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INSTITUTE OF SMART STRUCTURES AND SYSTEMS

SUKSHMA

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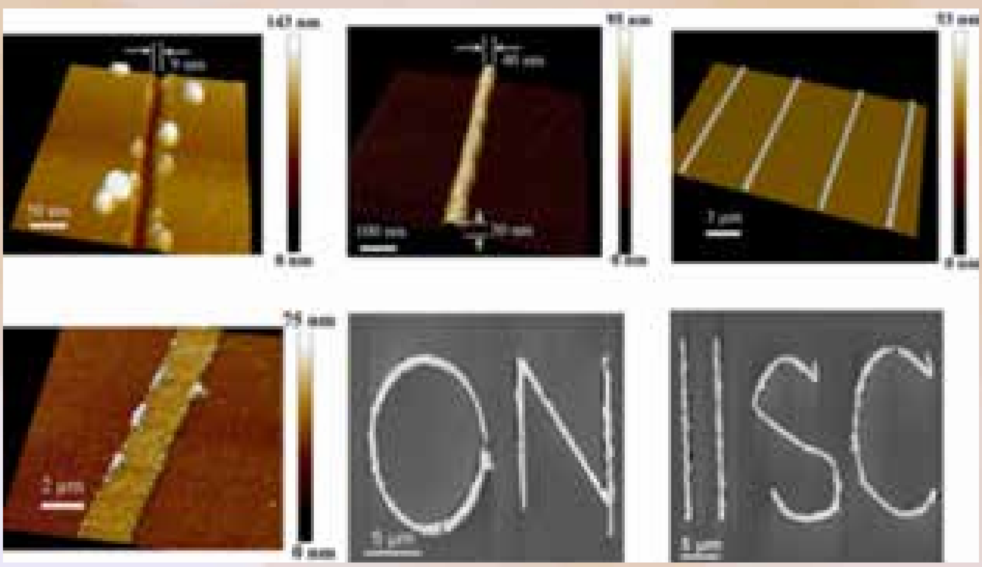
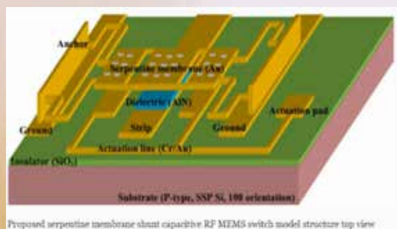


GLIMPSES OF THIS ISSUE

EVENTS

AWARDEES ARTICLES



FEATURE ARTICLE

CONTENTS

1 The Editorial

Dr. Nilanjan Chattaraj

We are delighted to share another issue of Sukshma!

In the last quarter, several Institutes in association with the ISSS have organized numerous events and activities such as short term course, certification course, webinars, technical talk series and many other events. The active participation in all those activities has reflected the enthusiasm of the people across the nation. Such an enthusiasm will definitely flourish the space and scope of ISSS. We feel extremely happy to see that the people are getting benefited through the ISSS platform. If the ISSS can inspire the young minds by giving them a national level platform to showcase their ideas, nothing can be better than this feeling.

In the previous issue of Sukshma, we started to share the articles, which were written by the ISSS Awardees of 2021. The last issue presented some of those articles, which were written by the under-graduate and the post-graduate students. As a continuation of that article-series, in this issue we have shared the remaining articles, which were written by the awardees under the Ph.D., Young Scientist and Technology category. In this issue of Sukshma, we have put an endeavour to share a feature article on Smart techniques for nano patterning. I would like to acknowledge Dr. Santanu Talukder of the Indian Institute of Science Education and Research Bhopal (IISER Bhopal) for contributing such a nice and relevant article.

I would like to wholeheartedly acknowledge Prof. Ananthasuresh, Dr. Vidyashankar and Dr. Veda for putting their consistent effort to keep the society so dynamic. I would like to continue my acknowledgement by thanking the editorial team members Dr. Maligi Anantha Sunil, Dr. Anurekha Sharma, Dr. Anjana jain, Dr. Mira Mitra and Ms. Madhumita Dinesh for their consistent support. Finally the vibrant effort of the whole ISSS team, which is distributed in several academic and research institutions, undoubtedly deserves an overwhelming applause for organizing so many value-added events and activities so well. The ISSS team would like to acknowledge all the individuals, who have contributed articles in this issue.

The ISSS has initiated an association with the IEEE Sensor council. This new endeavour offers opportunity to publish your scientific findings through the APSCON-23 conference, which will be held during 23rd to 25th January, 2023.

The ever-growing activities and events of the ISSS are really appreciable that are endorsed by their positive response. This will definitely motivate us to introduce several new value-added activities and events through the ISSS. Take the opportunity to develop your professional network through ISSS. The technology is expanding in all the directions. Explore your vision and express your thoughts through ISSS.

Happy Reading!

2 ISSS Activities and Events

Technical Talk Series, International Webinars, Certification Course, Short Term Course

Technical talk series "Sukshmabhilap Malika 2022", Centre for Nano Materials and MEMS, NMIT, Bengaluru

The Centre for Nano Materials and MEMS of NMIT, Bengaluru in collaboration with the Institute of Smart Structures and Systems (ISSS) organized an online technical talk series "Sukshmabhilap Malika 2022", on 'Recent Trends in MEMS Technology' on 5th and 6th of May 2022. Around fifty participants from all over India participated in the talk series including students, research scholars and faculties. Ms Veena, the in-charge of the Centre for Nanomaterial and MEMS welcomed the participants with a keynote address on the MEMS technology and the facilities, which exist in the centre to carry out the research activity.

Ms. Nithya G of the Department of ECE was the Convenor and Ms. Veena, Ms. Sthuthi A, Mr. Naveen K and Mr. Amruth S Pawar of NMIT were the faculty co-ordinators for that program. Eminent speakers from various Institutes delivered insights of MEMS and Nanotechnology in different applications such as RF switches, Photonic devices, Micro valve for lab on chip applications, SAW sensors, Nano sensors for emerging technology and Linear and Nonlinear coupling of MEMS devices. The topics and the Resource person for the event are listed below.

Category: Technical talk series

Sl.	Details of the Talks
1	**Dr. Ashok Kumar Pandey**, Professor, Mechanical and Aerospace Engineering, IIT Hyderabad Topic: *"Linear and Non-Linear coupling of MEMS"*
2	**Dr. Ganapathi**, Professor, IIT- Madras Topic: *"Nanoscale devices for emerging Technology"*
3	**Dr. Sujatha. L**, Professor and Head CEMM, Rajalakshmi Engineering College, Chennai Topic: *"Large scale integration of polymer microvalve array for Lab on chip applications"*
4	**Dr. Prita Nair**, Professor, ShivNadar University, Chennai Topic: *"Programmable Photonic devices"*
5	**Dr. B. S. Sreeja**, Professor, SSN College of Engineering, Chennai Topic: *"MEMS Based RF switches"*
6	**Dr. Veda Sandeep Nagaraja**, Senior Scientist II, Tyndall National Institute University College Cork, Ireland Topic: *"The world of Surface acoustic wave devices"*

Dr. Ashok Kumar Pandey, Professor, Mechanical and Aerospace Engineering, IIT Hyderabad

Dr. Ganapathi, Professor, IIT- Madras

Dr. Sujatha. L, Professor and Head CEMM, Rajalakshmi Engineering College, Chennai

Dr. Prita Nair, Professor, ShivNadar University, Chennai

Dr. B. S. Sreeja, Professor, SSN College of Engineering, Chennai

Dr. Veda Sandeep Nagaraja, Senior Scientist II, Tyndall National Institute University College Cork, Ireland

International Webinar, Certificate Course,
Centre of Excellence in MEMS & Microfluidics, Rajalakshmi Engineering College, Chennai – 602105

The centre of excellence in MEMS and Microfluidics of the Rajalakshmi Engineering College, Chennai, in association with the Institute of Smart Structures and Systems (ISSS) had conducted several technical activities such as international webinar, certificate course. The details of those activities are listed below.

Category: International Webinar

Sl.	Details of the Talks
1	**Dr. Bruce K Gale**, Professor and Chair, Department of Mechanical Engineering, University of Utah Topic *"Inertial Microfluidics"*, on 04.04.2022 (Monday) 10.00 a.m. - 11.30 a.m. was conducted both in online and offline platforms. 32 online and 60 offline participants were benefitted.

Category: Certificate Course

Sl.	Details of the Talks
1	*"Microfabrication of MEMS Devices",* starting on 02-04-2022 Saturday and continues for 4 consecutive Saturdays (02.04.2022, 09.04.2022, 16.04.2022 & 23.04.2022) in the Month of April was conducted both in online and offline platforms. 10 online and 25 offline participants were benefitted.
2	*"Microfluidics"*, starting on 05-03-2022 Saturday and continues for 4 consecutive Saturdays (05.03.2022, 12.03.2022, 19.03.2022 & 26.03.2022) in the Month of March and 23 offline participants were benefitted.

