CeNSE Newsletter

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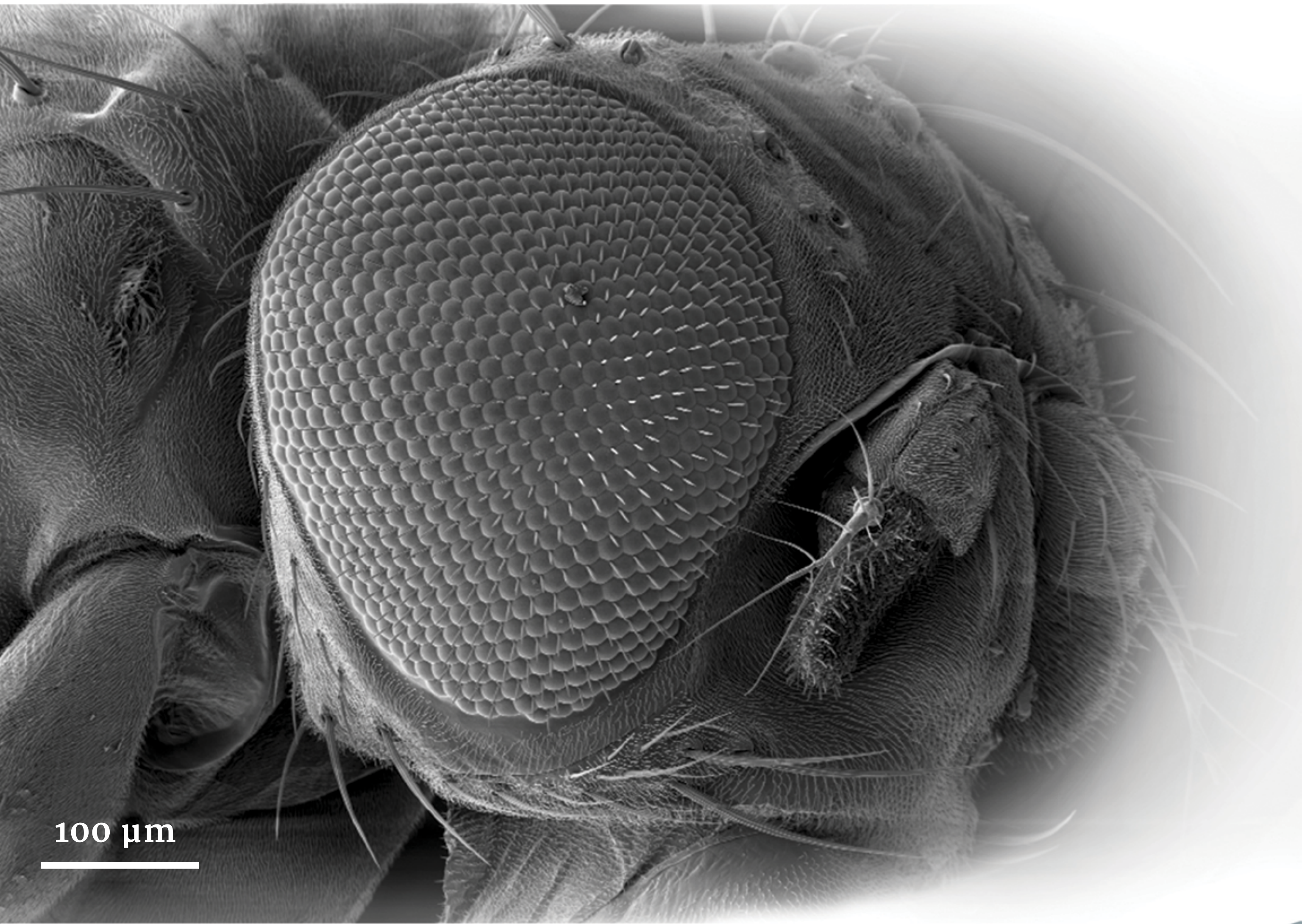
Centre for Nano Science and Engineering

CeNSE @ IISc



INDIAN INSTITUTE OF SCIENCE

CONTENTS

Cover photo: SEM image of the compound eye of Drosophila fly. Refer to page 11.

> *"The time has come for us to be fearless, for us to be confident in our abilities, and for us to use technology to deal effectively with our most pressing issues of poverty, health, and energy."*

Rudra Pratap

When the Centre opened its doors in 2011, our goal was not to just conduct good research — that is a job requirement; rather, our goal was to change the landscape of interdisciplinary research in India. After four years of hard work, I am happy to report that we have already achieved considerable success. Let me highlight three achievements. First, the Centre has trained a new breed of researchers who are uninhibitedly ambitious. By providing world-class facilities we have taken the issue of resource constraints off the table. We have also given intellectual freedom including the freedom to tinker, fail, and tinker some more. We are already seeing the fruits of this in the form of new ideas, new processes, and new science that has started coming out of the Centre.

Second, the Centre spearheads an unprecedentedly successful outreach programme. Through the Indian Nanoelectronics Users Programme (INUP), the Centre has provided access to its top-notch facilities to more than 1000 users from across India. These users are students, young faculty, and industrial researchers who never before had the opportunity to do hands-on research of the calibre made possible by the Centre. This invaluable experience has not only translated into over 80 research papers and 7 patents but, more importantly, has begun to change the way education is imparted all over India.

Third, the Centre has broken new ground in its outreach to industry. The Centre actively engages with more than 30 companies and national labs. We have especially close interactions with our 7 industry affiliates with whom we have joint projects, hold workshops, and develop technology. Increasingly. Indian industries want to move up the value chain, from low-tech production to high-tech innovation and we at CeNSE are active partners in their journey.

Looking ahead, I want the Centre to focus on technology that address India's needs. The ultimate goal is not research papers but social impact, and to achieve that, we have to make sure that our contributions reach the common man in the form of a product that he can use. CeNSE is more than eager to work with entrepreneurs, engineers, social scientists, and industry to identify a problem and develop a commercially viable practical solution. For too long we have looked east and west for innovations. The time has come for us to be fearless, for us to be confident in our abilities, and for us to use technology to deal effectively with our most pressing issues of poverty, health, and energy.

We are an inspired lot, full of enthusiasm and brimming with optimism. We invite you to work with us and pursue your goals in a work environment that gets more exciting every day!

PAPER AS A DIAGNOSTIC PLATFORM

Manoj Varma

Point-of-care testing for the detection of clinically relevant molecules, chemical contaminants in food and so on has emerged as an active and rapidly advancing field in recent years. This activity is in step with the increasing "personalization" of technologies, such as anytime, anywhere- computing and communication, possible with advanced smartphones. Along similar lines we would like to develop anytime, anywhere chemical analysis capabilities to quickly detect the onset of infectious diseases or toxic contaminations at their point of origin. This is the reason why point-of-care testing technologies have attracted the attention of a large community of researchers internationally.

Many of the earlier works in this area dealt with the fabrication of soft polymeric "bio-chips" akin to the more familiar silicon based electronic chips. The idea was to pump tiny amounts of fluids containing the sample to be analyzed, reagents and so on through micro-scale channels in these biochips to perform the tests required to detect the target molecules. However, such biochips require power sources for pumping the fluids, signal measurements and so on which reside outside the chip. Multiple sequential fluidic operations require micro-scale valves and mixers which are challenging to fabricate as well as suffer from reliability issues. Many of these challenges have impeded the widespread acceptance of point-of-care testing in our everyday lives. In this context, an exciting recent development is the use of the humble paper as a diagnostic platform.

Paper is a porous material mostly made up of cellulose fibers which can wick fluids through paper and transport them through capillary action. Due to this passive pumping mechanism, external power sources are not required for pushing samples or reagents through

paper “chips”. Moreover, the porosity of the paper also serves to immobilize reagents required for biochemical testing procedures in test and control regions. Paper has indeed been used in chemical analysis for quite some time now. Paper based pH strips are being used by almost all school children as part of their chemistry curriculum. Similarly, paper based glucose and pregnancy test strips have also been used popularly. The recent innovations in paper based chemical analysis have come in the form of methods which extend the functionality of paper in sensing. For example, by printing wax patterns on paper or by stacking single channel paper devices on top of each other with plastic separators, researchers have created paper based chemical sensors capable of higher degree of multiplexing as well as the capability to perform sequential mixing operations essential to many biochemical tests.

