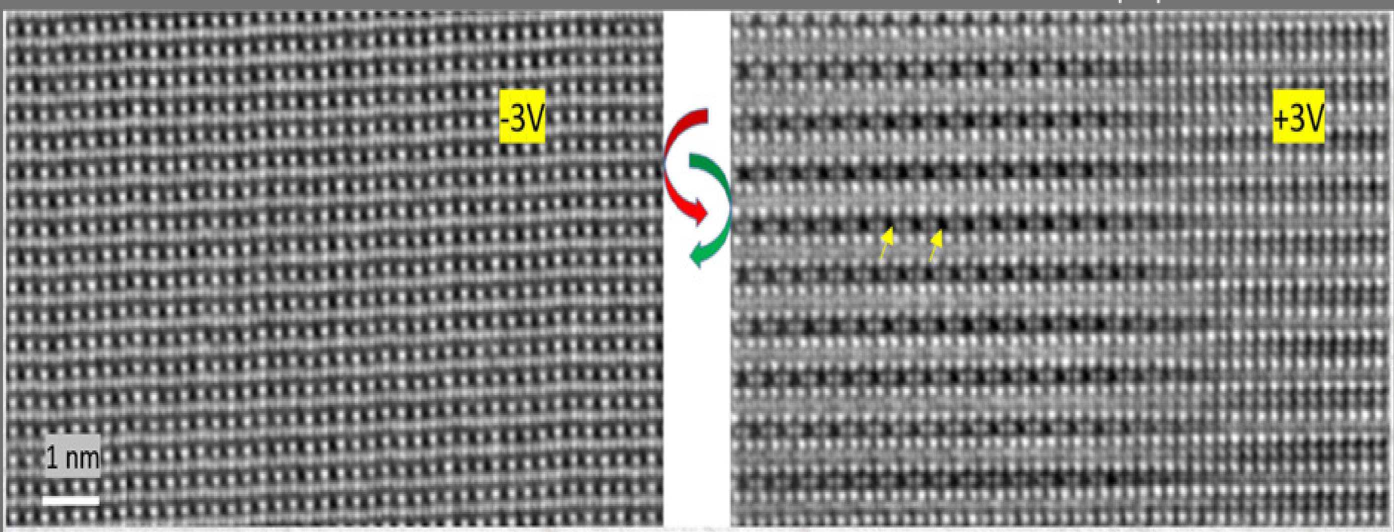


Figure 1: Imaging a reversible process of oxygen migration using *in situ* TEM (technique is called differential phase contrast STEM). On the left is the image of a perovskite thin film layer at -3V. On the right is the same layer at +3V. Yellow arrows indicate positions of oxygen that should have been there, but were removed. Thus we are imaging oxygen vacancies. It turns out that these oxygen vacancies migrate away from this layer to other layers in the heterostructure with negative bias, and come back in positive bias, giving a new type of ferroelectricity.

The next question is whether we can generalize these materials design principles to other simple oxide systems (which involves understanding fundamental physics and chemistry), and make a database of materials that are unconventionally ferroelectric.

The oxygen vacancy migration is also associated with lattice expansion and compression, giving rise to unconventional piezoelectric/electrostrictive effects. Not much is known about these materials in this direction. Driven by the huge interest in these phenomena in the MEMS community (also in CeNSE), I am quite looking forward to these investigations here at CeNSE.

Another example: Domain boundaries are 2D defects in materials that have properties/life of their own. In a ferroelectric material (conventional one), domain boundaries carry charge and upon the application of stress/voltage they move in a very jerky fashion. This can be externally detected as charge pulses. Here, an analogy can be made to neurons in real brains that communicate by neural pulses (charge pulses). Somehow this mode of communication allows for learning and cognition. So, if