A Value-added Course on “Design and Simulation of MEMS Devices”, Department of Electronics and Communication Engineering of BMS College of Engineering College, Bengaluru

The Department of Electronics and Communication Engineering of the BMS College of Engineering, Bengaluru, Karnataka organized a value-added course on the Design and Simulation of MEMS Devices during 20th June to 4th July, 2022 to expose the participants to the design of MEMS Devices and their simulation using COMSOL Multiphysics software. This programme was organized in collaboration with the Institute of Smart Structures and Systems (ISSS), professional body. The course included discussion on the design and simulation of devices such as, cantilever, accelerometer, displacement-amplifying compliant mechanism, the stiffness of beam suspensions using COMSOL Multiphysics software. Around twenty five students of BMS College of Engineering, Bengaluru participated in this course. Some of the photographs of that event are shared below

Session by Dr. Selvaraj Varadharajaperumal, Technology manager, Centre for Nanoscience, IISc

Group Photo of Valedictory function

Ph.D.: 1st Runner Up

Ternary Hybrid Junctions of Semiconducting Oxide Nanostructures, Reduced Graphene Oxide and Noble Metal for Improved Gas Sensor Device Applications

Dr. Sanghamitra Ghosal, IIEST Shibpur

ISSS Awards 2021 –Ph.D.: 1st Runner Up

The functionality and performance of gas sensor devices are commonly based on semiconducting oxides. These devices exhibit relatively slow response time, as well as, limited sensitivity and selectivity. Based on the advantages of the oxide nanostructures a considerably increased number of gas interaction sites and directed one dimensional (1-D) electron transport, some improvements in

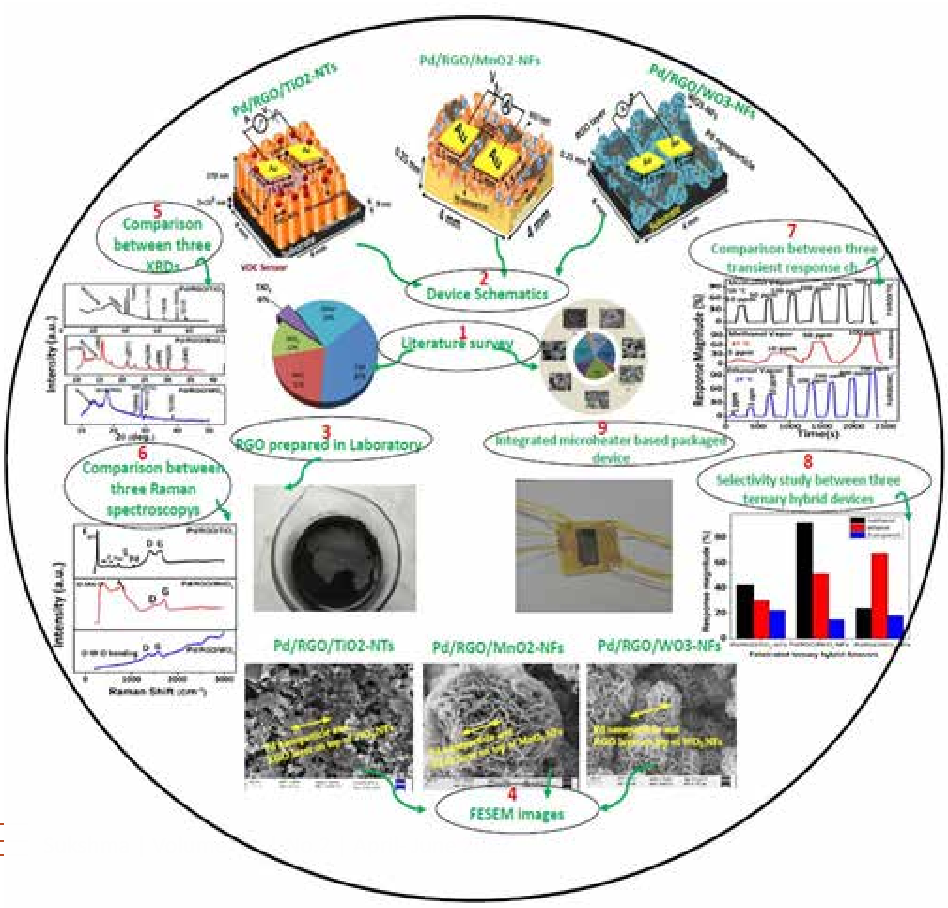


Figure 1. The nanostructures, physical device and response of the Gas sensor

the sensor characteristics have been achieved, but not at a very satisfactory level. Recently, new sensing materials viz. Graphene and its derivatives allow new design paths for the improvement of critical gas sensor components due to their unprecedented advantages, such as their extremely high electron mobility, huge specific surface area, low intrinsic noise and single molecular scale of sensitivity. Thus, future developments may rely on a synergistic hybridization approach of these two categories of materials as sensing elements. For gas sensor device applications the development of hybrid structures of semiconducting metal oxide (e.g. $TiO2$, $MnO2$, $WO3$) nanostructure-arrays together with Graphene derivatives can be expected to become the most efficient and high performance sensing material and device. However, there is also a scope for developing the ternary hybrid device that means the semiconducting oxide with transparent RGO layer will anchor with the noble metal like platinum, palladium. Based on this analysis, an attempt will be made to establish the underlying mechanistic framework model to correlate the structural / electronic parameters to the sensing attributes and achieve sub-milliseconds response time in case of the ternary hybrid devices through synergistic hybridization of dual surface engineering (together with noble metals and reduced graphene oxides to nanostructured semiconducting metal oxides).

Ph.D.: 2nd Runner Up

Adaptive control strategies for resilient Operation of grid interfaced solar energy Conversion system enabling power quality Improvement

Dr. Priyank Mukeshkumar Shah, IIT Delhi, Delhi

ISSS Awards 2021 – Ph.D.: 2nd Runner Up

State-of-art

The virtual induction generator (VIG) has manifold advantages over virtual synchronous generator (VSG) such as fault ride-through capabilities, auto-synchronization features using only local information, introduce virtual inertia to enhance the system frequency dynamics. Hence, it has become very popular due to plug and play type of operation in the system. It guarantees a smooth synchronization without a supplementary nonlinear controller unlike virtual synchronization. However, the smooth synchronization, dependency on phase-locked loop, islanding operation, rigorous tuning requirement of proportional-integral (PI) controller of the virtual-inertia-fed microgrid, have yet remained unexplored in the literature.

The design and analysis of the grid-connected and islanded operation of the VSG are analyzed in the literature. This controller analyzes the sub-synchronous resonance in a grid-connected and islanded operation of VSG. To suppress the oscillations in the active power, the modified virtual inertia controller-based grid interfaced VSG is presented in the literature. Similarly, the corresponding transient analysis for the VSG is analyzed for mitigating the phase jump while meeting the requirements in case of closures or re-closures of generation to suppress the transient power oscillation. To analyze the stability of the system under fault, the system is studied through power-angle control method. These state-of-art algorithms require more than two proportional-integral or proportional-resonant controllers, which make the system sluggish under dynamic operating conditions and may lead to instability operation of VSG. The aforementioned controllers are not capable to operate under islanded scenarios.

Owing to these limitations, a seamless transition of synchronverter with virtual torque and virtual flux linkage control is presented in state-of-art with a reduced number of the proportional-integral controller as compared to the state-of-art techniques. However, this algorithm still has a dependency on the synchronizing unit such as phase-locked loop and prone to system integration with the weak grid. Therefore, a continuous development in controller is mandate to improve the system performance

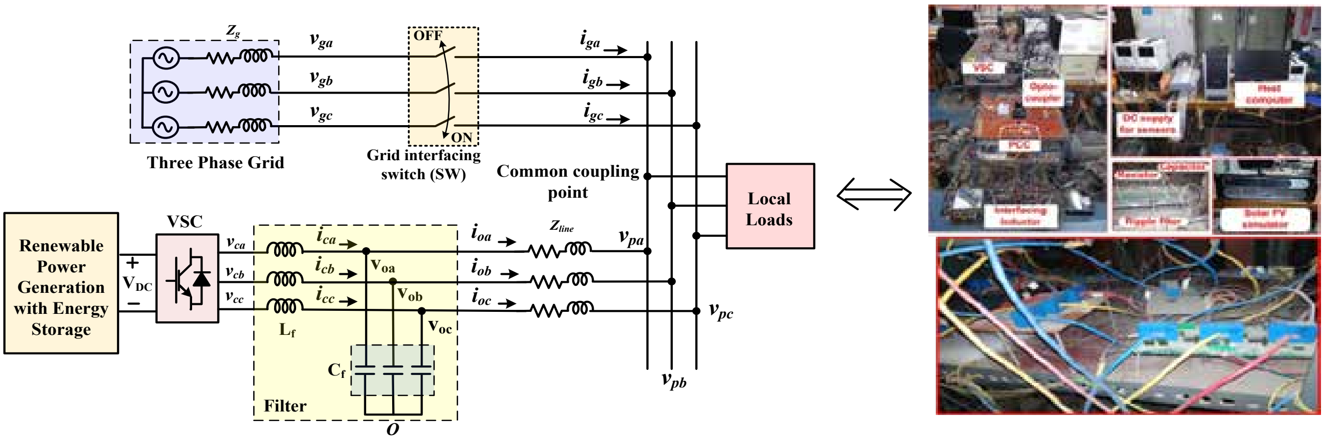


Figure 1. The schematic circuit of the renewable power generation system and its bench-top setup

Contributions

The virtual induction generator with second frequency regulation and self-synchronizing capabilities is proposed herein to improve the power quality of the distribution grid. The nonlinear loads are practically connected at the common coupling point, which lead to a grid current imbalance and deteriorate the power factor of the grid. The major contributions of the presented treatise, are briefly explained as follows.