Similarly, by using dissolvable barriers embedded in paper, valves have also been demonstrated. Color change has been used as the dominant signal read-out method in paper based diagnostic devices. Some of the recent advances in signal read-out have been in the acquisition of color changes using smartphone cameras with automated image analysis capability to reduce the subjective bias in interpreting color changes.

Recent work has also focussed on electrochemical and impedance measurements with higher detection sensitivity compared to color based detection. Another interesting application of paper based devices is in the fabrication of 3D cell culture media by stacking paper devices embedded with growth media. These 3D cultures are expected to be behaviourally closer to the in-vivo tissue structures compared to the 2D cultures typically obtained using other methods. We expect to see more such innovative uses of paper in sensing and other biochemical applications in the years to come.

NEUROELECTRONICS LAB AT CENSE — NEURONS IN A DISH CONTROL A ROBOT

Sujit Kumar Sikdar

My association with CeNSE was rather unusual. Our work on the use of multielectrode arrays (MEAs) at the Molecular Biophysics Unit, IISc to understand the changes in neuronal network topology during epileptic activity using an in vitro model of epilepsy, with neurons cultured on planar multielectrode arrays strangely caught the attention of Profs. Amrutur Bharadwaj and Navakanta Bhat from the ECE dept. The interest then, was to start a program on fabricating retinal implants at IISc with the initial aim of fabricating the multielectrode arrays locally.

The first prototype was ready in a few months by Prof. Navakanta's group. It was decided to take it to an advanced level by creating a Neuroelectronics laboratory at the new CeNSE building that had just come up, where locally fabricated multielectrode arrays could be tested by actually culturing neurons on them. The group became larger with inclusion of faculty with varied expertise and one of the thrust areas was to understand if we could use the activity of a network of randomly connected neurons to control a device like a robot or train them. This was brought to fruition by the infectious enthusiasm of Mr. Jude Baby George, who joined the interdisciplinary PhD program at CeNSE under the joint mentorship of Prof. Bharadwaj and myself.

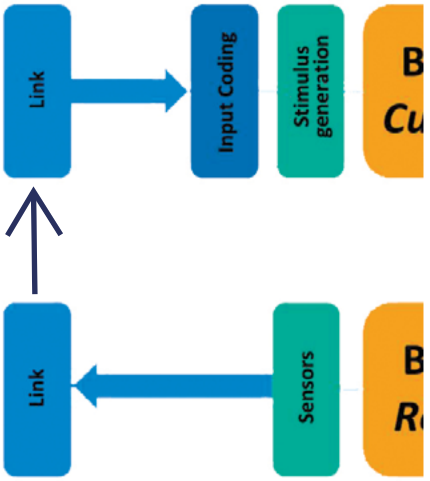
The electrical activity of the brain and its constituent cells has fascinated many for centuries.

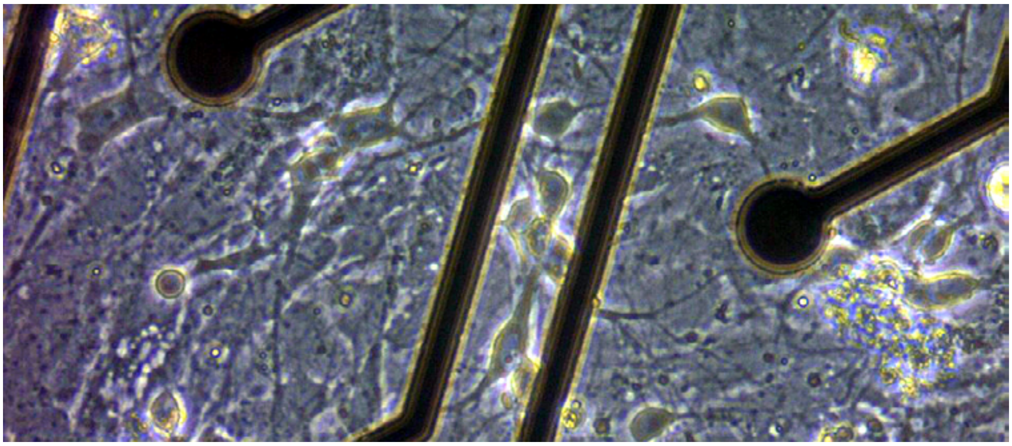
Tapping its activity and learning the secrets of how they operate has been a continuous engagement. One way of doing this at the single neuronal level is by using multielectrode arrays (MEAs). Multielectrode arrays are devices that serve as neural interfaces and connect neurons to electronic circuitry with plates or pillars using which electrical signals from neurons can be either obtained or delivered. Unlike the implantable MEAs, the non-implantable MEAs are planar arrays and used for in vitro studies.

Electrical activity in neurons and other excitable cells occurs due to the regulated activity of ion channels that are special membrane proteins with pores that are embedded in the membrane bilayer and carry ionic current. The MEA electrodes transduce the voltage due to the redistribution of ions in the immediate environment of the neuron, into an electronic current.

During stimulation, electrodes convert electronic current into ionic current through the salty tissue culture medium causing the activation of voltage gated ionic channels that lead to depolarization of the neuron and firing of action potentials. The recording and stimulation are achieved by mounting the MEA dish with live neurons on an electronics platform that receive and deliver electrical signals through the embedded electrodes with which the neurons make tight contact.

The setup is placed inside a sterile tissue culture incubator to allow a contaminant free and healthy environment for the neuronal culture to survive and grow.





Neurons grown on MEA. This provides us a system to study the behavior of a living network of neurons.

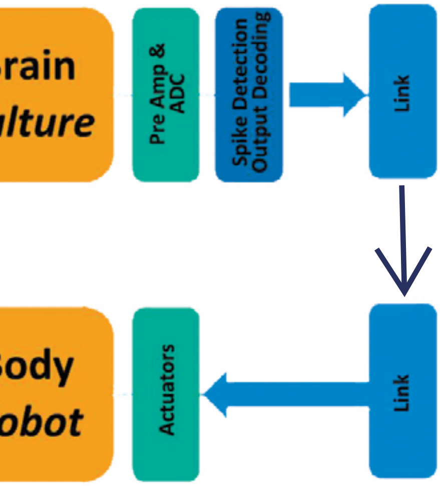
The longest period that we could keep the neuronal network alive is about 100 days. The tissue culture skills and attention of Grace Mathew Abraham was important in this.

Using a computer and a coding system, the extracellularly recorded spike activity of the network of neurons picked up by an array of 120 electrodes was decoded and in turn was used to train the network of neuronal cells to generate specific signal responses to specific codes. This in turn was integrated with the robot with infrared light sensors placed outside in a circular arena. The robot used the light sensors to "sense" the presence of obstacles in its vicinity and relayed it to the electronics platform via a wireless connection. The sensory information from the robot was converted to specific stimulation sequences that served as input codes to the neurons in the MEA dish.

The neuronal cells responded to this stimulus by generating their own electrical activity. The software then analyzed this activity in real time and decoded and mapped it to an appropriate command for the robot so that it could avoid obstacles. The brain cells in the dish controlled the robot seamlessly. The following clip shows the robot exploring an arena while avoiding the obstacles (*http://youtu.be/j4asE9l7OsI*). It illustrates how a bunch of brain cells in a dish can deliver precise electrical instructions to control the robot when appropriately trained.

The research comes under Neuro-electronic hybrid systems and the field is attracting a lot of attention, where, the natural information processing and problem solving ability of brain cells are being understood and exploited. The Neuroelectronics lab at CeNSE in IISc is now amongst the select few laboratories in the world where this technology has been successfully implemented using planar MEAs. The study was presented in the 28th International Conference on VLSI Design and Embedded Systems (2015), for which it was awarded the A. K. Choudhury Best Paper Award.

The other activities of the Neuroelectronics lab in brief, include fabrication of nano-needle gated FET array for intracellular recording and stimulation of neurons, development of optical setups for recording electrical activity of neurons and stimulating them optically.



