SUKSHMA

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Editorial

We are delighted to bring you another edition of Sukshma. The previous edition's release coincided with the ISSS-Researchers' Symposium in March 2018, in Bangalore. The highlight of this event was the panel discussions involving experts from academia, industry and R&D organizations. More than 40 researchers across the country participated. You can get additional details in the report of that event in this edition.

ISSS has embarked on several new initiatives to enhance its reach and impact on the technology community. The first and foremost of these is conducting annual design competitions in the broad areas of micro and smart structures and systems. In the first stage, these events will be held in several regions pan India and then the winning entries would be show-cased in the national level event. ISSS would be happy to support the national level winners, depending on the nature of the entry, by providing potential exposure on international stage and/or commercialization. One of the primary objectives is to encourage researchers to come out with innovative products or realizable solutions with a strong focus on making make not only the cities but also the towns and villages in India smart. Please be on the look-out for detailed announcements coming to you soon.

The second initiative is to create a platform for educative and informative videos in the broad areas of smart materials, structures and systems. These would include videos of lectures from experts for ISSS community and also a link to the videos in other internet sources. This should get underway in a month's time and Members can access these via www.isssonline.in.

The third major initiative is to foster a strong relationship with the younger and newly introduced people within and outside of ISSS through mentorship, guidance and interactions between ISSS members. A strong need was articulated in several fora that ISSS should take lead in providing such a service to students or early career faculty. To facilitate this, ISSS has initiated several steps including fostering formal and informal engagement with mentors and mentees and to create an online platform on our website for these interactions.

We eagerly look forward to hearing from you your impressions on Sukshma and how we can make it more informative and an enjoyable reading experience. The editorial board expresses its gratitude to all those who have contributed to this edition. *Happy Reading*!

Self-sensing Shape Memory Alloy Actuators

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A transducer is a device which converts one form of energy into another form. Actuator is an example of a transducer which transforms electrical energy into mechanical output. Similarly, the mechanical output can be converted to an electrical signal to measure the output; for which a sensor is employed. Off late, the need for miniaturization in various fields, e.g., in medical and defence industry, requires a decrease in size and weight of the actuators and sensors. For such systems, smart materials offer a superior choice. These group of materials include piezoelectric, electro-active polymers, magnetostrictive, thermally and magnetically activated shape memory alloys (SMA), etc. Out of these materials, the SMA has the maximum energy density but offer low actuation frequency. Presently, one of the groups in Smart Materials and Structures Lab of IIT Guwahati focuses on applications of SMA based actuators with self-sensing feature.

Constitutive phases of SMA and Its Behaviour

SMAs are a unique type of materials, which can recall its high temperature state. In general, there are two distinct phases, namely, a low temperature phase or Martensite (***M***) and the high temperature phase or Austenite (***A***). Martensite comprises of monoclinic structure, possessing low elastic modulus; whereas cubic structure is found in Austenite, offering higher elastic modulus. As the material is cooled from its high temperature phase ***A***, in the absence of stress, ***A*** transforms to ***M***, referred as forward transformation. This results in a self-accommodating variant of ***M***, called as Twinned Martensite (***TM***); offering no macroscopic shape change. When SMA in this state is subjected to load above a critical value, it exhibits a macroscopic shape change due to formation of Detwinned Martensite (***DM***). *This deformation remains even after unloading and the undeformed state can only be recovered at higher temperature, through reverse transformation from* ***M*** *to* ***A*** (Fig.-1).

Fig.2 shows the stress temperature loading path for SMA wire exhibiting Pseudoelastic or Superelastic behaviour. The corresponding stress-strain behaviour of SMA is illustrated in Fig. 3. This happens due to the constant temperature stress induced transformation between A and DM, as can be seen in Fig. 2. Physically, the SMA wire undergoes a large strain (~3 to 6%) upon loading and can subsequently recover the same upon unloading. This phenomenon is widely exploited in biomedical applications; e.g., stent.

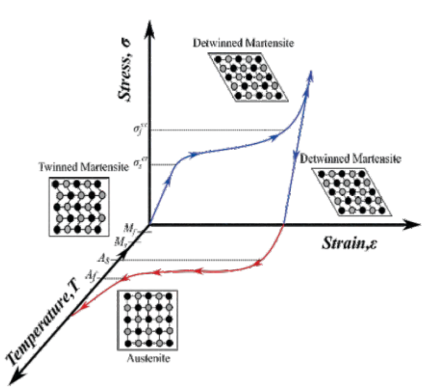

Figure 1: σ -ε-T curve depiction SME of SMA [Brinson 1993]