- The VIG has the inherent self-synchronizing capability and does not require control reconfiguration and/or dedicated additional synchronizing toolbox for seamless operation between on-grid and off-grid operation.
- The proportional-integral-less regulator-less secondary frequency regulation scheme is presented for a VIG to improve the system frequency dynamics even under a large variation of active power.
- The dependency on the separate synchronizing tool (such as phase-locked loop) and PI regulator are completely waived-off in the presented control strategy.
- The VIG has inherent ride-through capabilities toward disturbances in the grid such as incipient fault transients. Therefore, it is more suitable for a low inertia based distribution grid.
- The comparative performance is analyzed herein to demonstrate the necessity of the inertia-assisted distribution generation.
- The effectiveness of the VIG is demonstrated with quantitative and qualitative analysis under the presence of harmonics in the grid voltages.

Research challenges in Shape Memory Alloys towards Smart actuators and Sensors for different functional Device's development

Dr. I. A. Palani, Mechatronics and Instrumentation Lab, Department of Mechanical Engineering, IIT Indore

ISSS Awards 2021 -Young Scientist Award

The Shape memory alloys (SMA) are thermo-responsive materials, which exhibit shape memory effect. This distinctive characteristic is governed by the diffusionless solid-state phase transformation mechanism. A wide range of applications can be realized as a sensor and an actuator owing to its energy density, ability to recover large transformation stress, high damping capacity, good chemical resistance, and biocompatibility. The application perspective of these smart materials resulted in various issues such as near net shape structures, tedious training process, retention of properties after fabrication, etc. Focusing on these critical aspects of the SMA, our lab research is as follows

Customized additive manufactured components- We developed near net shape components using Laser-assisted manufacturing (LAM), Wire Arc Additive Manufacturing (WAAM), and Laser-Induced Forward Transfer (LIFT). The LAM and WAAM processes used to fabricate intelligent porous structures have shape memory and pseudoelastic effects. Strain gauges were easily manufactured in required dimension using an In-house developed micro 3d printer.

SMA Thin-film bimorph- Inducing Two Way Shape Memory Effect (TWSME) in SMA requires a tedious training process. Our research group developed SMA bimorph using a flexible substrate for energy harvesting and opto mechatronics application (smart mirrors). The developed bimorph can lead to high-end applications such as micro platform and adaptive control in various automation sectors. This research can be utilized as a parameter set by the industries for developing actuators on a large scale for various applications

Reliability and Life Cycle behaviour with Contact & non-contact based actuation- our research team developed an In-house testing setup for the life cycle and reliability of the designed SMA structures at different contact and non-contact-based actuation conditions. The SMA sample showed excellent life cycle behaviour exceedingly more than 30,000 cycles without any deterioration in its actuation performance.

Multifarious Shape Memory Alloy (SMA) based Bio-Inspired Soft Robots- In our laboratory, we explored the possibility of using soft robotics to create robotic systems with flexible structures completely made of soft materials. There are many scopes to analyse alternative actuators to produce flexible and complex movements, which are impossible with motor-based actuators. The use of soft materials and smart actuators can improve flexibility like real creatures and result in high manoeuvrability. Bio-inspired robot plays a significant role in surveillance applications. Conventional bio-inspired robots are made of complicated rigid materials and mechanisms.

Development of optical fibre sensor for the cryogenic application- Cryogenic temperature sensing for the different systems is a challenging task. There are currently few sensors available that can detect few kelvins but faces several limitations regarding their usage under a harsh environment. Therefore, optical fibre-based sensors could be a better alternative for sensing

Figure 1. Different forms of SMA actuators

and monitoring applications due to their immunity to electromagnetic interference and power fluctuations. We turned our attention towards using Shape Memory Alloy (SMA) coatings over the optic fibre. The response was highly improved due to the hybrid properties of the smart alloy. Notably, Copper-based SMA showed significant displacement at high and low temperatures. Hence, integrating copper-based SMA structures with optical fibers could improve fibre sensitivity and be a viable option for the cryogenic application.

Young Scientist Award

Smart Materials and structures, Laser Assisted micro fabrication,Soft Robotics systems

Dr. Koushik Guha, National Institute of Technology Silchar

Field of Specialization: MEMS, Bio-MEMS, Microfluidics, Sensors & Actuators, VLSI

ISSS Awards 2021 -Young Scientist Award

Dr. Koushik Guha is an Assistant Professor (Grade-I) with the Department of Electronics and Communication Engineering in the National Institute of Technology, Silchar, Assam, with 11 years of experience in teaching and research. He is now an Associate Dean of Students Welfare in NIT Silchar. Dr. Guha believes in the fact “research makes the world beautiful for the present and future generations”. He is a true technology enthusiast with desire to make innovation that helps the society. He has research interests in RF MEMS, Bio-MEMS, Radio Frequency & Microwave Engineering, Antenna, EM Theory, Advance Electronics Circuits, Semiconductor Devices, and Biomedical VLSI circuits. Dr. Guha has wide range of publications in almost all his areas of interests, which represents his research excellence. Continuous efforts Dr. Guha has resulted in establishing The National MEMS Design center in NIT Silchar with world class computer tools and is running successfully. He is a joint advisor of Advanced VLSI design lab in NIT Silchar. The collaborative research of Dr. Guha within and outside India has benefited to NIT Silchar and Research scholars as well. Dr. Koushik Guha is awarded Distinguished Faculty Award 2021 by NIT Silchar for his outstanding performance in teaching and research. Recently he has been awarded Institute of Smart Structures and Systems Young Scientist 2021. He is a life member of various research societies and reviewer for reputed journals. He has successfully guided 3 PhD scholars to their thesis, and 17 M. Tech and 25 B. Tech students. He is currently guiding 08 Ph.D. scholars, 3 PG projects, and 3 UG projects.