Reference:

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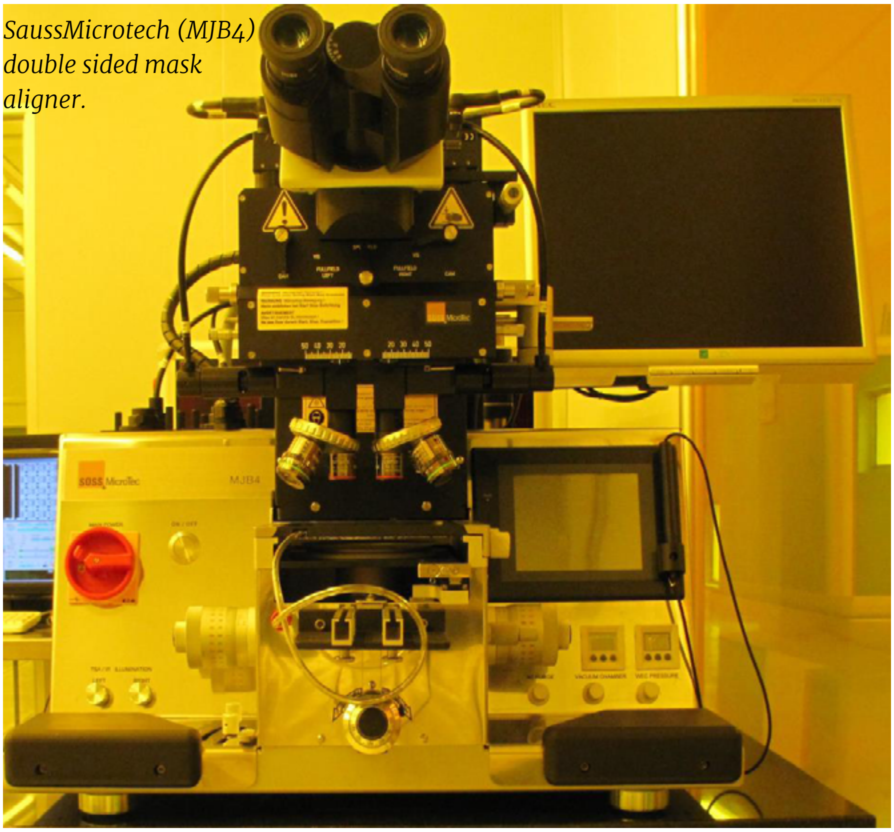
LITHOGRAPHY

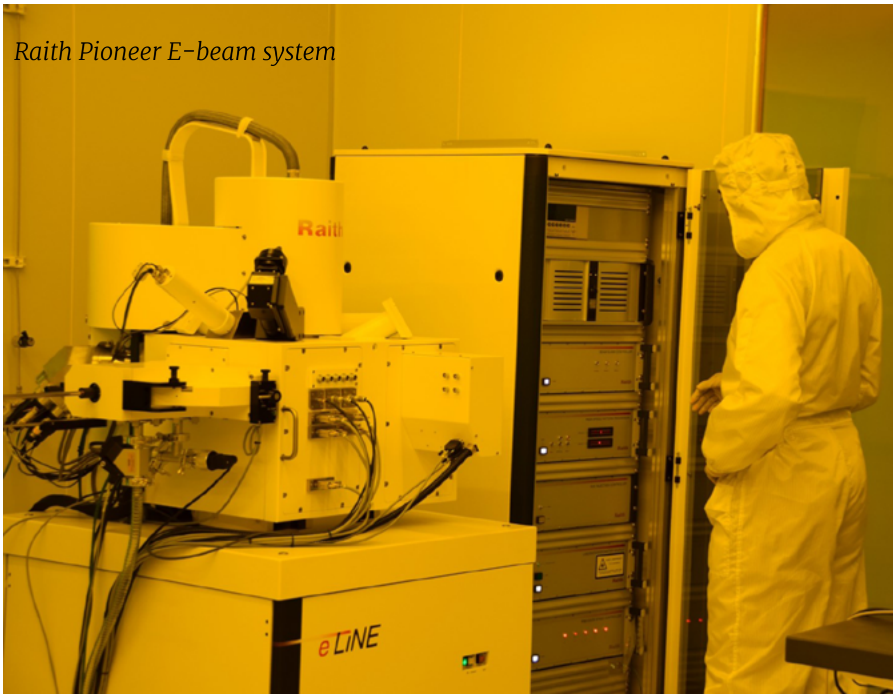
CAPABILITIES

Gopalkrishna Hegde

The heart of micro-nano fabrication is lithography, as the minimum feature size of the micro-nano devices/structures to be achieved is decided by the capability of the lithography facilities established in the so-called Fabrication Centres or simply Fabs. CeNSE has established state-of- the- art lithography facilities and the same is being used by many researchers not only from within India but also those from abroad. NNfC has a "class 100" clean room spread over 2000 sq. ft. dedicated to lithography. It houses both optical and electron beam lithography systems, mask-writing facility, a wafer bonder, and in-line testing facilities. Some of the lithography facilities available at NNfC are shown in the figures.



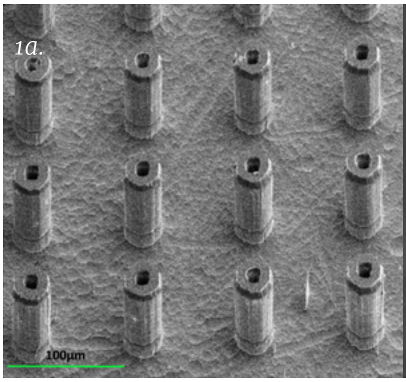
SaussMicrotech (MJB4) double sided mask aligner.

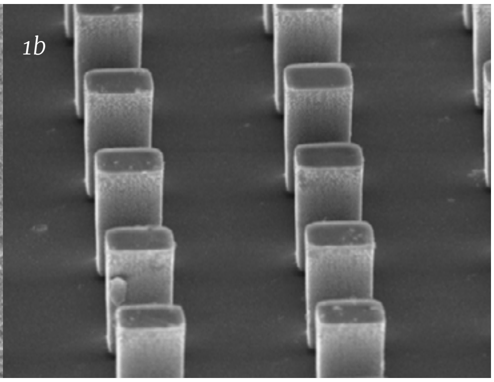


Raith Pioneer E-beam system

The heart of lithographic process is mask fabrication. NNfC has two systems for this, one Laser-based (Microtech LW-405) and the other LED-based (Heidelberg uPG501). Over the last five years, we have fabricated more than 1500 masks, with a minimum feature size down to 2 micrometers, on 5" soda lime glass mask plates, for researchers from the academia, industry, and the strategic sector of the country, and a few universities abroad.

We have two mask aligners (Suss MicroTec. MJB4 and EVG620) in the optical lithography section with similar specifications and capabilities in terms of, minimum feature size and wafer handling. In addition, the MJB4 has a nano-imprint lithography attachment. We have achieved critical dimensions of 1 micrometer on silicon using the available tools and explored various types of photoresists to suit users' research interests. So far we have optimized the lithography processes for about 15 different photoresists (AZ-series,

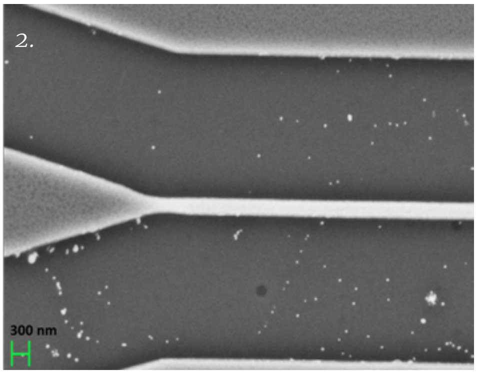




1a) SEM image of tapered hollow Si microneedles (200um height and 80um outer dia) for drug delivery,

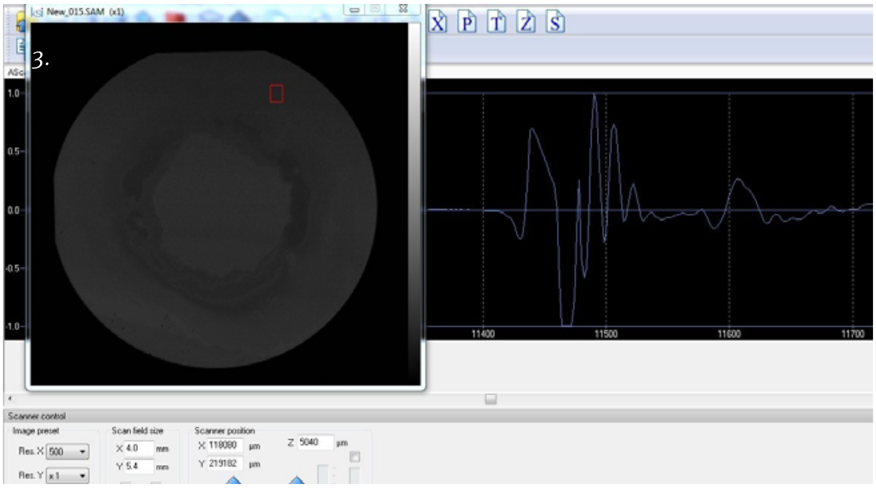
1b) Oxide coated square micro pillars (10 μm), fabricated using Laser writer, EVG Mask aligner and DRIE.