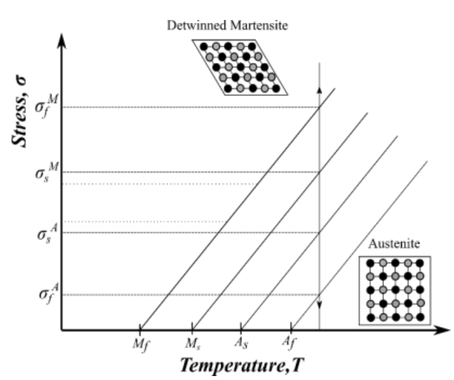

Figure 2 : σ - ε curve depiction PE

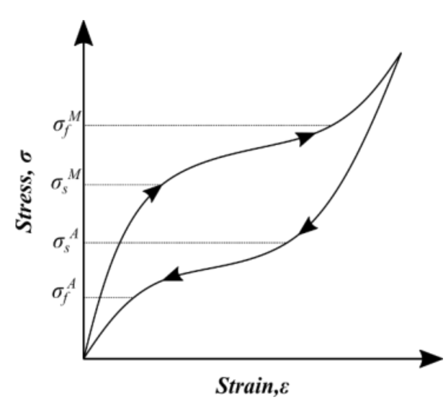

Figure 3 : Pseudoelastic loading path of an SMA

Applications

SMAs are used in a wide variety of fields like aerospace, robotic, medical and civil applications. The various grippers and positioners aboard the NASA mission `*Mars Pathfinder*' were made of SMA. Ni-Ti springs are used in flow control valves. SMA based couplings, sleeves and connectors are indispensable in oil industry, navy, missile technology, etc., due to their incumbent corrosion and fire resistant properties. Stents used in angioplasty surgery, are made of Ni-Ti alloys. SMA based spacers are applied for spinal cord correction of scoliosis patients. Robotic grippers are employed with SMA springs to produce two-way jaw movement. SMA wire based muscles are also preferred for actuation of robotic limbs. They are also used to prevent crack growth in concrete and employed as structural reinforcements.

Self-sensing of SMA Actuator

The recovery stress developed during reverse transformation (**M→A**) is exploited in actuator applications of SMA wires. In constrained recovery, the variation of stress with temperature of a SMA wire actuator is depicted in Fig 4. The nonlinear and hysteretic behaviour can be observed. Thus to control the system output, one needs to resort to a sophisticated control system, where a feedback sensor is inevitable. This renders the whole system bulky and makes SMA wire a less preferable choice for miniature applications. To obviate this, the electrical resistance variation in SMA wire during phase transformation, has been harnessed as a measure of the output of the system. During phase transformation the modulus of elasticity, thermal conductivity, specific heat and electrical resistivity of SMA wire are found to vary. Due to the change in electrical resistivity as well as geometry, the electrical resistance of the SMA wire changes significantly during transformation. This information can be used as a measure of the output of the system being actuated. Thus, the SMA actuator can simultaneously work as a sensor as well and hence referred as self-sensing SMA actuator. Typical electrical resistance variation during constrained recovery is shown in Fig.5. In SMSL, IIT Guwahati, Kalman filters based estimators are developed to explore the self-sensing ability of the SMA wire actuators.