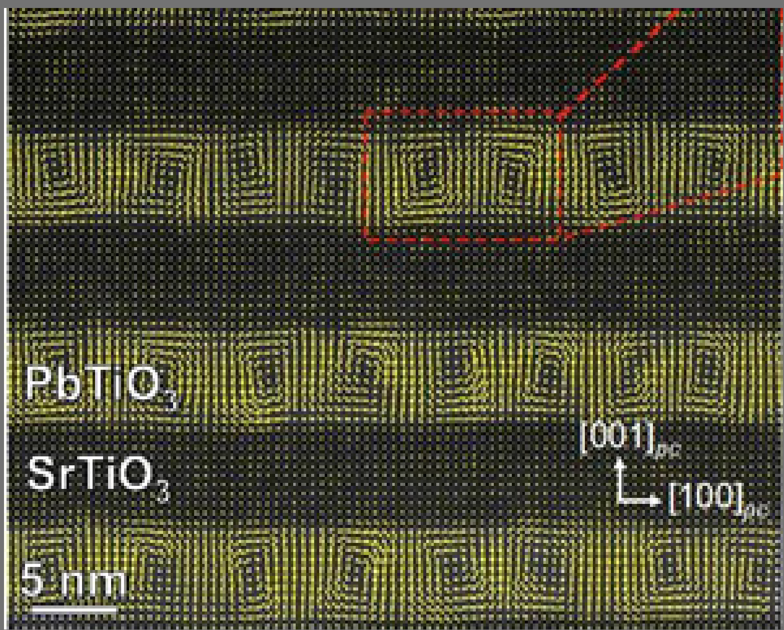


Figure 2: Complex polarization patterns (and defects) in ferroelectric layers ($PbTiO_3$) in this heterostructure, that can be used for neuromorphic applications. (Image from A.K.Yadav et al., *Nature* 2016)

we have inorganic analogues of these biological systems (such as defects in ferroic materials), we can think of having brain-like energy-efficient computing on chips. Or better, we can get more insights into the working principles of real biological brains. Here the ambitious problem statement is to find materials that can perhaps be suitable candidates for brain-like function. More importantly, design experiments that would enable formulating guidelines for others in the community to use.

In all this research, material synthesis (with control over defects) is a very crucial part, and essential starting point. Then comes rigorous characterization. My own expertise lies in *in situ* electron microscopy and X-ray diffraction, where we apply external stimulus and measure both structure and properties simultaneously inside an electron microscope (X-ray diffractometer) at various length scales. Various materials characterization and fabrication techniques will be the workhorses to make and study functions in real thin-film devices with various types of intentional and unintentional defects (2D- interfaces, domain boundaries etc, 1D: dislocations, ordered defect chains etc, 0D: point defects).

3) Will you be teaching any courses at CeNSE?

Not this semester. But, I have plans of offering courses on structure-defect-property relations in materials, and one on scattering techniques to investigate materials with particular emphasis on X-ray diffraction and electron microscopy, and spectroscopy in the coming semesters. The broad idea will be to equip students with basic principles to think in the direction of materials selection and design for a required function, rather than the converse (conventional) approach of "there is a material with so and so properties, take it or leave it".

4) What brought you to CeNSE?

Firstly, I wanted to come back to India. Rather than any family reasons, this boiled down to a moral argument. I got quality education here in India by paying almost nothing. To the contrary, my peers in the west or Indians that go to the west for university degree (bachelor's/master's), pay a tonne of money for similar education. This meant that if I can contribute anything, it should be here, back in India.

People kept telling me about the forward-looking, non-bureaucratic nature of CeNSE before I applied. I came to CeNSE once before in 2018 informally, and chatted with Navakant, had lunch with Ambarish, and went back with a gut feeling that this should be good. I was particularly attracted to the fact that if I join here, given the already established state-of-the-art infrastructure, I can start my research on day one. I formally applied after that visit, and within one day, Vasu invited me to visit formally. I had lovely conversations with all the faculty, nevertheless faced the toughest interview of my life. I interviewed in one more place subsequently in India, but the level of discussion at CeNSE goes unparalleled. On a lighter note, perhaps it is my Indian-ness , a.k.a correlating the quality of a job/education with how difficult it is to get into it, that prompted me to take the offer as soon as it was made, without a second thought. Call it a honeymoon period, I have been having a good time ever since I joined (despite the CoVID situation). Perhaps, some form of harsh reality will hit me soon, but I am growing in confidence day-by-day that with the support system at CeNSE, I can face it.