2) SEM image of long (4mm) waveguide structure with tapering at one end fabricated on SOI wafer using our E-line attached with FBMS (DRDO funded) facility



3) Gold-gold bonding process recently optimized at NNfC. Scanning Acoustic Microscopy (SAM) image of the perfectly bonded 3" wafer

4) EVG501 Bonder



Scanner control
Image preset
Res. X 500
Res. Y x1
Scan field size
X 4.0 mm
Y 5.4 mm
Scanner position
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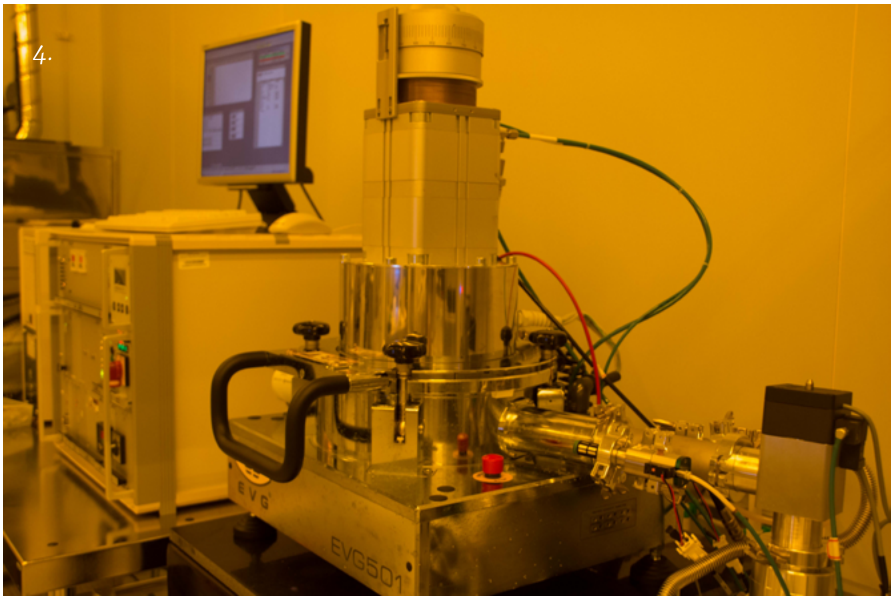
Z 5040 μm



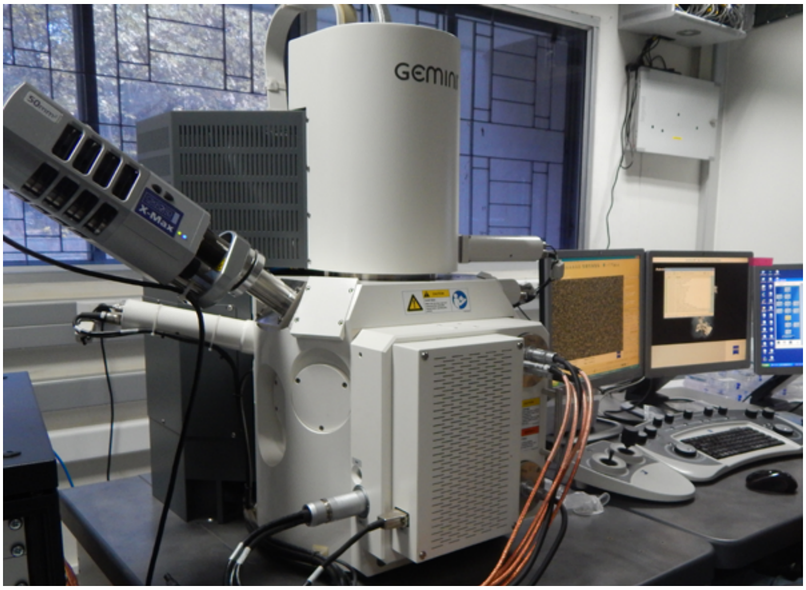
S1813, nLOF, SU-8 series) both positive and negative tone catering the needs of micro-nano research community. Exploring efficient new photoresists, developing new processes, stretching the tool capabilities and the "service motto" are the strengths of our litho team. Some of the new structures fabricated using the processes developed at NNfC are shown aside [1a, 1b, 2, 3].

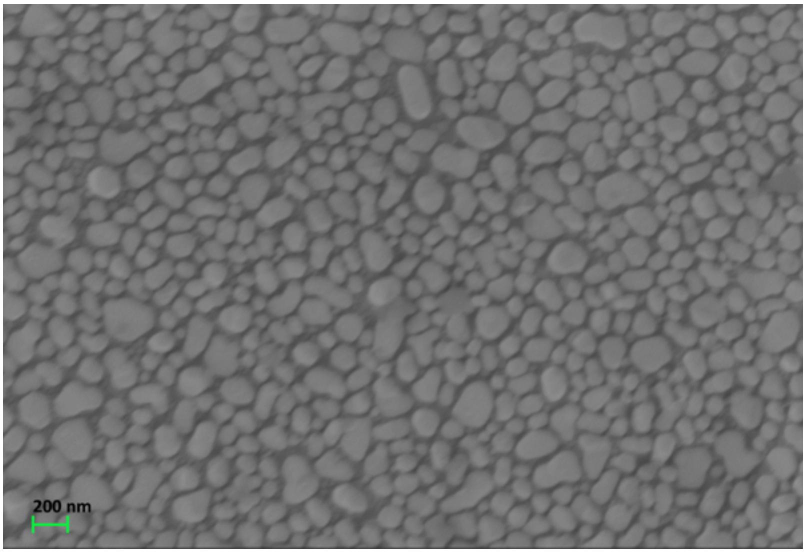
It is well known that optical lithography is limited by the diffraction limit of light. It is not possible to use the UV-lithography effectively when desired structure dimension are below 500 nm. In such cases, E-beam lithography can be used: NNfC has advanced E-beam lithography facility as well. The clean room houses two electron beam systems, E-line and Pioneer (Raith, Germany). With these, we have optimized processes to fabricate structures with minimum feature size down to 10 nm. Further, we have optimized E-beam lithography processes for seven photoresists (PMMA, HSQ, Ma-n- 2401), both positive and negative, to achieve critical dimensions of 10-50 nm. We have also introduced two photoresists (PMMA, AZnlof 2070) suitable both for optical and E-beam lithography. Some interesting structures fabricated by processes developed at NNfC using optical, E-beam lithography, and other associated process are shown.

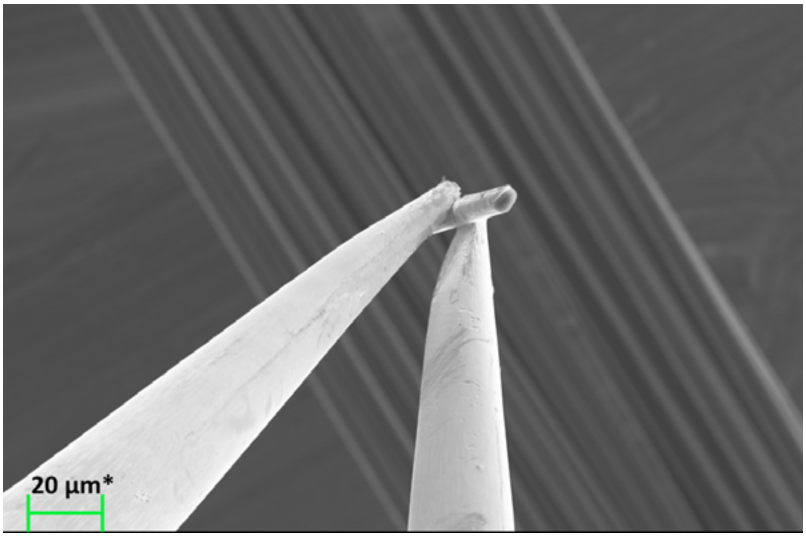
The lithography facilities and fabrication processes developed using these facilities at NNfC are comparable to any other similar facilities established in academic institutions elsewhere in the world. The NNfC also facilitates laboratory courses in the Institute.