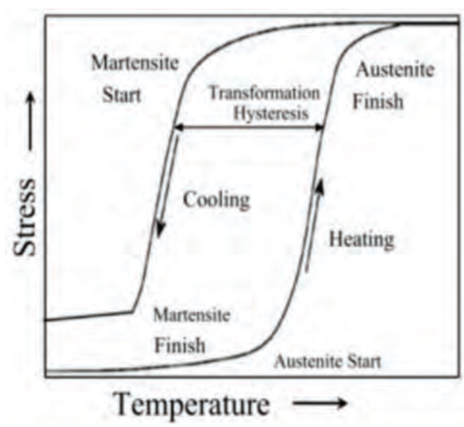

Figure 4 : Variation of stress with temperature

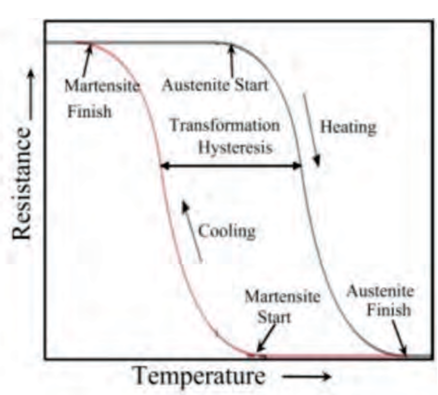

Figure 5: Change in electrical resistance with temperature

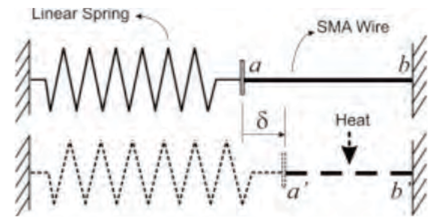

Figure 6: Schematic of a linear spring biased SMA wire actuator

SMA wire actuated linear system

To start with, a typical linear spring biased SMA wire actuator is chosen, as is illustrated in Fig. 6. The linear spring mimics the linear force-displacement offered by any other linear system to be actuated. An undeformed SMA wire is stretched to produce a desired pre-strain in the wire and is connected to the linear spring in series. The other ends of the SMA wire and the spring are restrained between two rigid walls. As the SMA wire is undergoing Joule heating, it starts to contract because of reverse transformation and faces the elastic force offered by the spring, preventing it from recovering. This leads to development of stress in the SMA wire as well as some extension of the spring; depicted as δ in the figure. In this process, the electrical resistance of the SMA wire drops, due to reduction in electrical resistivity as well as the decrement in the length of the SMA wire. As the external power source is switched off, the temperature of SMA wire drops due to convective/natural cooling. At lower temperature and higher stress the ***A*** becomes unstable and transforms back to ***DM***, allowing the SMA wire to return to its initial deformed length. In this process, the electrical resistance of SMA again increases to its initial value. This allows the SMA wire to be ready for the next actuation cycle. The idea is to find the displacement of the system from the change in electrical resistance of the SMA wire. The main challenge lies in estimating the output displacement from the noisy, nonlinear and hysteretic electrical resistance data of the SMA wire.

Development and Implementation of EKF

An EKF model of the SMA wire actuated system is developed at SMSL-IITG, relating change in electrical resistance of the SMA wire to the displacement of system. The state variables of the dynamic system comprise of stress and temperature of the SMA wire and the electrical resistance is taken as measurement. The system's dynamics is modelled using the constitutive model of SMA wire, relating stress-strain-temperature of SMA (Brinson, 1993) and the heat balance equation, relating input voltage with temperature of the SMA wire. EKF comprises of two basic steps, namely, "Time Update" and "Measurement Update". In Time update, an EKF estimates the state variables and the covariance matrix at the current instant from the same at the previous instant. The obtained state is called the a-priori state. Then a-priori state and the covariance are updated using measurement at current instant in the Measurement update.

For verification an experimental set-up is developed (refer Fig. 7 and 8), comprising of a real-time controller from dSPACE, a DC programmable power supply, a laser displacement sensor, and a voltage divider circuit. All the input and output signals are controlled through a Desktop-PC using Simulink©MathWorks and dSPACE hardware. The voltage signal is designed in Simulink©MathWorks and is applied to the SMA wire through dSPACE, and then power supply. The laser displacement sensor is used to measure the displacement 'δ'. A simple voltage divider circuit is designed to measure the electrical resistance of the SMA wire during phase transformation. The schematic of the complete experimental setup is depicted in Fig. 7 and the actual setup is shown in Fig. 8.