Contributed Research Areas

RFMEMS Research: Design, Modelling and Simulation of RF Switch

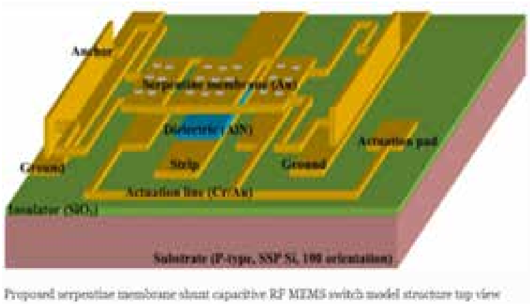


Figure 1. Top view of the proposed capacitive RF MEMS switch model structure

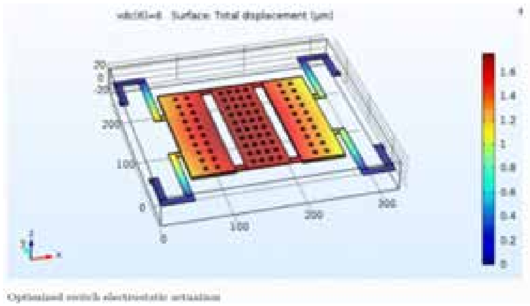


Figure 2. Electrostatic actuation in the optimized switch

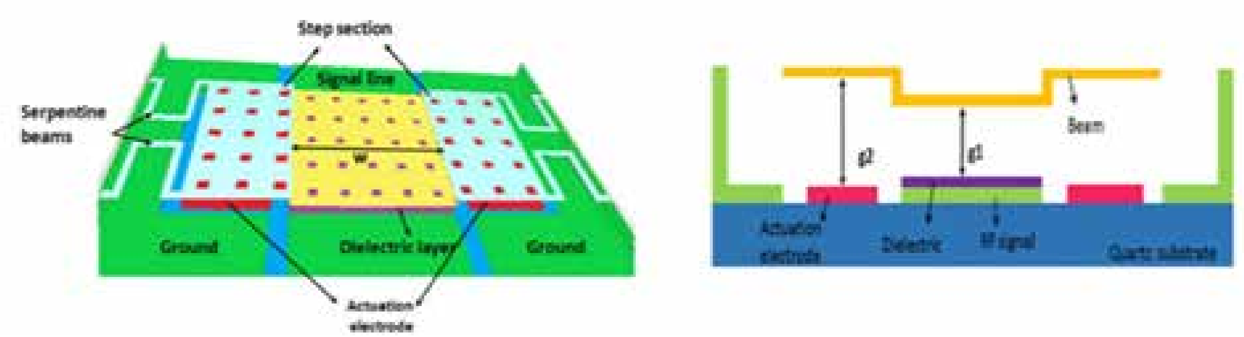


Figure 3. Schematic diagram of the electrostatic switch

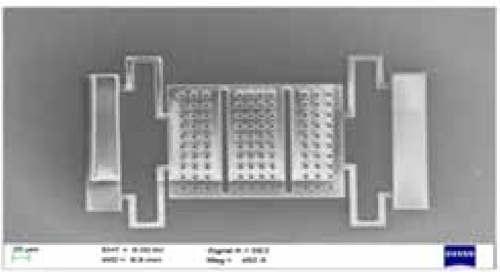


Figure 4. Physical shape of the electrostatic switch

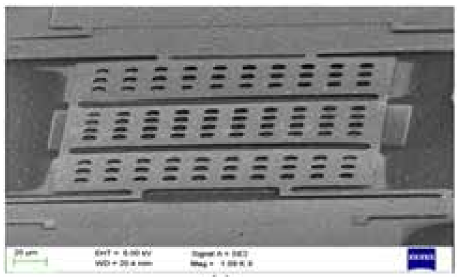


Figure 5. Physical shape of the electrostatic switch

RF MEMS drives towards applications as in RF MEMS switches, varactors, inductors, high-Q resonators, micromachined transmission lines, filters, RF micromechanical resonators. RF MEMS switches find their applications in high-isolation switch circuits, low-loss phase shifters, and tuneable antennas, filters, and networks. His interest in the field of RF MEMS, which is Micro-Electro-Mechanical System (MEMS) for RF applications, has resulted in numerous Publications and Book/ Chapters in reputed Journals and Books. In fact, he received his Doctoral degree from NIT Silchar producing an impactable thesis work on "Design and Modeling of RF MEMS Shunt Switch'' in 2016. The entire thesis work is concentrated on modelling and simulating of pull-in voltage, capacitance and switching time, which are crucial aspects of the RF Switch. Dr. K Guha who has been working on RF MEMS switches, currently has a RF MEMS switch fabricated and characterized from CeNSE, Indian Institute of Science, Bangalore. The collaborative work on CMUT (Capacitive Micro machined ultrasonic transducer) with Mizoram University has been started long back and has seen some interesting results. Another brick in the research work of Dr. Guha is tunable filters. Tunable filters form a major building block of RF communication system used in 5G NR technology.

Substrate Integrated Waveguide (SIW) provides a very good platform for the tunable filters compared to its counterparts. SIWs are to be used for filtering and the tuning will be accomplished with the help of RF MEMS switches. The study about different topologies of SIW and suitable RF MEMS switches will carried out. Dr. Guha is working in collaboration with Prof. Ameen EL Sinavi, Khalifa University, Abu Dhabi, United Arab Emirates on the reliability aspects of RF MEMS switch.

Research in VLSI Field

Dr. Guha's current research work also involves design and optimization of analog front-end circuits for application in brain-machine interfaces. The key aspect of their work involves design of optimized amplifier circuits for neural recording applications. The amplifier designed can be employed in human brain as a part of the recording system to capture the neural sensory signals thereby aiding in many disease detections such as epilepsy, Parkinson's disease etc. Another major aspect of their collaborative work is to develop high performance nature inspired algorithms based on food search mechanisms of various organisms. The algorithms once validated can not only be used in optimal amplifier design, but also in every field of study. Some of the key achievements of this work includes:

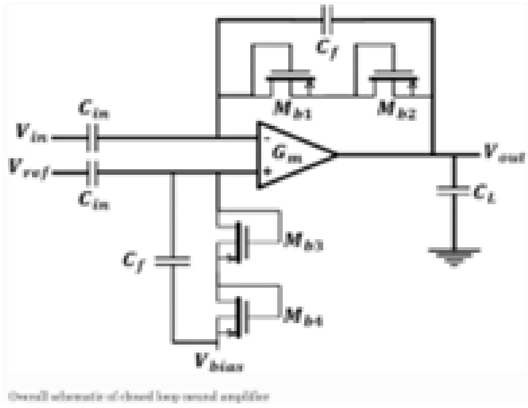
- Neural Amplifier ASIC was developed and fabricated at SCL Mohali in 180 nm technology as a part of the SMDP-C2SD project. The fabricated ASIC is the first to be designed indigenously by NIT Silchar and has been received in Dec. 2019 and experimental analysis are now being performed.
- A Hybrid Whale Particle Swarm Optimization (HWPSO) was developed and also employed for optimization in various areas. It showed superior performance as compared to many state of the art algorithms.
- 3 research publications have been done in this area in reputed journals by the authors.

Dr. K.Guha has been performing collaborative research work with Dr. K. L. Baishnab, who works in the field of Analog VLSI circuits, optimization and cognitive radio. Under this collaboration, the plan is to merge the MEMS based designs with analog front end circuitry to design the complete optimal systems.

- Under this collaboration 6 research papers have been published in reputed journals.
- 2 ASIC have been designed by NIT Silchar (one fabricated and one in pipeline) under this collaboration.
- One ASIC is neural amplifier while other is Microphone preamplifier. Both are designed in SCL 180 nm by SCL Mohali.

Biomedical VLSI Circuits

The research work primarily focuses on design and modelling of the analog front end of compact electronic wearable gadgets and implantable ICs. The analog domain witnesses inherent trade-off between its design parameters, which makes the designs critical and challenging. The market for portable battery operated devices have emerged as the new era, which increases demand for low power, compact and sustainable devices. The analog pre-processing end is a time consuming and complex domain, which has great potential and is a thriving area of research.



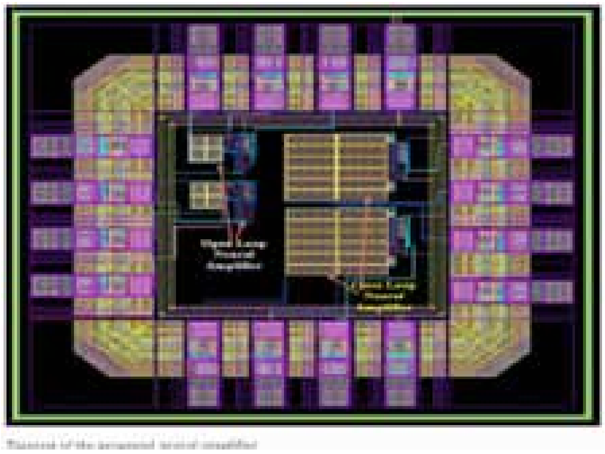
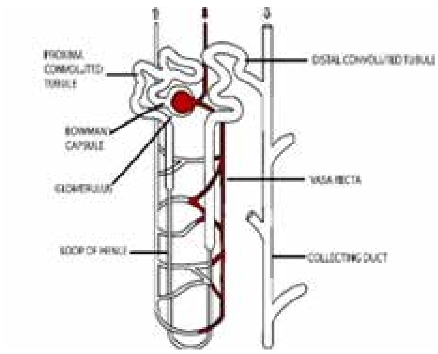


Figure 6: Overall schematic of closed loop neural amplifier

Figure 7: Tape out of Proposed Neural Amplifier

Artificial Kidney Research using Microfluidics

The development of Organ-on-Chip devices will make the transplantations easier and less costly. Especially, Kidney-on-Chip devices will help in diagnosing the CKD in early stages to prevent much damage to happen. Kidney-on-Chip is important not only in India but also globally, as the world is facing a big threat of kidney failure. Kidney failure cannot be eradicated, but the damage can be brought down using early detecting devices and transplantable devices. The only option for the problem is Kidney-on Chip (KOC) technology. For ESRD patients Kidney-on-Chip will be a great relief. KOC will avoid the frequent painful dialysis treatment. Transplanting with KOC is little easier than replacing a new human kidney. Because a new human kidney needs to be treated very carefully. The storage of the same is very expensive and a complex process. Dialysis equipment is bulkier than the proposed solution. The water wastage is high, the treatment process is painful, and most importantly that is costly. KOC using microfluidics will allow to integrate all the actions performed by the kidney in a small area, no pain to the patient and cost effective. For KOC devices such difficulties never arise, and availability will be high.



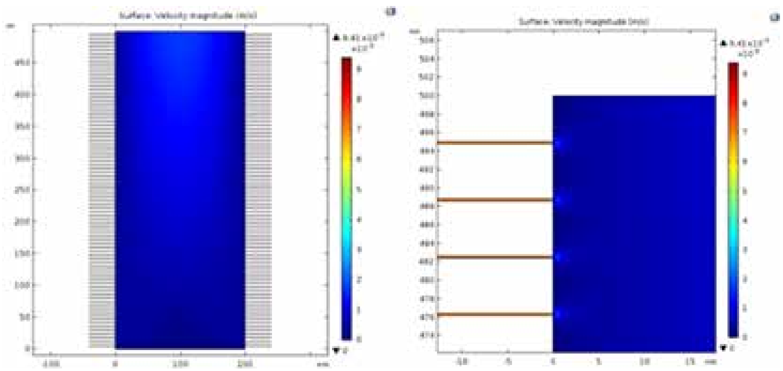


Figure 8: Structure of individual nephron in kidney

Figure 9: Proposed Design for mimicking reabsorption and simulated resulted

The major accomplishments of the work:

- The work has started in 2017 and seen some intersing advancements.
- This work produced colloborations with Medical practionars and Indian Industries.
- The work has been published in major journals like IEEE Transactions on nanobiscience and artificial organs