SEM EDS CAPABILITIES

S. Varadharaja Perumal







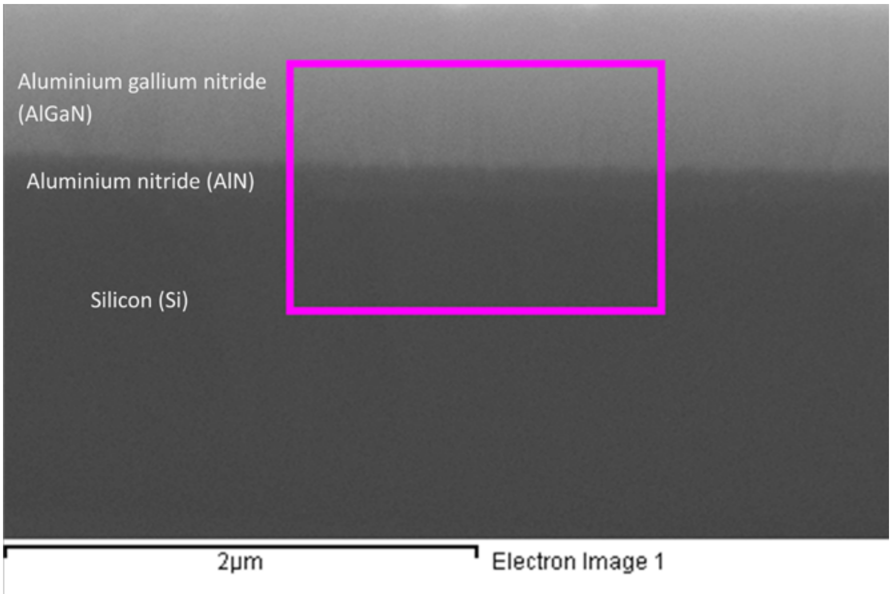
The Micro and Nano Characterization Facility (MNCF) is a centralized facility for characterization of Micro and Nano structures and devices. The MNCF is a 5000 sq. ft. precision-controlled environment, housing four distinct laboratories for Electrical, Mechanical, Optical and Material Characterization. This national facility with a plethora of high-end equipment spanning multiple disciplines of Nano Science and Engineering is one-of-a-kind and rarely to be found under a single roof. The mission of this facility is to support research and educational objectives of IISc researchers, external academic users, INUP users, Industry, and National Laboratories.

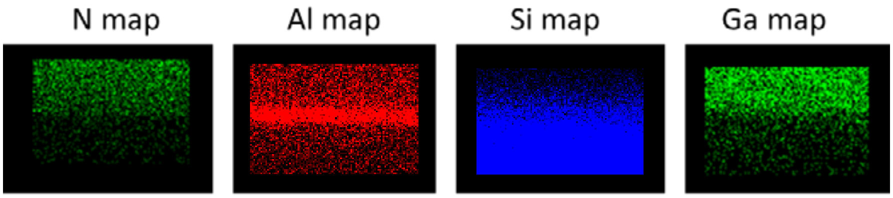
The Materials Characterization laboratory has Scanning Electron Microscopes (SEM), a Focused Ion-beam microscope, and an X-ray Photoelectron Spectrometer for studying different materials properties (structural, functional) with high precision. The tools are handled by highly trained technical and support staff. This article highlights the capabilities of the SEMs and the associated Energy-Dispersive X-ray Spectroscopy analysis (EDS) through selected examples. Recent updates to the MNCF website and SEM utilization statistics are also provided.

A Scanning Electron Microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The detailed three-dimensional and topographical imaging and the versatile information can be gathered from different detectors.

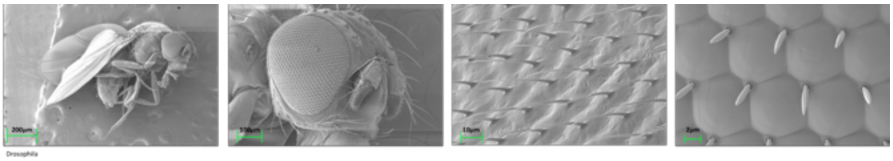
CAPABILITIES AND ACHIEVEMENTS USING SEM

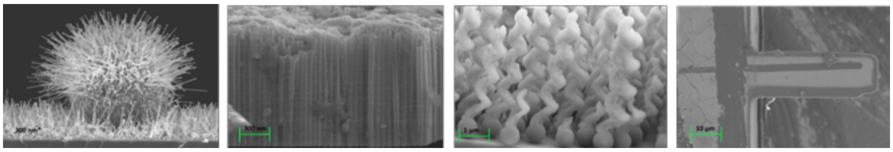
SEM imaging at very low accelerating voltage (100 eV) was done with a standard Au/C sample.





Topmost: EDS spectrum of AlGaN/AlN/Si sample
Top: Cross-sectional EDS mapping of AlGaN/AlN/Si
Below: Cross sectional images taken from different experiments using SEM at MNCF, CeNSE.
Bottom: Biological samples were studied and presented during IISc Open Day 2015





<- Opposite Page:

Top: SEM tool at MNCF, CeNSE
Middle: Low accelerating voltage (100 eV) imaging of Au on C sample
Bottom: Micromanipulator holds a 20 µm carbon fibre.

SEM WITH MICROMANIPULATOR

The advantage of having micromanipulator enables to locate and do measurements such as Force and I-V characterization.

APPLICATIONS ON SEM-EDS

SEMs with X-ray microanalysis can provide qualitative and quantitative elemental analysis of a specimen with a sampling depth of 1-2 microns. The interaction of the incident electron beam with atoms in the sample causes electronic transitions which result in the emission of X-rays. The energies of the X-rays emitted are characteristic of the elements constituting the sample. Detection and measurement of energy permits the elemental composition of the sample to be identified by this non-destructive technique. Quantitative compositional analysis can also be obtained by analysis with and without standards.

Cross-sectional EDS mapping was carried out on a multilayer AlGaN/AIN/Si sample to obtain qualitative and quantitative elemental analysis, as shown aside.

VISUALIZATION CAPABILITIES OF SEM

The SEMs at the MNCF are used heavily. Recent user statistics are as follows:

IISc researchers: 750; Industry and National labs: 11; External Academia: 150; and INUP users: 50; thus a total ~1000 active users and growing. We at the MNCF foresee even greater demand from users in all sectors for SEM analysis in the coming days.

The MNCF website was recently upgraded for ease of use with up-to-date details on the tools, facility information, on-line manuals. Activity tracking and convenient payment modes are some key features of the new web site. Please visit www.cense.iisc.ernet.in/mncf.htm for more information.

Tuning the Dynamic Range of Graphene Resonators

Marsha M. Parmar

Miniaturization trends in semiconductor technologies have carved the pathway for devices in the sub-micron regime. Reducing dimensions has led to various advancements in sensing applications and has increased packaging density. But these advantages have come at the cost of significant reduction in linear operational range due to lower onset of nonlinearity at the much smaller displacements that arise. The linear operational range of NEMS (nanoelectromechanical systems) is set by noise levels at the lower end and by the onset of nonlinearity at the upper end. In our research work, we are exploring the nonlinear behavior of single-atom-thick graphene sheets which, due to reduced mass, higher mechanical strength, together clubbed with exceptional electrical properties, present great potential for mass sensing applications.

Measurements: Graphene sheets were suspended above a global back-gate, clamped by metal electrodes, making a doubly-clamped beam structure. Figure 1 shows a graphene resonator with the measurement scheme.

A typical response of the graphene resonator at resonance is shown in figure 2. We were able to tune the resonance frequency by changing the strain present in the graphene sheets. In our devices, strain is tuned (approximately by two orders of magnitude) largely by changing the temperature (from 300 K to 200 K) and partially by changing the back-gate voltage, as shown in Fig. 3. The strain calculated in these devices is ~0.01% at 300 K and ~ 1% at 8 K.