C-DNA Familiarization Workshop

The C-DNA Familiarization Workshop, supported by the Department of Biotechnology, aims to be an awareness program that exposes participants to all the facilities available for nano-biotechnology research at CeNSE. Amidst the Corona Virus pandemic, this year's workshop was conducted online from 8th to 10th September, 2020.

The 3-day training program was open to all researchers interested in pursuing nano-biotechnology research. Out of the 92 registrants invited to participate, 60 participants successfully completed the program. The training program had extensive lectures by faculty members at IISc, Bangalore, and AIIMS, New Delhi. There were 16 live-streaming lectures along with pre-recorded videos of state-of-the-art facilities at CeNSE, such as National Nanofabrication Centre (NNfC) and Micro and Nano Characterization Facilty (MNCF). The lectures were followed by Q&A sessions attended by Technical staff of NNfC and MNCF.

At the end of the training program, participants were made familiar with different fields of research under nano-biotechnology at CeNSE. The participants were encouraged to utilize the facilities available at CeNSE for their nanotechnology research, and to submit research proposals to be considered for hands-on training as well as for short-term projects at CeNSE.

The program was coordinated by Ms. Grace Abraham, with the support of Ms. Akila Chetan and Ms. Sai Prathyusha, under the guidance of Prof. Ambarish Ghosh.

Feedback from some of the participants...

"Amidst the Corona pandemic, it is a great initiative to have the workshop online. All the lectures were really excellent, very informative. The time duration of 90 minutes was apt, because we could have interactive sessions too. The organizers have made an excellent effort to include the "Virtual lab visit". We could get a gist of what to expect when we have hands-on training during second phase. Eager to be a part of the second phase of the training soon. Excellent overall. Thank you again." -

Dr. Shyama Prasad Sajankila, NMAM Institute of Technology, Nitte, Karnataka.

"Highly informative lectures which were delivered in a well structured manner. Lab sessions were very useful since it had given a good insight into every minute detail of synthesis and analysis methods of nano-materials." -

Dr. Neena P, SNM College, Ernakulam, Kerala.

"Extremely important and informative. I am looking forward to learning more on hands-on training. Thank you very much IISc, for giving this wonderful opportunity." -

Dr. Sambashiva Daravath, Osmania University, Hyderabad, Telangana.

Best Thesis Award, PhD - 2020

Dr. Anamika Singh Pratiyush has won the Best Thesis Award for the year 2020. Her citation reads:

"In the area of Gallium oxide (Ga2O3) based UV devices which is an emerging and fast-expanding field of research, Anamika demonstrated some of the 'first time' as well as record-performing devices, making a mark in the community. Her first 1st -authored paper (Appl. Phys. Letter., 2017) has gathered 116 citations in the last 3 years and was picked by the Editor as one of their Top Ten most highly cited papers of 2017-2018. This paper is still considered one of the seminal works in the field of Ga2O3 photodetectors. This could probably be the highest cited paper from CeNSE published in the last 3 years (by a CeNSE student)! She has four 1st -authored journal papers in total, of which, two of her key papers reporting the first self-powered lateral UV device (Jap. J. Appl. Phys.) as well as vertical Schottky device (IEEE Photonics Letters) have garnered 56 citations in total in the last two years. Besides citation, she was the reason why her advisor, Prof. Digbijoy Nath, ended up getting a US AFOSR research grant to study optical properties of Ga2O3, because the program manager (Dr Ali Sayir) was extremely impressed with her presentation (research results as well as her oratory skills) during Gallium Oxide Workshop held in Columbus, USA in August 2018. He was then asked to write a white paper and subsequently a proposal on the same, which got granted. In the 3rd Workshop on Gallium Oxide (GOx) held at Columbus, USA in August 2018, there was only one oral talk from India which was Anamika's talk. Even in the 2nd International Workshop on GaO (IWGO) held in Parma, Italy, Anamika's presentation was the only oral talk from India. Both talks were very highly praised. Her talk at ICEE 2018 was highly admired by several professors from USA as communicated to her adviser directly by them. In short, apart from an outstanding performance on the research front, Anamika has shone brilliantly on the international stage, representing IISc (and the Indian Ga2O3 community!), helping her advisor in forging collaboration and in getting research grants."