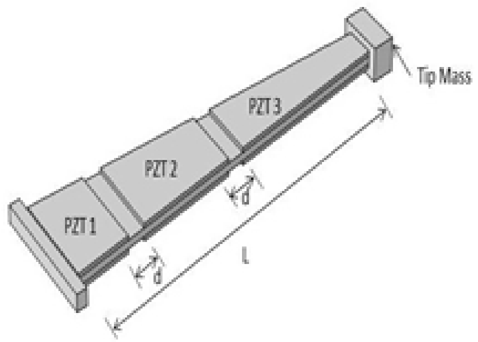


Figure 10: PZT based device used to make Energy harvester

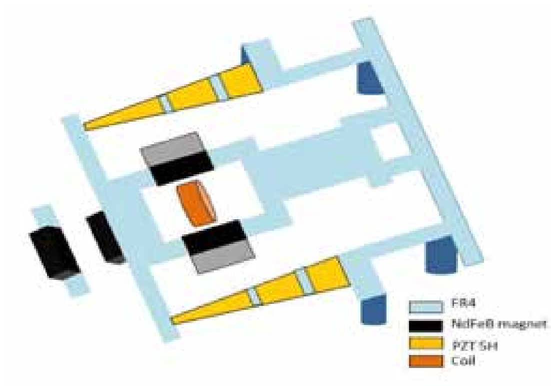


Figure 11: Energy harvester using PZT based device

Research in Piezoelectric Energy Harvesting using MEMS Technology

One of the major challenges for Vibration Energy Harvesters (VEHs) is its relatively narrow operational bandwidth which limits their application in practical scenarios where the ambient vibration source is frequency-variant or random. Also, the amount of power generated to date has been generally low that rarely satisfies the power consumption requirements of most commercial sensors and communication methods. To overcome these challenges, the research interest is to work on enhanced broadband and low-frequency hybrid energy harvester (HEH). A complete prototype model of a segmented electrode based trapezoidal-shaped hybrid piezo-magneto elastic VEH in bi-stable quartic potential well (BQT) configuration and storage for wideband, high power and higher efficiency with increased lifetime is accepted to be fabricated in the Tyndall National Institute, Ireland in collaboration with Prof. Saibal Roy.

Research interests

Biomimetic, Kidney-on-Chip, BioMicrcofluidics, Regenerative medicine, Mathematical modelling, MEMS and, miniaturized devices, BioMEMS sensors for disease detection, Biomedical VLSI Circuits, Parkinson's disease detection

Development of piezo MEMS process Technology for underwater acoustic sensor applications

E.Varadarajan, M. Kathiresan, S.Premkumar, C. Manikandan, Jain Jose, T. Santhanakrishnan, R. Ramesh and V. Natarajan, Research & Innovation Centre (RIC), IITM Research Park, Taramani, Chennai

ISSS Awards 2021 -Technology Award

“PIEZO-FILMs” are considered for acoustics and vibration-sensing applications. Like any new technology, there have been an extraordinary number of applications, where PZT thin film is one of the most popular device for a series of ferroelectric applications, such as ferroelectric memories, piezoelectric micro-electro-mechanical systems (MEMS) and acoustic imaging RF MEMS, pyroelectric detection etc. Especially, the MEMS application has found huge potential for PZT where the piezoelectric phenomena is utilized for micro-actuator, sensor and transducer devices. Dimensions of the piezoelectric devices are limited to the manufacturing limitations while preparing PZT in bulk ceramic form. However, due to the development of high-density IC technology associated with silicon, further miniaturization of the MEMS devices became possible and thus stimulated intensive research on ferroelectric thin films. Therefore, thin film PZT as a replacement of bulk ceramic has become the candidate for a new generation of piezoelectric MEMS devices. Therefore, the techniques used for fabricating high-quality films have been of special interest in recent times.

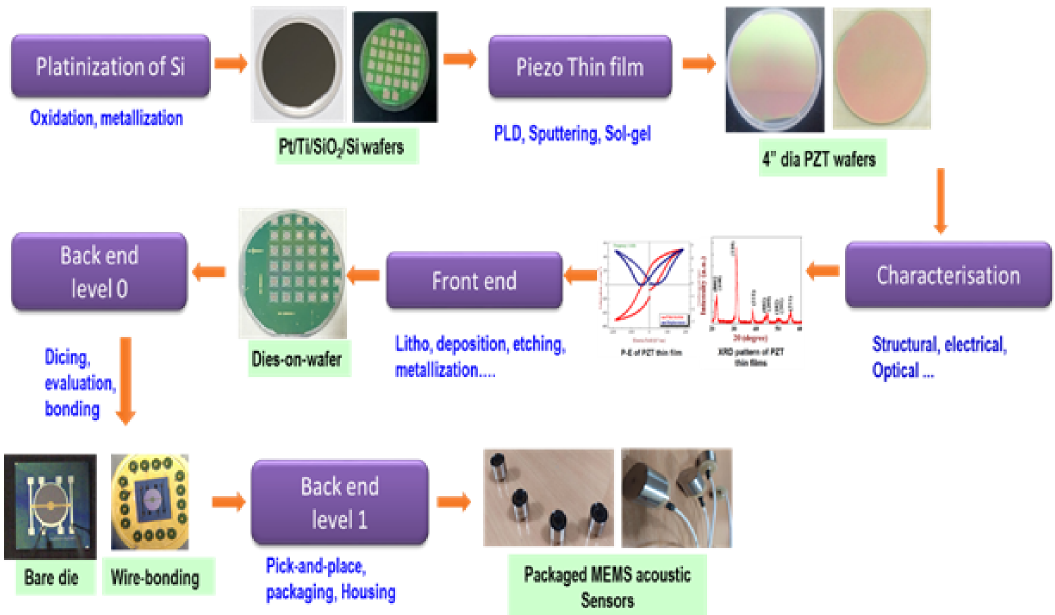
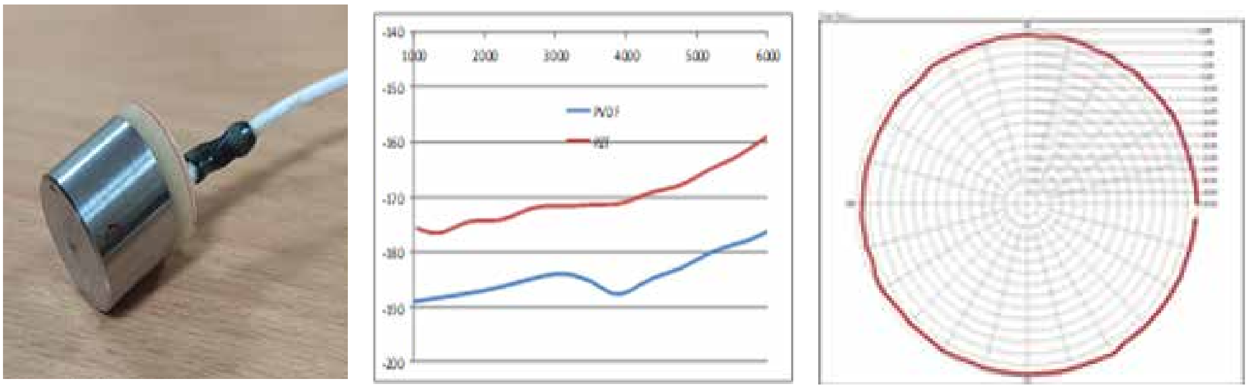


Figure 1 A series of successive processes for fabricating Piezo MEMS Acoustic Sensor

The need of piezoelectric MEMS technology is to bridge the technology gaps leading to the development of state-of-the-art futuristic naval sensor and devices for underwater applications. PZT thin films of 75 – 100 mm diameter and thickness ~1-2 µm were fabricated by RF sputtering and sol-gel methods for the development of various MEMS devices such as acoustic sensor, accelerometer, pressure sensors, micro actuators and energy harvesters.

PZT film was successfully etched using both dry and wet etching processes with an etch rate of ~14–15 nm/sec. Piezo MEMS process recipe has been successfully developed and ensured functionality of piezo materials after completing all the fabrication processes. The entire piezo MEMS process steps are given in figure 1.

Finally, underwater acoustic sensor with PZT thin films are fabricated (figure 2(a)). We evaluated their performance and compared with PVDF based acoustic sensor. Their receiving sensitivity was -170 dB at 4 kHz (Figure 2(b)) for PZT whereas for PVDF sensor was -187 dB re V/µPa. Directivity pattern of the fabricated MEMS acoustic sensor Figure 2(c) confirms the omni-directional behaviour. The device performance clearly proves that this technology can be used for fabrication of high-sensitive piezo acoustic sensors on wafer level. The performance of the devices of various batches of same piezo MEMS process has confirmed the repeatability of acoustic sensor performance. The present outcome of this study enables the development of piezoelectric thin film-based MEMS device applications in the country. Realized large area piezo thin films and MEMS process technology will support the on-going/ futuristic technologies for Next Generation SONAR programme of DRDO for Indian Navy.



a. b. c.

Figure 2 (a) PU encapsulated MEMS acoustic sensor based on patterned PZT film (insert fig) (b) Receiving Sensitivity of PZT and PVDF thick film acoustic sensor and (c) Directivity pattern of fabricated acoustic sensor at 4 kHz

Way Forward

Excellent initiative has been taken by RIC in the area of piezoelectric MEMS by integrating the experts together and realising the product. RIC-DRDO team has successfully developed functional oxide thin films and piezo MEMS process technology for underwater sensor applications. There exists in-house-developed technology for bulk micromachining of metal oxide thin films, that is the most crucial step for realizing various functional oxide-based MEMS devices. This effort has yielded tangible results meeting the DRDO's Naval sensors project needs. Developed wafer-level fabrication methodology for piezoelectric MEMS will form a significant basis for integration of CMOS circuitry into these devices, and will ease implementation of future unique devices for many other applications.