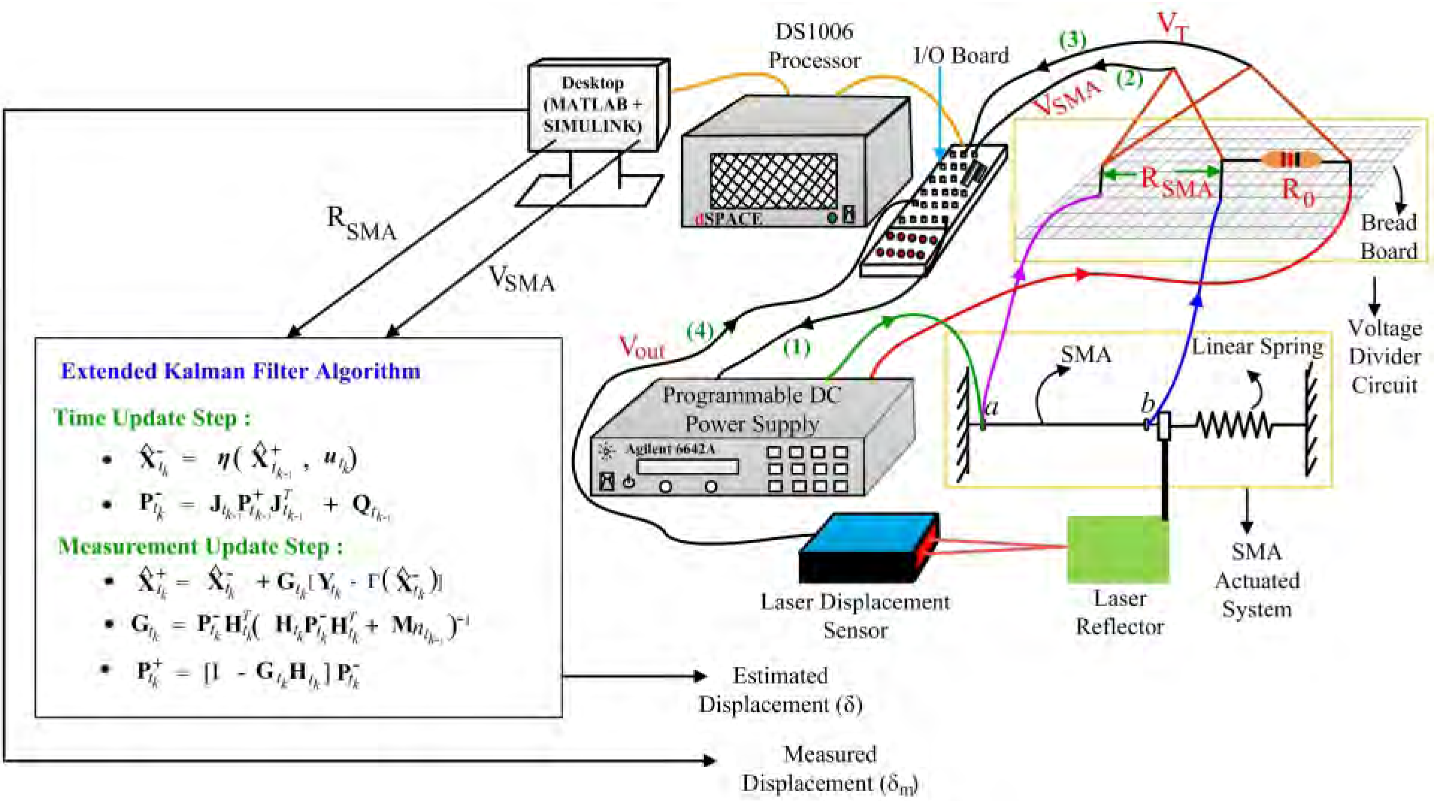

Figure 7 : Schematic of the process

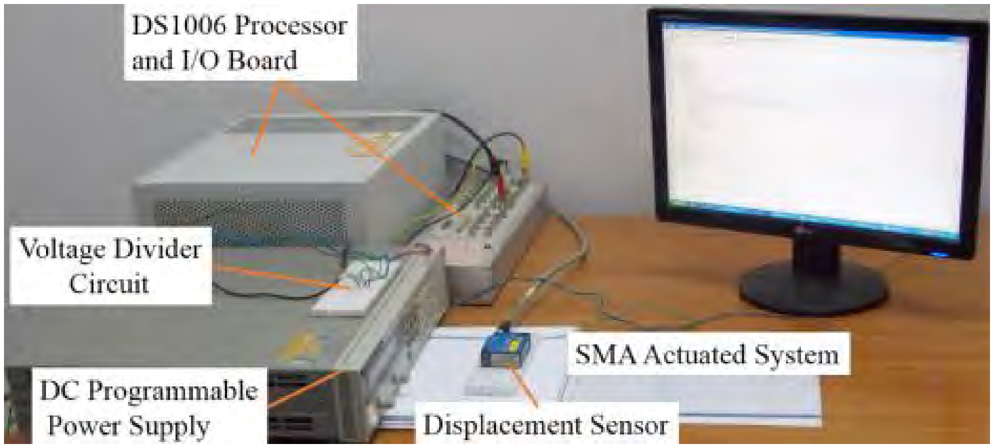

Figure 8 :Experimental setup

Results

To demonstrate the ability of the proposed method, the estimated and experimental displacements are compared for different input signals. A periodic voltage with decreasing amplitude, as presented in Fig. 9a, is applied to the SMA and the corresponding measured electrical resistance of the SMA wire is shown in Fig. 9b. Figure 9c illustrates the estimated displacement with applied voltage. The estimated displacement over the measured resistance is depicted in Fig. 9d. Finally, the estimated and measured displacements are compared in Fig. 9e.