Results: To estimate the smallest mass that can be sensed using these resonators, we calculate the Allan variance of graphene resonators, which is proportional to the square root of the thermal noise floor and inversely proportional to the square root of strain present in the devices. Although it is mainly thermomechanical noise which sets the lower limit of linear operational range, it is important to mention here that we were not able to observe the thermomechanical noise floor. The experimentally observed noise floor in our measurements is one order of magnitude higher at 300 K than that at lower temperatures. Thus, the Allan variance decreases at lower temperatures and hence the mass resolution (which is proportional to Allan variance) improves. We have achieved a mass resolution of 100 yoctogram (10-24 g), which is an order of magnitude better than values reported earlier.

References:

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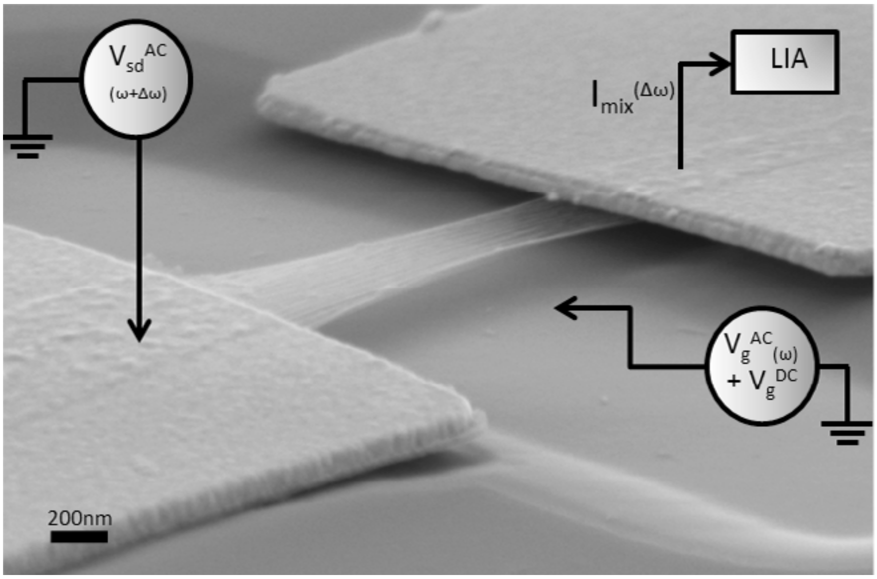


Figure 1: SEM image of graphene resonator with electrical connections.

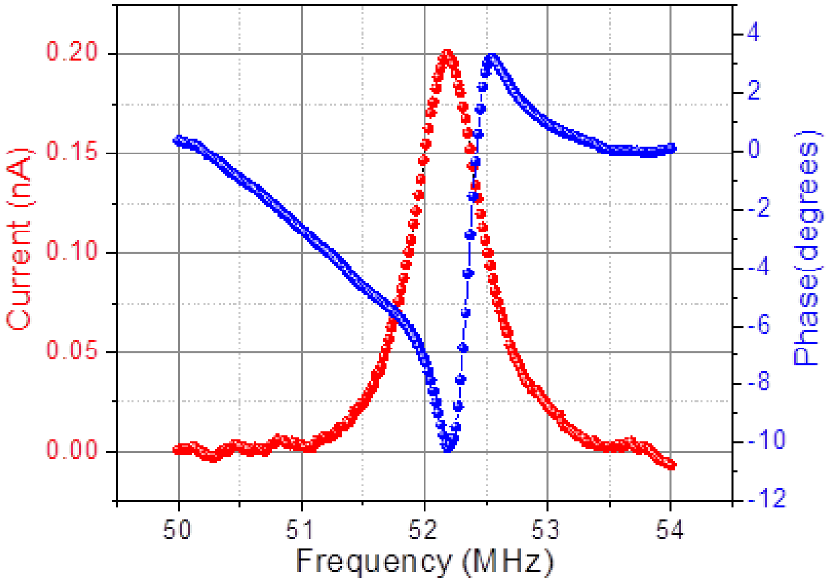


Figure 2: Frequency response curve of graphene resonator.

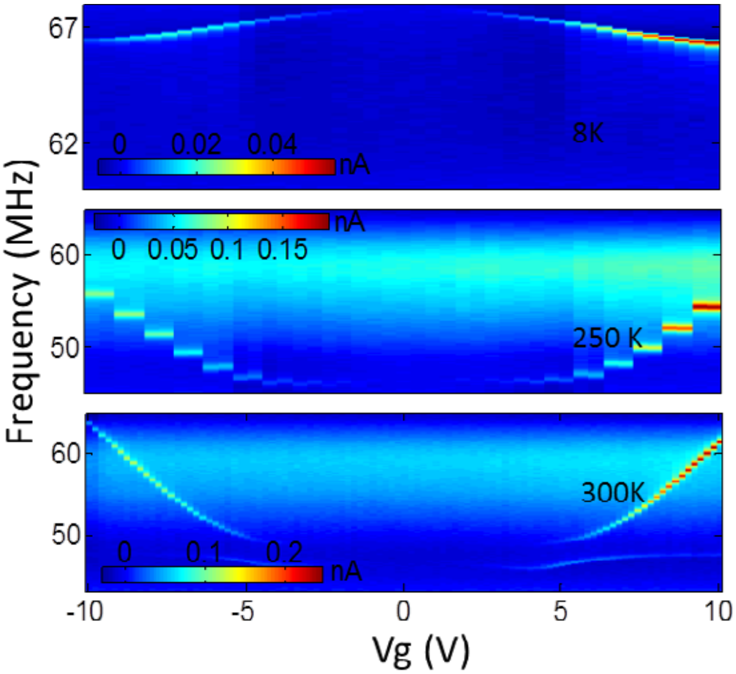


Figure 3: Tuning of resonant frequency with gate voltage at different temperature.

Silver Nanoparticles

Adorn graphene to utilize light efficiently

Atomically separated nano particle arrays for sensing and opto-electronic applications

Debadrita Paria and Ambarish Gosh

Electric field localization and enhancement near metal (plasmonic) nanostructures can have various interesting applications, such as in sensing, imaging, and photovoltage generation. As such, significant efforts are aimed at developing plasmonic systems with well-designed electromagnetic response. Wafer-scale fabrication of a unique three-dimensional plasmonic structure has been realized. The near-field enhancement in the visible range of the electromagnetic spectrum obtained in these structures, of the order of 106, is close to the fundamental limit of what can be obtained in this and similar EM field enhancement schemes. The large near-field enhancement has been reflected in a huge Raman signal of a graphene layer in close proximity to the plasmonic system, which has been validated by FEM simulations.

Smart integration of graphene with such a plasmonic material has enabled record photovoltage generation with responsivity in the order of A/W. This is the highest photovoltage obtained in any plasmonic-graphene hybrid photodetection system to date.

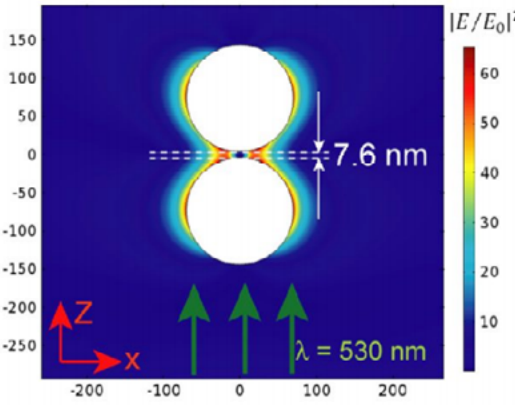
The electric field around a metal nanoparticle is greatly enhanced when illuminated by an electromagnetic wave of appropriate wavelength, due to the collective oscillation of conduction electrons in the metal nanoparticle. This is the underlying concept of the promising field known as ‘plasmonics’.

When two metal nanoparticles are placed very close together, not only the magnitude of electric field enhancement increases by several orders, but the field is also tightly confined to their junction, as shown.