Shortly this technology is expected to get matured and the DRDO's MEMS foundry (STAR-C) will be in a position to adopt this technology to develop piezoelectric MEMS for underwater application for larger quantities through ToT. This is an endeavour to develop the advanced technology to provide a cutting-edge sensor technology, which will be advantageous to the armed forces.

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4

Feature Article

Smart techniques for nano patterning

Dr. Santanu Talukder, Department of Electrical Engineering and Computer Science, IISER Bhopal

Electronic ICs, sensors, and devices are at the heart of modern-day technology. From a mobile phone to space-satellites, every system uses electronic components. Micro & Nanoscale fabrication technology holds the most significant role in manufacturing electronic components. Products of this technology are used in Automobile, consumer electronics, energy, optics/photonics, aviation, healthcare, space technologies and in many other fields. In a nutshell, micro- and nano-fabrication process technologies are going to take front seats in future technological developments.

One of the burning issues of today – 'Chip shortage' – is also related to this technology to a significant aspect [1]. A Si wafer needs to go through several complicated process-steps for fabrication of transistors or other components in a very small scale (μm-nm). This technology demands for many sophisticated and state-of-the-art tools along with highly skilled manpower. So, if the production goes down, it cannot be brought back to its original capacity overnight. For pushing up the manufacturing capacity or starting a new manufacturing factory a substantial amount of capital investment and in-depth knowledge of semiconductor fabrication process will be required. It may take a couple of years or more for establishing this kind of semiconductor chip fabrication facility along with the ecosystem it needs. In the scope of this article, I am going to focus on lithography or patterning which is one of the fundamental steps of the microfabrication process.

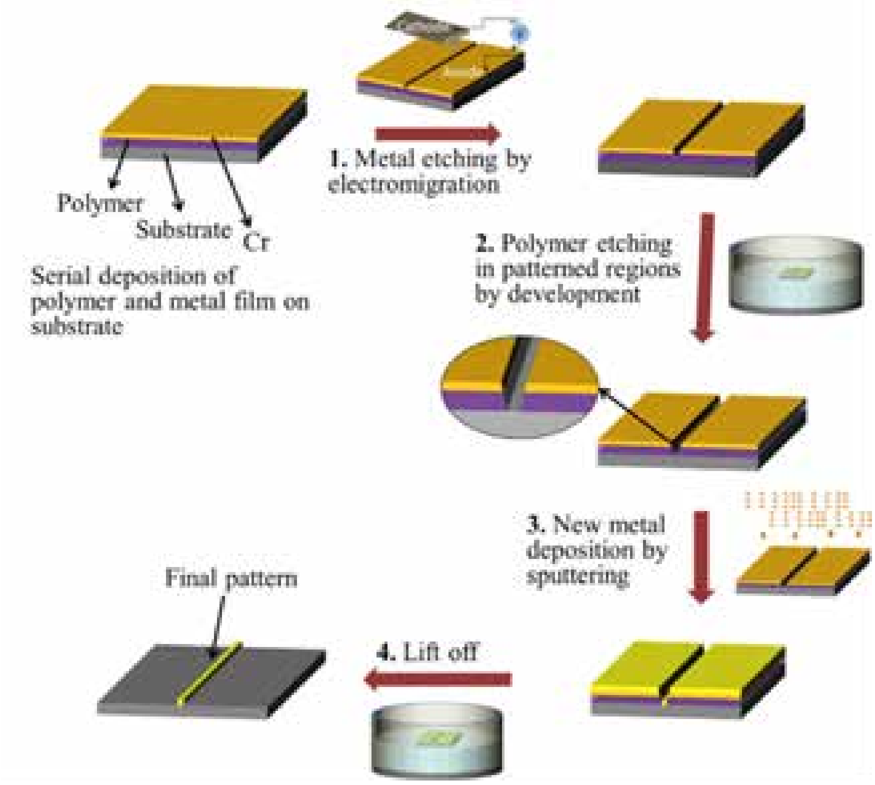
Similar to the macro scales structures, in micro or nano scale fabrications also we majorly deal with a few fundamental steps such as, designing or patterning, addition of material, and subtraction of material. In microfabrication, these basic process steps are majorly known as deposition/coating/growth for addition of material, etching using wet chemical agent or reactive gases for subtraction of material, and lithography or patterning for drawing the structures. In addition, wafer (majorly Si) cleaning is associated with all the fabrication processes. In many cases, doping, annealing, etc., steps are also performed depending on the process flow. Resolution of a pattern is majorly defined by the lithography process. So, how closely packed circuit we can make or how many numbers of circuit elements we can put in a little piece of IC depends on the lithography step. Though lithography and controlled patterning of standalone structures at multiple length-scales are critical for fabrication of various small-scale devices, but fabrication of such closely-knit multi-length scale components with scalability and versatility is not readily available through the existing patterning techniques.

At present, photolithography is the most popular patterning technique used for mass scale production in microelectronics and integrated circuit (IC) industries [2-5]. On the other hand, electron beam lithography (EBL), the most popular choice for direct nanoscale patterning [6-8], requires ultra-high vacuum (UHV) and high-energy electron-beam sources for its basic operation, making the process very expensive and complicated. Moreover, being a direct and serial writing technique, EBL suffers seriously on throughput and, consequently, is far behind the industry standard photolithography. So, in industry, there exists techniques like projection lithography, immersion lithography, etc., which are capable of making structures in nanometre scale with the help of predesigned photomasks. Nevertheless, for making a mask for photolithography, we do not have any alternative to direct writing at present, and hence a considerable part of production cost goes into writing masks [9,10]. Hence, an alternate universal lithography technique with larger scalability at an affordable cost is still a dream for the semiconductor industry.

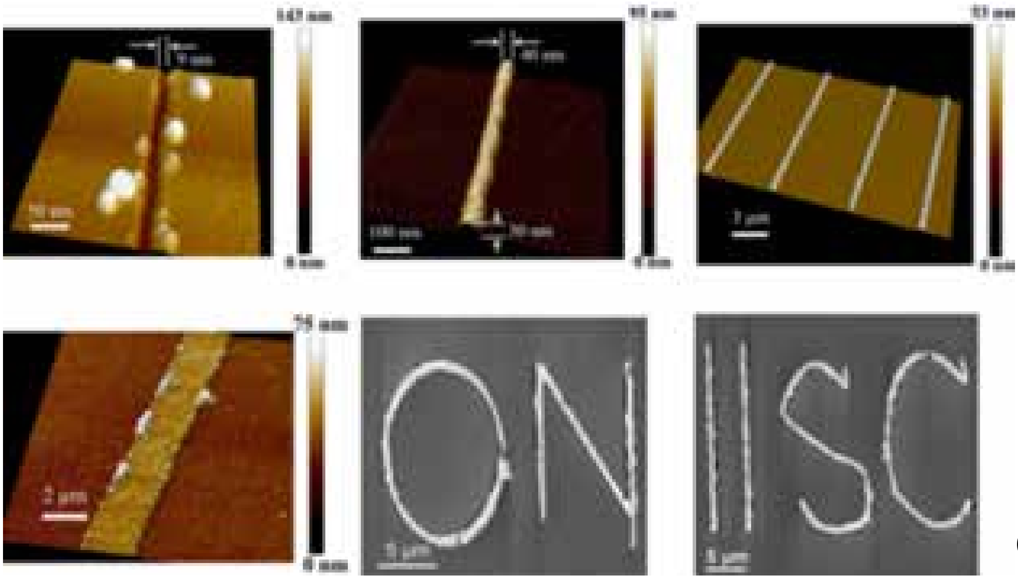
Citing the above-mentioned reasons, in academic and industry research, unconventional lithography methods induced by electric field, thermal effect, chemical reactions, etc., are getting popularity with the help of the scanning probe-based technologies [11-13]. Though it will require a fair amount of time and further research for industries to adopt these, but with an adequate knowledge and experience on scanning probe techniques, these methods can be immediately implemented in research laboratories at much lower cost. In this article, I shall introduce two such unconventional lithography techniques (1) electrolithography technique driven by electric field induced material transport and (2) Constructive lithography driven by chemical reaction.