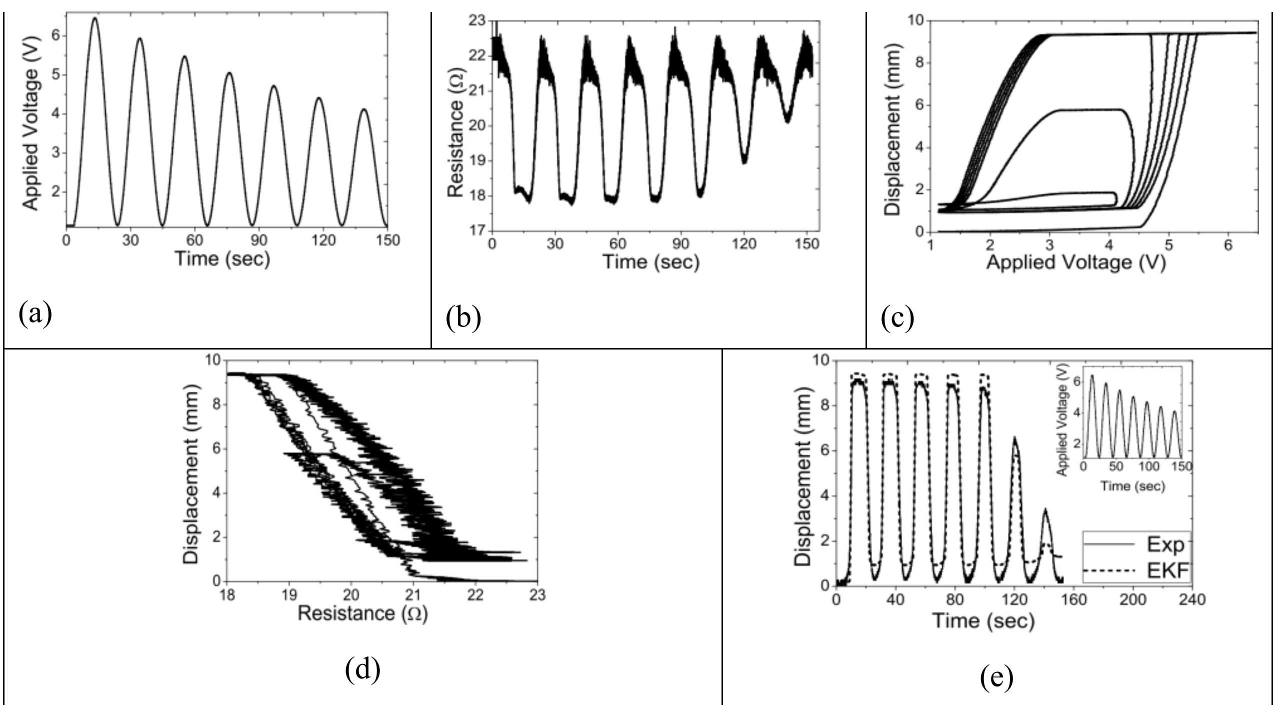

Figure 9: (a) Applied voltage across SMA wire, (b) measured electrical resistance of SMA, (c) variation of measured displacement with applied voltage, (d) change in measured displacement with electrical resistance of SMA and (e) comparison between measured and estimated displacement of the system

Summary

The self-sensing capability of the SMA wire actuators has been demonstrated by the proposed EKF based approach. The modified version of this approach is also implemented in real-time with commercial hardware, Arduino, exhibiting the effectiveness of the proposed method. More advanced estimation techniques are now being explored in SMSL. In addition to the self-sensing applications, different feedback control strategies for SMA actuators are also implemented and tested in SMSL, IIT Guwahati.

MEMS Activity in Department of Electronic Science, Kurukshetra University, Kurukshetra

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The Department of Electronic Science in Kurukshetra University was established in 1990 with a grant from UGC and MCIT with a thrust area of VLSI with the objective to generate trained personnel for the state-of-art technology. In 1990 M.Sc in Electronic Science was started and subsequently M.Tech (Microelectronics and VLSI Design) was introduced in 2004 and M.Tech (Nanoscience and Technology) in 2009. To keep oneself abreast of the state of art technology, the syllabus is updated and upgraded regularly. Hence, MEMS was introduced as a part of the M.Sc and M.Tech syllabus in 2009. In 2009, Department received funding from Aeronautical Development Agency, Bangalore for establishing National Programme on Micro and Smart System (NPMASS) MEMS Design Centre. This funding further gave impetus to MEMS education and research. The department already has well established material characterisation facilities and basic IC processing facilities (Fig. 1). These facilities will shortly be uploaded on the I-STEM portal for the benefit of researchers and faculty members. MEMS design tools received as the part of NPMASS program augmented these research facilities and material science researchers in the department could simulate the behaviour of the device by putting the parameters of the materials in the design tools. There are eight regular faculty members and five of them have research interests in materials for Electronics and Nanotechnology, three of them in VLSI Design and modelling, and one in MEMS design and fabrication.

NPMASS MEMS design centre not only helped material science researchers but, it also helped researchers like me who are interested in MEMS device fabrication. Some of the devices fabricated through Chip-INVITE Programme of NPMASS are showcased in Figures 2 and 3 along with their simulation and experimental results. The devices shown in the Figs.2 - 4 are different designs of Electrothermally Compliant (ETC) actuators. While thermal actuators exploit thermal expansion due to difference between the thermal coefficients of two materials, compliant structures actuate due to clever design in the geometry involving the same material. Electrothermal actuators, make use of the joule heating effect to bring about thermal expansion. As can be seen in the figure 2 and 3, the structure consists of a narrow(hot) and broad (cold) beam. The narrow beam because of smaller cross-section has a higher resistance in comparison to the broader beam. When a voltage is applied across the two beams, the hot beam has more temperature rise and hence, greater thermal expansion as compared to cold beam. This uneven thermal expansion results in the movement of the beam outward. A bit of modification in the design results in a bidirectional actuator as shown in Fig 4. These actuators are typically used for manipulation of biological cells. Simulations were done in the Department and characterisation was done in the Micro and Nano Characterisation Facility (MNCF), at Centre for Nano Science and Engineering (CeNSE), IISc, Bangalore. Figure 4 is the SOI-MUMPS based bidirectional actuators designed at Department of Electronic Science and fabricated under the aegis of NPMASS and characterised at MNCF at CeNSE, IISc. These devices served as orientation programme for designing, fabricating and characterising MEMS devices. Therefore, the next logical step was to undertake a research problem and take it to its logical conclusion.