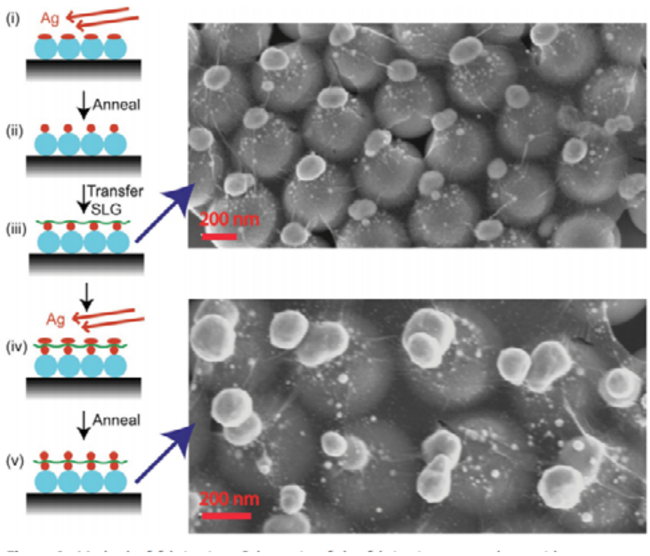
Field enhancement becomes greater as the two particles are brought closer and closer, until a fundamental limit is reached, whence electron tunneling between the two particles takes place. Tunneling is predicted to begin at a separation of about 3 Å and field enhancement is completely quenched at this range. Thus, 3 to 5 Å is the optimum separation between two nano particles to obtain the maximum near-field enhancement.

Fabricating such a “nano gap” is not trivial; conventional techniques like lithography and ALD have failed to reduce inter-particle gap below 2 nm

Numerical simulation showing field enhancement and confinement between two Silver nano particles[1]



Fabrication schematic & SEM images of various steps[2]



Raman map showing hexagonal arrangement of hotspots[2]

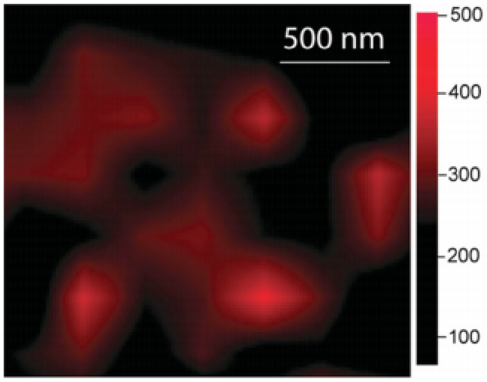
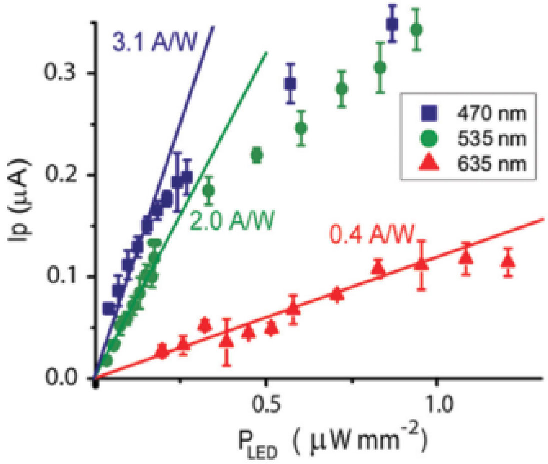


Photo response of the device[2]



(20 Å). In the present technique, a gap of 0.34 nm (3.4 Å) has been achieved uniformly over a large area by combining a shadow evaporation method, known as Glancing Angle Deposition (GLAD) carried out at liquid nitrogen temperature, with conventional graphene transfer protocol, as shown on the right.

Optical characterization by Raman spectroscopy shows a huge enhancement in electric field intensity at the junction of the two nano particles. Thus, such narrowly separated metal nanoparticles can act as a highly sensitive SERS substrate, with great potential for chemical and biological sensing.

Electrical characterization shows that such nanoparticle structures are suitable as a highly sensitive and large-area photo detector. A record-high photo responsivity in the order of A/W has been demonstrated.

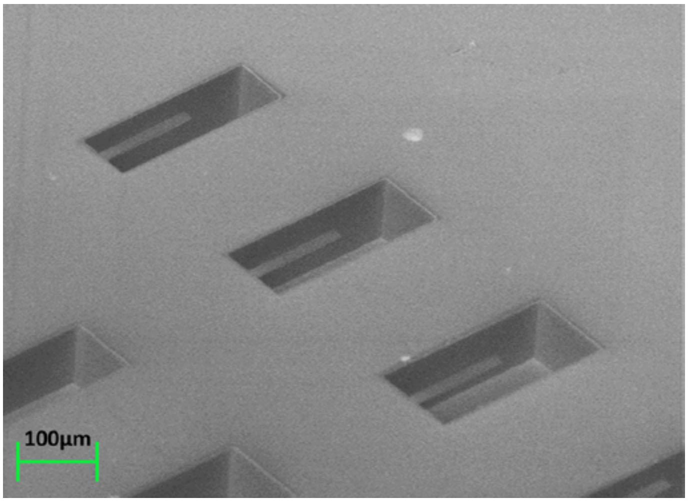
Further, wavelength-selectivity, i.e., photo response which depends on the wavelength at which the nano particle plasmonic resonance occurs, is observed. Thus, such a device can be used as a colour-selective photo detector. The device is easily tunable because of the simple fabrication technique that allows large-area coverage.

Our unique integration of an ultra-thin membrane with plasmonic structures promises to open up a new era of highly sensitive and large-area photodetectors.

References:
[1] Debadrita Paria et al., Proc. SPIE 9371, Photonic and Phononic Properties of Engineered Nanostructures V, 93711G (February 27, 2015).
[2] Debadrita Paria et al., Advanced Materials 27 (10), 1751-1758, 2015.

Alumni Column

S. M. Mohanasundaram,
Project Leader, Soliton Technologies.



My association with CeNSE goes back to 2007, when I joined as a Ph.D. student in the inter-disciplinary program of Nanoengineering for Integrated Systems. When I look back at my early days at IISc, I was too naïve to comprehend or visualize this great facility of national pride, as it stands today. Somehow, I got the impression that a 'Nano' department already existed when I joined. I even remember roaming around the campus for the first few days, searching for this building, which did not exist at the time. All I knew was from observing my Professors, who held frequent, long meetings, and discussed some ambitious plans.

In my early years as a student, our Professors were the face of this Centre, as they trained me in truly multi-disciplinary research. I took courses in five different departments, and visited the labs of many more.

As I started with my research problem, trying to make simple MEMS devices with the facilities available then, it was a struggle. Each process step would be done in a different facility, and I would constantly be on the move in my bicycle, with my precious little device supposedly secure in my pocket. The only thing that kept me going was my Professors' support and encouragement that helped me eventually overcome all the difficulties.

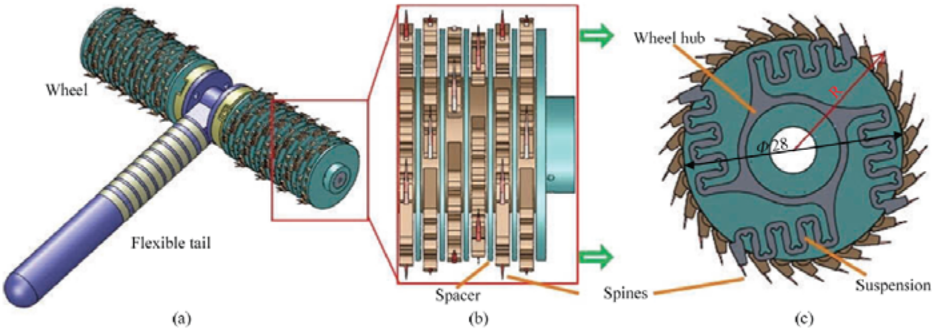
I was fortunate to fabricate the first successfully released MEMS cantilever at IISc. Today those devices would look like child's play. Yet, my professors appreciated and cherished those images, which made all the efforts worthy.

Once the CeNSE cleanroom started functioning, life was easier, thanks to the tireless efforts of our Professors. I could make my devices much quicker. By that time, my research was mature enough to interpret results and draw conclusions. This was the stage when CeNSE faculty were the most valuable.

What CeNSE and its faculty trained us as part of the Ph.D. program go much beyond academic excellence. It is about how to approach a problem in the best possible way, and patience and perseverance needed to succeed. This training takes me a long way, as I venture into the industry, trying to find the problem that's worthy of my life. I am very grateful to have been part of CeNSE and the lasting impact of my experience here.