Electrolithography

Electrolithography is a new patterning technique based on electric field induced material transport [12]. Electrolithography can be used for drawing patterns having dimensions from a few nanometres to a few hundred micrometres or even in millimetre scale. It does not need any UV or e-beam source, and can be performed in ambient condition. Electric current, assisted by Joule heating, can induce long-range flow of material; this phenomenon is known as liquid electromigration [14, 15]. In particular case of Cr thin film deposited on an insulating substrate, application of high electric-field between two point electrodes results in formation of a liquid material and subsequent flow of the liquefied material in a radially symmetric fashion away from the cathode. If the negatively biased tip is moved in a straight or curved path then the materials get removed from the path of the probe. Hence, the Cr can be etched by the negatively biased scanning tip according to a desired pattern or design. The schematic diagram of the electrolithography process is shown in Fig. 1 (a) [12]. In electrolithography, a thin Cr film is used as a masking layer and a polymer layer beneath it acts as a pattern transfer layer. A conducting sharp tip is moved on the Cr layer in a predefined path to etch metal according to the desired pattern. Once the metal is etched, the polymer layer below it gets exposed. The pattern drawn on the metal layer is transferred to the polymer layer by etching the polymer with an appropriate solvent. For the sacrificial layer polymers like PMMA can be a good choice and a mixture of solvents like acetone,



(a)

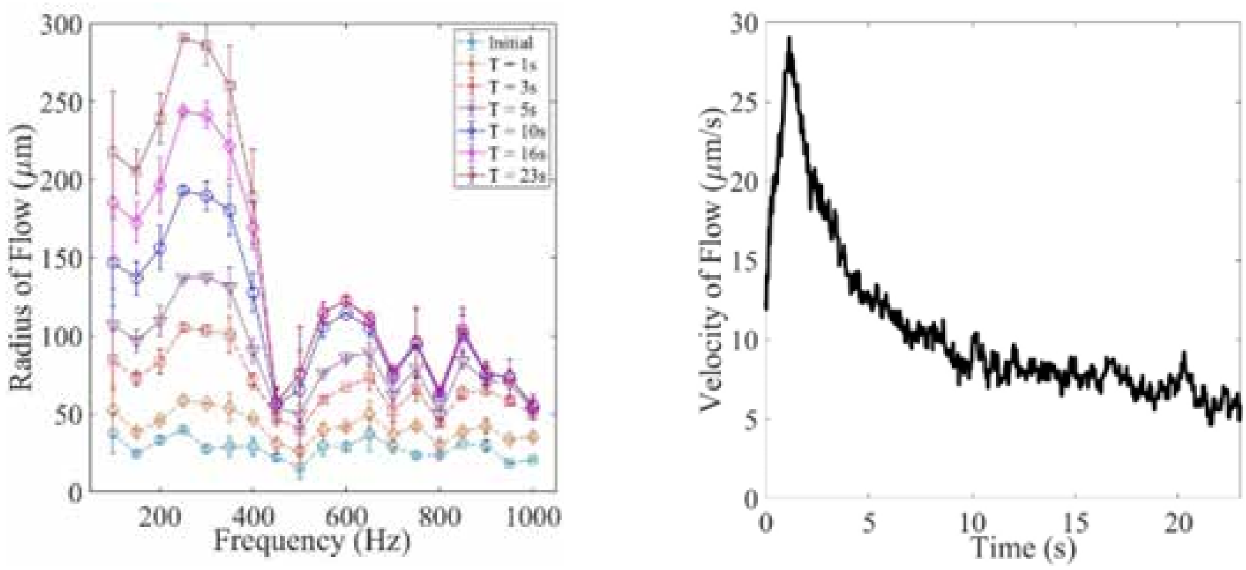


(b)

Figure 1: (a) Schematic diagram of electrolithography process flow. (b) Various patterns created using electrolithography: 3-D AFM images of the narrowest trench in PMMA with a channel width of 9 nm and narrowest Ti thin film line with an average width of 40 nm and thickness 30 nm; parallel lines of Ti each of width 100 nm; Bottom SEM images are of various types of patterns fabricated in Au (75 nm thick) on Si substrate (taken from Ref. [12]).

IPA , and DI water can be used as the developer. Once the substrate gets exposed in the desired pattern, the pattern is transferred to the desired material layer using a standard film deposition technique, followed by conventional lift-off process. The same pattern can be transferred to the substrate by etching the substrate also. Using this technique, best resolutions achieved are of 9 nm on the polymer, and 40 nm on transferring the pattern to another material. Few patterns drawn with this technique are shown in Fig. 1 (b). In common SPL techniques, the depth of the patterns drawn on the polymer layer are often very small. Thus, transferring those patterns to other materials becomes very difficult. However, in electrolithography process, etch depth in the polymer is same as the polymer layer thickness (usually ~ 200 nm). Therefore, patterns are easily transferrable and final patterned structures can be as thick as 100 nm, enabling their usage in microelectronic devices. In electrolithography, polymer is used only to transfer the patterns. Hence, any polymer and corresponding developer can be used in this process thereby, removing need of costly and toxic chemicals from lithography processes. This process also has potential for direct writing or resist less patterning for making mask.

In a further study, the extent and nature of mass transfer under the effect of varying frequencies of AC square wave signals have been investigated [16]. The extent of spread of liquid flow is studied with respect to various controlling parameters. A number of exact reasons have been brought forward to help understand the phenomenon better. It has also been inferred that AC current stressing is more aggressive than DC on few tens of nanometer thick Cr thin film. When the thin films were stressed using a DC bias, the maximum radius of the liquid region was much less, usually in the range of 50 µm to 60 µm. On the other hand, using an AC bias the achieved flow radius is quite high, being more than 100 µm in a number of cases as can be seen from figure 2(a). It is also evident from Fig. 2(a) that the frequency of the applied AC signal has a significant effect on the extent of the mass flow. The peak velocity is comparable to the peak velocity under DC stressing, showing a value of more than 25 µm/s, as has been shown in figure 2(b).



(a) (b)

Figure 2. (a) Mean Radius plots with respect to frequency for Square Waves of some frequencies within the range of 100 Hz to 1000 Hz. (b) Velocity plot, after smoothing, for a particular experiment corresponding to frequency of 250 Hz.

A mathematical model is proposed which relates the radius of flow to time. The model is derived from an electrical and electrochemical viewpoint, and it correlates well with the experimental results. The differential equation of the proposed mathematical model gives the velocity, which is also a good fit to the velocity data, as shown in Fig. 3. The model is discussed in detail in Ref. [16].

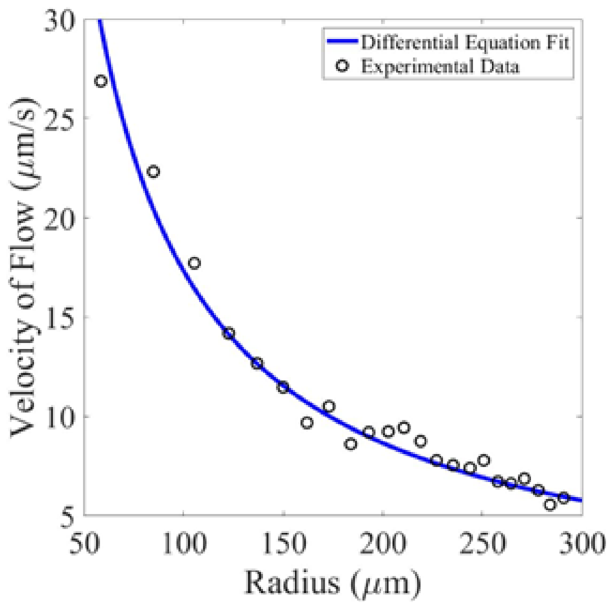
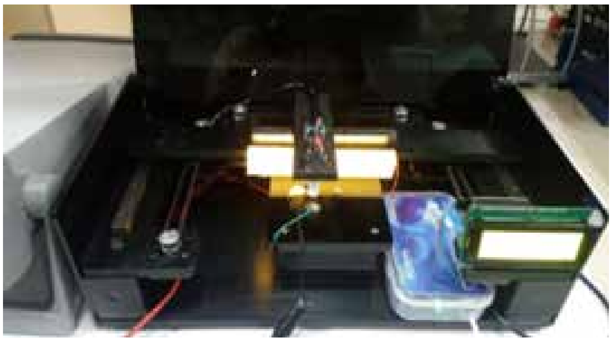


Figure 3. Plot showing the velocity- ring radius experimental data agreeing to the kinematic differential equation proposed by the model [16].

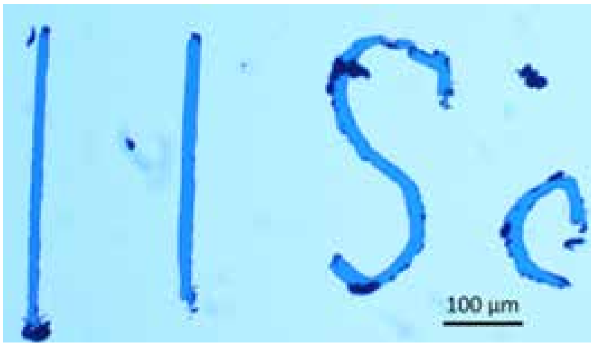
By varying the frequency, the intermittent time acts as a constant changing factor in each set of the experiments. The experimental results have been explained with the help of qualitative reasoning by using opposing effects from the chemical and electrical outcomes. The frequency parameter and the intermittent nature of the applied electric field has significant effect on material flow properties. In case of electrolithography process only using DC bias, the control parameters were mainly the magnitude of the DC bias and the velocity of scanning. The film thickness also plays a significant role in deciding the resolution in the lateral directions. However, by applying AC biases of varying frequency, an extra control parameter is obtained which can help in getting better range and resolution while creating micro and nano scale patterns on Cr thin-films. Intermittent nature of AC electric field being more aggressive than DC, increases the velocity and range of mass flow. Hence AC bias can potentially improve the throughput of the electrolithography process compared to DC electrolithography. The wave shape and the duty cycle can also be used as controlling parameters in the electrolithography process and help in tuning the resolution of the patterns.

In a recent work, electrolithography has been performed under water and named as W-ELG [17]. Though the resolution of W-ELG is currently in sub-micron scale but the patterns are smoother or cleaner compared to electrolithography performed in air [17].

In addition to optimization of the electrolithography process, a prototype table top system has been designed and developed for performing electrolithography. A custom made 3-axis micropositioners, electrical source measurement unit, force sensor, high resolution optical system, and an electronic display board have been interfaced with the master computer using feedback controlled algorithm. In this system different hardware components have been controlled using two Arduino micro controller boards and the software part is taken care of using LABVIEW (NI). A photograph of the prototype system and an optical micrograph of 'IISc' pattern drawn with this tool are shown in Fig. 4.