Design and fabrication of ZnO energy harvester with interdigitated electrodes was taken up through Indian Nanoelectronics Users' Programme (INUP). The purpose of the research was to design, fabricate and characterise ZnO cantilever energy transducer on Si(c) without the use of SOI wafers, thereby, reducing the cost of fabrication. The energy transducer is operated in the longitudinal mode through the interdigitated electrodes. This is for the first time, that we had attempted to fabricate a cantilever transducer with interdigitated electrodes on Si(c). The design frequency was chosen in the range of 700 Hz to1 kHz for a typical Tyre Pressure Monitoring System (TPMS) application in mind. The experimentally obtained frequency was 876.25 Hz and d33 was calculated as 3.9 pC/N from the measurements. The experimentally obtained material parameters were used for simulation of the structure to corroborate the results. The experimental results were further validated by simulation.

a) PAN Analytic XRD

b) NT-MDT AFM

c) Surface Profilometer

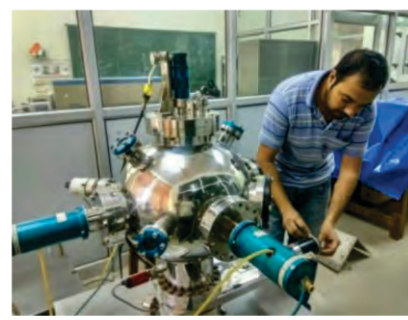
d) Ellipsometer

e) UV-VIS Spectrophotometer

f) Electrochemical Workstation

e) Physical vapour Deposition

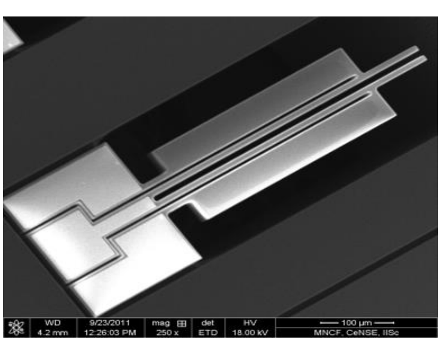
f) Spin-Coater



g) Sputtering System

h) Oxidation Furnace

Figure 1 a - h. Facilities at the Dept. of Electronic Science



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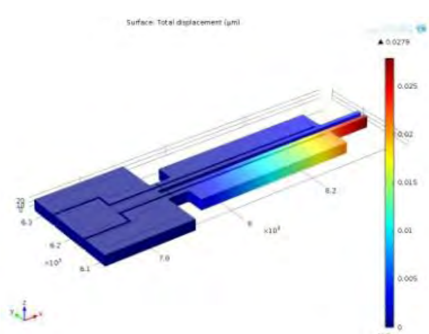

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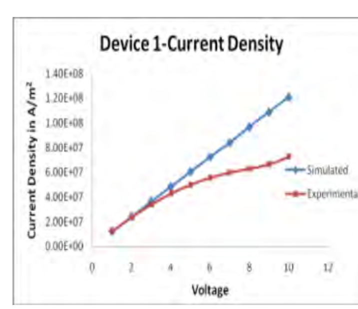
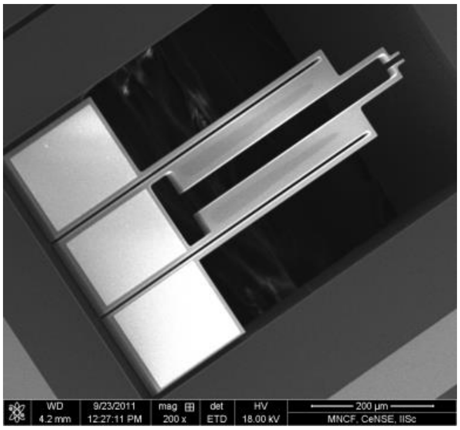
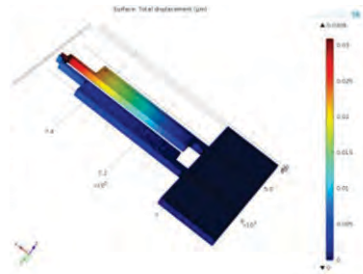
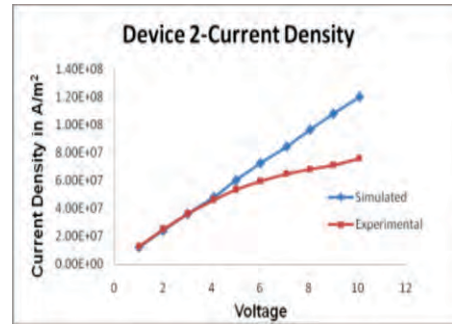


2 (c)

Figure 2 a) SEM image of Unidirectional ETC actuator Device
b) Simulated Displacement c) Comparison of simulated and experimental results

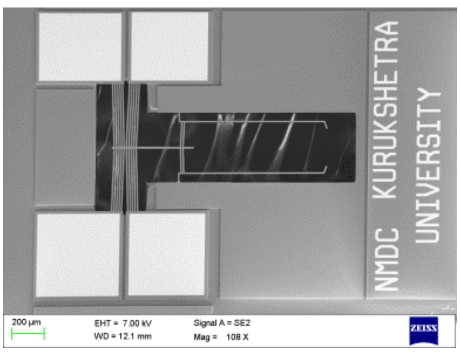


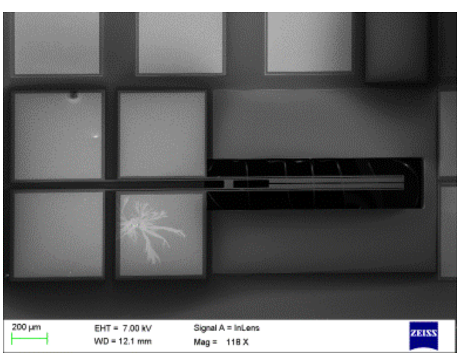




3 (a) **3 (b)**

Figure 3 a) SEM image of unidirectional ETC actuator Device 2
b) Simulated Displacement c) Comparison of simulated and experimental results