A Wheeled Wall-Climbing Robot with Bio-Inspired Spine Mechanisms

By Yanwei Liu et al. in the Journal of Bionic Engineering (2015) is demystified through images and sequential drawings.
Collected and annotated by Vamsy Godthi, CeNSE

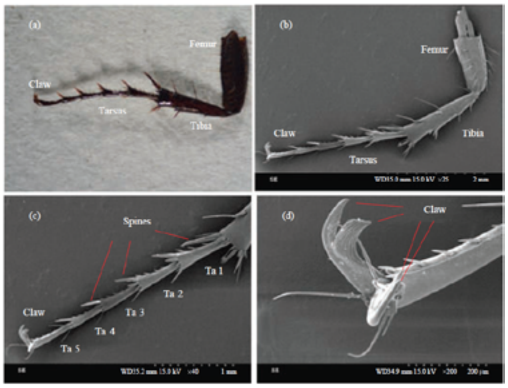


(a) CAD model of the robot design; (b) detail view of spine wheel configuration; (c) section view of the spine wheel.

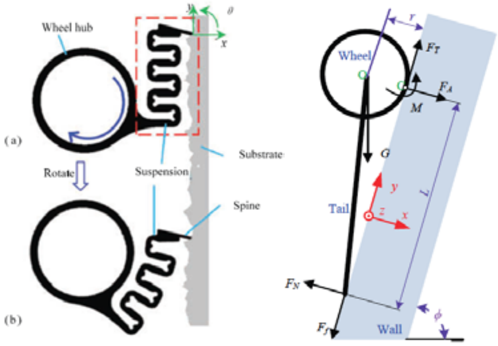
The paper presents a wheeled wall-climbing robot (consisting of two driving wheels and a flexible tail, just like letter "T", so named Tbot) with the ability to climb vertical walls using circular arrays of miniature spines located around the wheel. Inspired by the structure and mechanics of the tarsal chain in the Serica orientalis Motschulsky, a compliant spine mechanism was developed.

With the bio-inspired compliant spine mechanism, the Tbot can steer and travel on the floor at a speed of 50 cm/s. The Tbot is capable of climbing on a 100° (10° past vertical) brick incline at a speed of 10 cm/s and making horizontal-vertical transition.

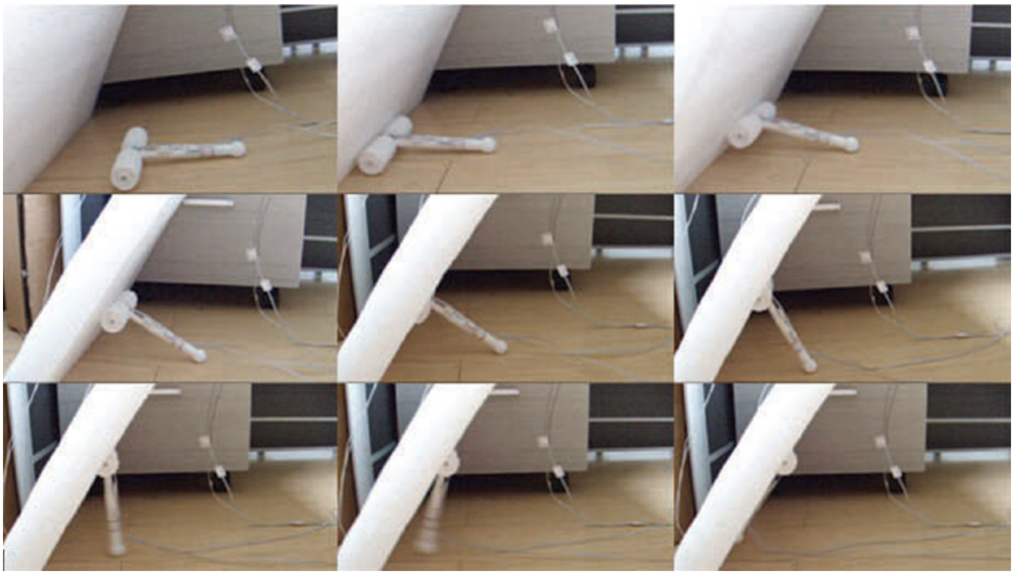
The Tbot is also able to climb a 120° vertical pearl brocade surface up and down at a speed of 20 cm/s. The paper also presents a mechanical model to analyze the forces acting on a spine during a climbing cycle and the simulation and experiment results show that the mechanical model is useful in the optimum design of the Tbot.



The source of inspiration: The compliant tarsus of the Serica orientalis Motschulsky. (a) A photograph of the middle leg; (b–d) SEM micrographs of the middle leg. The tarsus consists of five segments (Ta1–Ta5) with spines at the first four segments, and strong claws on pretarsus.



Bio-inspired Compliant Spine (a) Compliant spine mechanism without deformation; (b) Deformed compliant spine mechanism after rotation of the wheel hub. (c) Free-body diagrams of Tbot



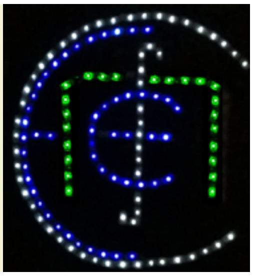
Tbot Prototype climbing a vertical wall: Still frames from a video showing a Tbot prototype making the transition from floor to a 120° pearl brocade surface. To view the video, access the link: http://dx.doi.org/10.1016/S1672-6529(14)60096-2.

Events and Announcements

	SEMINARS	WORKSHOPS
April	“Looking back, looking forward in Diabetes Research” by Dr. Hemraj B Chandalia - Director, DENMARC, Mumbai. *10th APR* “Intense THz generation, detection & its applications” by Dr. Lakshman Krishnamurthy - Intel Fellow, New Devices Group Director, Applied Innovation Engineering. *14th APR*	
May	“Electric stimuli as instructive cues to guide cellular differentiation on electrically conductive biomaterial substrate in vitro” thesis colloquium by Greeshma T. *15th MAY* “Integrated Si Photonics for Today’s and Tomorrow’s Systems” thesis colloquium by Sindhu Seethamraju. *25th MAY*	INUP Familiarization Workshop *18-20th MAY* INUP Hands-on Training Workshop *21-29th MAY*
June	“Introduction to Photonics : A talk in Kannada“ by Dr. Gopalkrishna Hegde. *24TH JUN*	IISc Alumni Global Conference *25-28th JUN*

ANNOUNCEMENTS

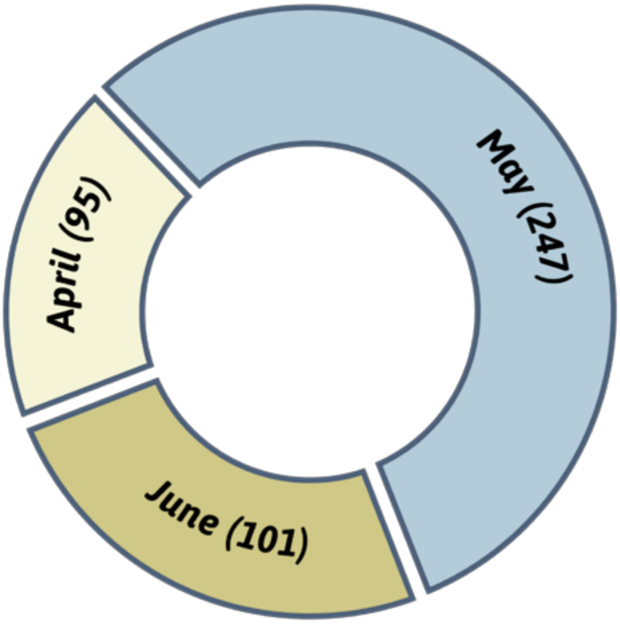
"Harvesting energy from vibrations all around us": work by Rammohan Sriramdas was featured in a Bangalore Mirror article. The logo adorning the CeNSE building, made of 147 LEDs, is illuminated by energy harvested from building air vent/duct vibrations.



IEEE recognises Prof. Shankar Kumar Selvaraja for his significant contributions to technical and professional excellence by elevation to the grade of IEEE Senior member.

Prof. R. Muralidharan joins CeNSE as a Visiting Professor. He was previously the Director, SSPL - DRDO, GOI, and successfully developed Gallium Nitride (GaN) and Gallium Arsenide (GaAs) technologies. His current research areas are GaN, GaAs, Solar Cells, and MEMS.

CeNSE VISITORS



TOTAL VISITORS ~450

UPCOMING EVENTS:

Visit

www.cense.iisc.ernet.in/news_events.htm

Photo by Rahul Singh Kotesa, Ph.D student, CeNSE

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