(a)



(b)

Figure 4: (a) An image of the prototype micro-positioner system for performing electrolithography. (b) An optical micrograph of 'IISc' pattern drawn using the same system [13].

For further improvement of the the lithography system, a new SPL system - nm3P (nm - mm Patterning), which is capable of drawing patterns with nanometer scale resolution and millimeter scale range, is being developed currently in our lab. Nanostructures having width of sub -100 nm and length of few mm can be fabricated using this system. Any scanning probe-based lithography process including electrolithography and constructive lithography (discussed later) can be performed using this system. No existing commercial SPL system can provide such a huge range with a nm level of precision. The import cost for the usual nano lithography systems are about Rs. 3 crores, whereas this system can be realized with a cost within Rs. 20-30 lakhs. This system will be put inside an environment-controlled chamber where the humidity, gas concentration, pressure, temperature, etc., can be tuned. A photograph of the assembled nano positioner system and a very preliminary drawing of 'IISERB' pattern using this system are shown in Fig. 5.

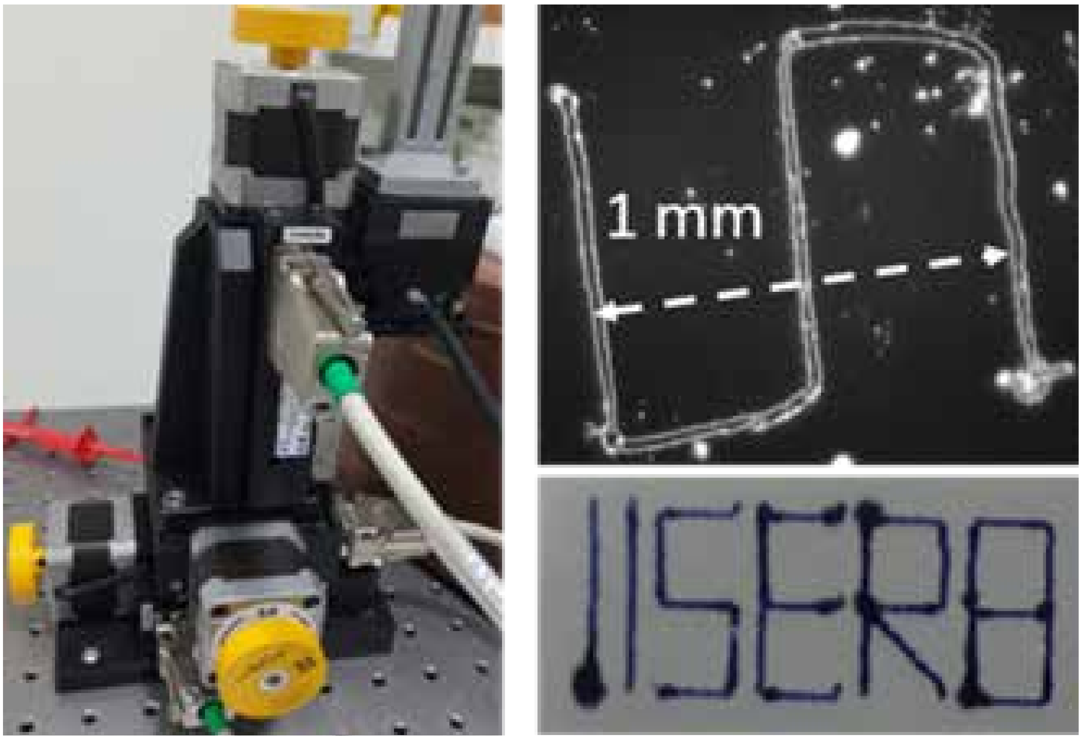
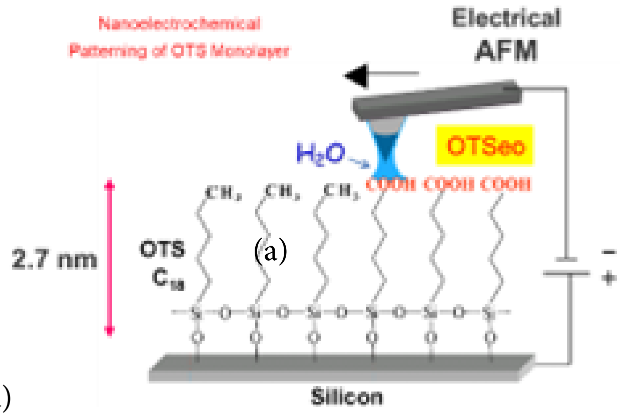


Figure 5: Photographs of the positioner assembly (left) and patterns created (right) using this system. Bottom-right image is the very first pattern drawn on a paper using an ink pen. Top-right photo is an optical microscopic image of the 'S' letter of an 'IISERB' pattern created by etching Cr thin film on a Si wafer.

Considering the complexity and the cost of the lithography processes, this technique is more affordable and simpler than the e-beam lithography or UV based photolithography, which require high energy e-beam or UV sources, ultra-high vacuum and very expensive instrumentation to reach nano-scale resolutions.

Constructive Lithography

In constructive lithography, patterns are drawn on a highly ordered organosilane monolayer (OTS) self-assembled on silicon using localized chemical reaction induced by an electrically biased tip or a focused e-beam [18]. Basic principle of this patterning technique is based on water bridge-mediated electrochemical oxidation process to selectively convert surface exposed to $-CH_3$ groups of the monolayer to –COOH. Figure 6(a) depicts a pictorial representation for the constructive lithography using a conductive AFM tip in presence of a suitable humidity. In a dry and closed chamber, using a hydrophilic polymer e.g. polyvinyl alcohol (PVA), it is possible to locally oxidize the top $-CH_3$ groups of OTS to –COOH, as shown in Fig. 6(b). Figure 6(c) represents the AFM image of a nano channel of OTS oxide patterned on Si on OTS mono layer. Using this patterning technique macro, micro and nano surface channels having exciting electronic properties have been successfully fabricated with resolution up to 20 nm. Such patterned monolayers on silicon substrates were shown to exhibit unusual electrical transport properties, associated with extremely high ionic conduction confined to the single-layer ionic surface paths (channels) inscribed in the patterning process [18]. It is observed that the ionic conduction in this single-layer material appears to be enhanced via a novel mechanism of ionic-electronic coupling involving mobile charges in the silicon substrate, which is separated from the conductive surface paths by an insulating barrier with a thickness of 4.5 nm consisting of the organic monolayer core (2.6 nm) plus the native oxide present on the silicon surface (less than 2 nm). It is also found that, the ionic transport in narrow nano-channels of this kind may result in lateral electrochemical growth of electronically conducting metal filaments with a limiting thickness of 1 nm that appear to inhibit further ionic transport along the metal covered path.



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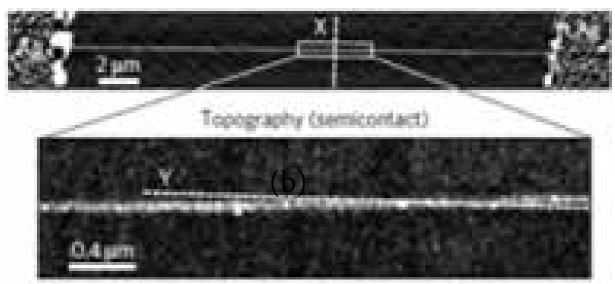

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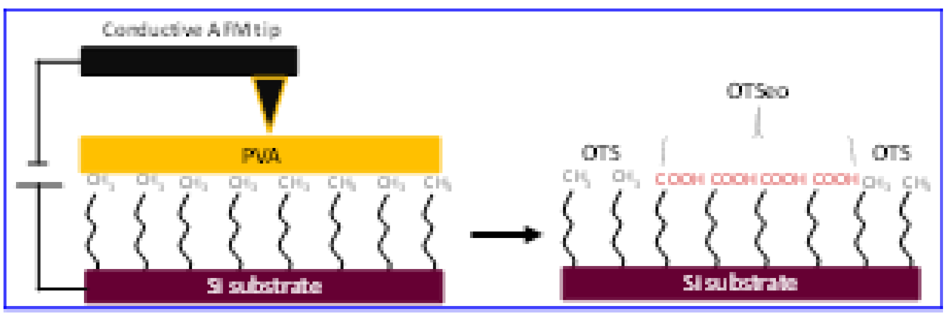

(b)

Figure 6: Schematic diagrams of (a) the constructive lithography process using a biased AFM tip in presence of humidity (b) constructive lithography on OTS monolayer using a PVA layer. (c) AFM image of a nano channel of OTS oxide patterned on Si on OTS monolayer using constructive lithography [18].

In conclusion, elecrtrolithography and constructive lithography can be used in fabricating novel devices, which are difficult to be made using conventional lithography techniques. These are scanning probe-based techniques and do not need any UV or e-beam system. So operating power consumption and instrument costs are much low for these two lithography processes. In electrolithography process, pattern resolution on polymer is 9 nm and on transferred material it is 40 nm. Nano-channels of width 20 nm have been successfully fabricated using constructive lithography technique. The installation costs of these systems and operational costs of these processes are much less compared to existing lithography techniques.

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