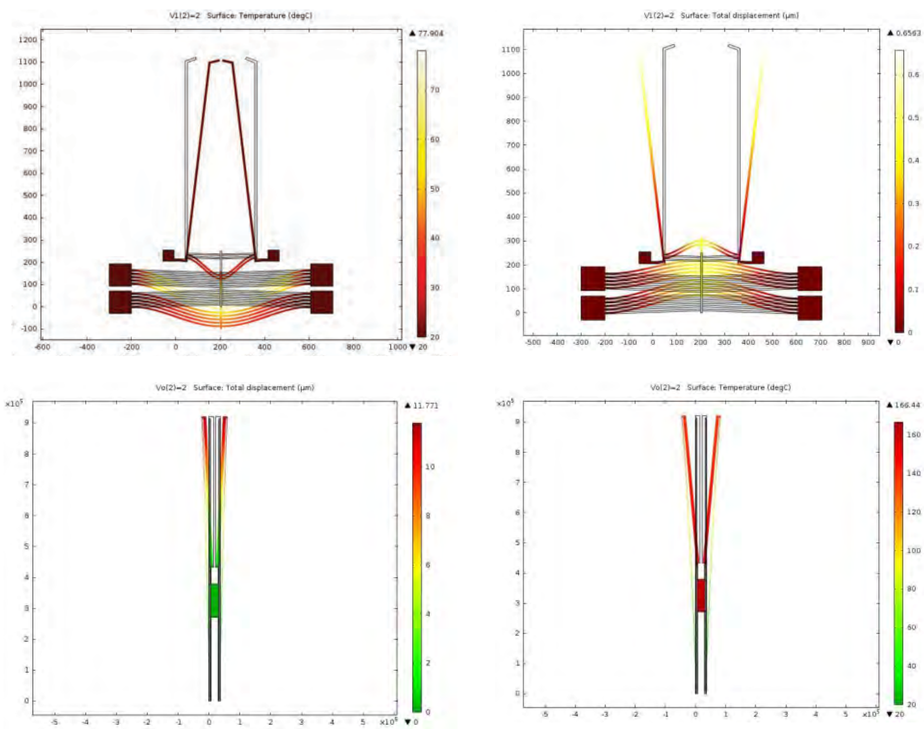


Fig 3 Two designs of Bidirectional ETC Actuator

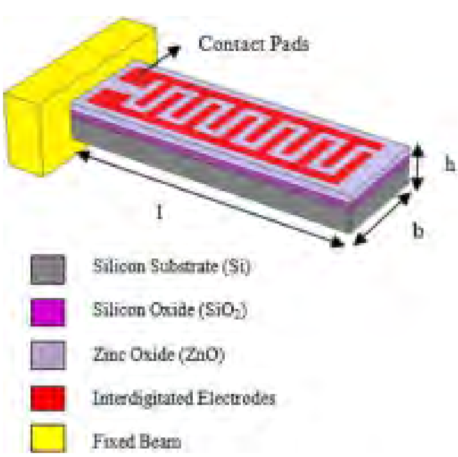


Fig 4 Structure of the harvester

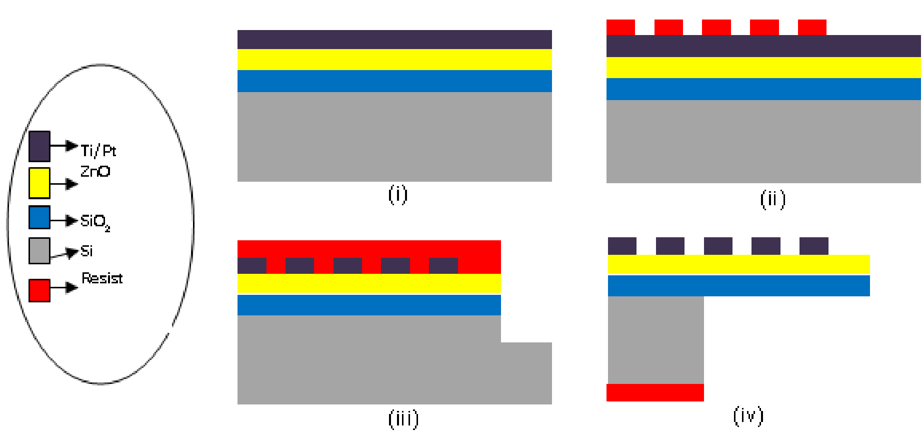


Fig 5 Schematic of Fabrication process of ZnO Cantilever for piezoelectric Energy Harvester
(i) Functional films preparation: Si/ SiO2/ZnO/Ti/Pt, (ii) functional films pattern,
(iii) Top side etching by DRIE (iv) Cantilever release by backside DRIE