Other finalists to contend with Anamika for this award were Dr. Velpula Balaswamy (adviser: Prof. VR Supradeepa) and Dr. Souvik Ghosh (adviser: Prof. Ambarish Ghosh).

Best Student Paper (2nd place)

Viphretuo Mere and team received the Best Student Paper AWARD (2nd Place) for their paper titled *Silicon Photonics Enabled on-Chip Optical Readout of piezoMEMS Resonator* at IEEE Sensors 2020.

Viphretuo Mere

Sudhanshu Tiwari

Prof. Aditya Sadhanala has been awarded the **2020 MRS Nelson "Buck" Robinson Science and Technology Award for Renewable Energy**. The award recognizes work done for the development of novel sustainable solutions for the realization of renewable sources of energy.

Prof. Digbijoy N Nath has received the **Young Engineer Award-2020 from the Indian National Academy of Engineering**. The award recognizes outstanding achievements/contributions made by Young Engineers in a branch of engineering.

Prof. Ambarish Ghosh has been elected **Fellow of the Indian National Academy of Engineering.**

Prof. Srinivasan Raghavan has received the **Abdul Kalam Technology Innovation National Fellowship** from the Indian National Academy of Engineering. The award recognizes and supports translational research to achieve excellence in engineering, innovation and technology development.

In Memoriam

Remembering Prof. V. Venkataraman

Prof. Venkatakrishnan Venkataraman, Venkat to the ones close to him, joined IISc in the year 1994 as an Assistant Professor in the department of Physics. He obtained his Bachelors (B.Tech. in Electrical Engineering, 1988) from IITM and PhD from Princeton University (1993). He served as the Chair of the Physics Department and the Centre for Cryogenic Technology (CCT). His main research interests included Semiconductor Physics, Microfluidics, and Device Technology. He is remembered by his students as a great teacher who achieved the remarkable feat of bringing a Mechanics class to life!

> *"A diligent individual committed to doing his bit properly."*

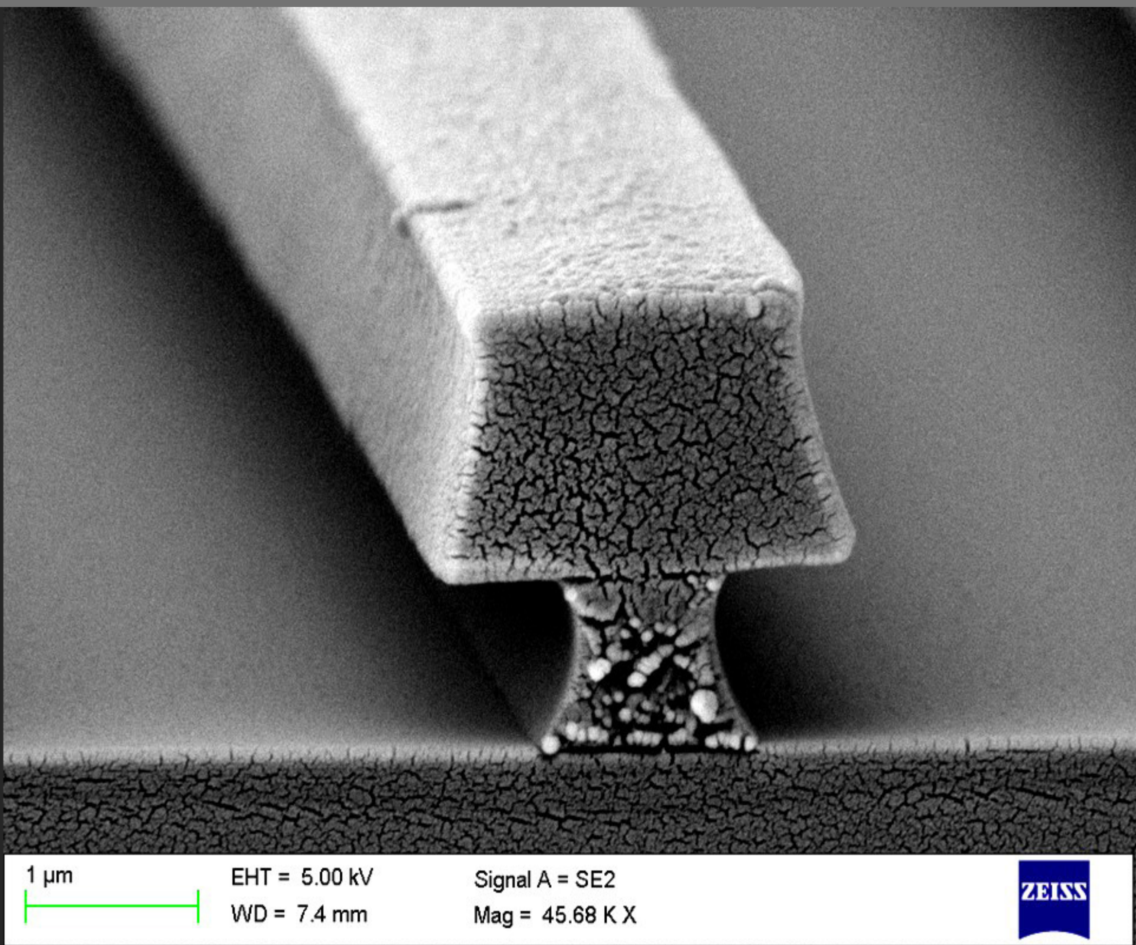
Prof. Venkataraman got involved in CeNSE right from the Centre's early days and played an instrumental role in implementing the Indian Nanoelectronics Users Program (started in 2008 with the support of Ministry of Electronics and Information Technology, MeitY). He was one of the co-investigators in a team of four. As part of the program, research proposals were invited from researchers around the country, and were reviewed and screened so that the selected participants could be invited to work on their projects at CeNSE. Prof. S.A. Shivashankar (CeNSE), who was the chief investigator of this program, remembers Prof. Venkataraman as being very diligent in executing the process and particular about doing his bit properly. He was committed to mentoring the horde of participants during the entire first phase of INUP (2008 to 2013), which successfully produced multiple manuscripts, patent filings, and parts of PhD/Masters theses and dissertations.

Prof. Venkataraman speaking at an INUP workshop.

Prof. Venkataraman's reports and presentations on the progress and success of phase I to MeitY and reviewers of the program were key to MeitY renewing INUP for its second phase (2014 to 2019). He was the Principal Investigator (PI) during the second phase and thus, was even more involved than before in making sure that the program was a success. While serving as the PI for INUP during this phase, Venkataraman became the Chair of the Physics Department as well as CCT. He also led an active group of researchers and taught courses to graduate students. Despite all these commitments, he never wavered in offering his support to the participants of INUP and was always available to anyone who needed his mentorship. He also offered lectures and seminars as part of INUP, which sometimes were conducted in remote parts of the country. These lectures have been important in promoting INUP and driving the participants' interest in the program.

Prof. Venkataraman's support to INUP continued even after the program began to expand to offering workshops to international participants (through MEA's ITEC program). Prof. Shivashankar recalls that during one such workshops in 2019, Venkataraman gave a lecture to a group of participants from 13 different countries, where he made an outstanding presentation on Microfluidics (one of his primary research interests) - a talk well appreciated because of the clarity it offered on various concepts of Microfluidics.

Prof. Venkataraman also served as an Adjunct/Associate member on the faculty at CeNSE. In this role he contributed to ideas that shaped CeNSE itself. He is remembered by his colleagues and students alike as being friendly and approachable. His untimely demise has left many in his personal and professional circles with a deep sense of loss, and he is very dearly missed by all of them.



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