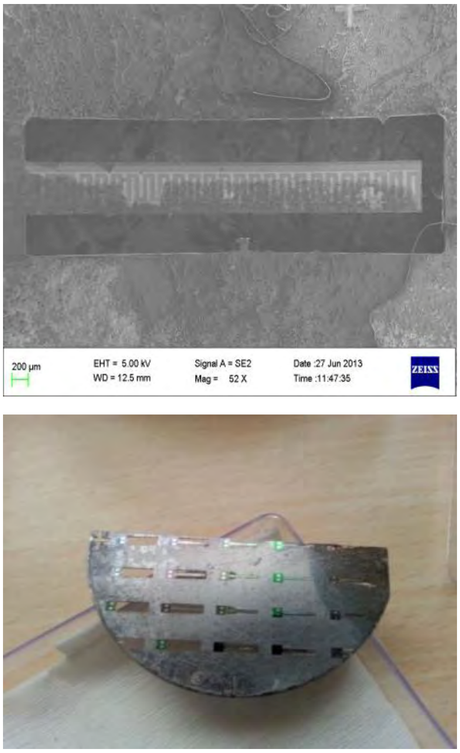


Figure 6: Images of released cantilever

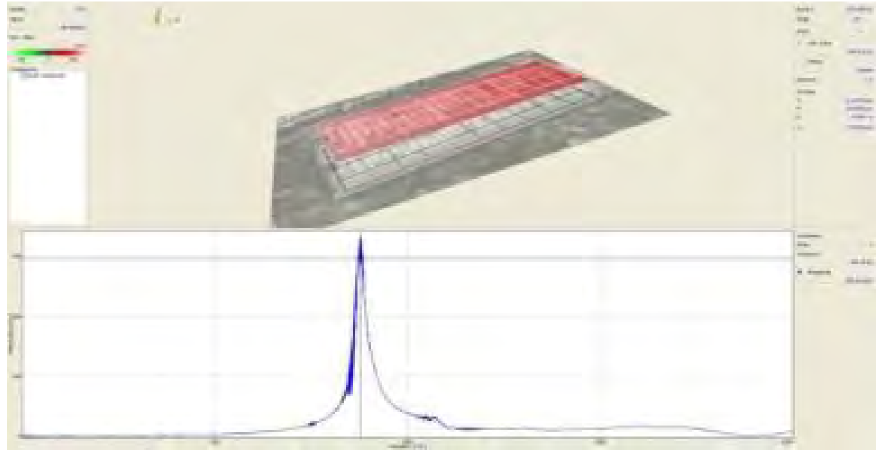


Fig 7 Resonant response of the ZnO Cantilever obtained from LDV

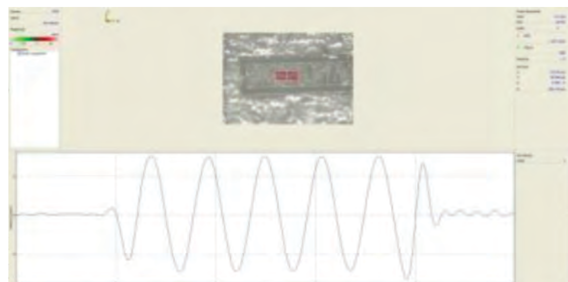


Fig 8 Dynamic response of cantilever to10 V, 875 Hz sinusoidal signal across electrodes

Through this research the feasibility of using ZnO with interdigitated electrodes as energy harvester was demonstrated. The research work led to a publication in Journal for Microsystems Technology. The structure of the harvester is shown in Fig 4 and fabrication process is shown in Fig 5, the experimental results are shown in Figs 6, 7 and 8.

Further, work on energy harvesting was shifted to Aluminium Nitride (AlN) because of its CMOS and biocompatibility. The preliminary work on design and simulation for AlN energy harvesters for biomedical implants was done in the department, whereby, different geometries were studied for generating maximum output voltage. The work was furthered to design and fabricate low-g and low frequency AlN energy harvesters for use in self powered devices at Tyndall National Institute, UCC, Ireland, where I worked as a Schlumberger Foundation Faculty for the Future Fellow. The harvester was fabricated on an SOI wafer with a 30µm device silicon layer which serves as the structural beam on which a 0.5µm AlN layer is sandwiched between the top and bottom electrodes. The handle silicon serves as the proof mass. The harvester has a measured resonant frequency of around 114 Hz and an average output power of 54 nW, measured at optimal load and a low level of acceleration (24 mili-g). A 3D finite element model of the harvester was created in COMSOL Multiphysics and the simulation results are in close agreement with the measured data. Figures 9 and 10 show the schematic view and top view of the fabricated device respectively. Figure 11 shows the resonant frequencies obtained for three different devices. Figure 12 shows the power output for an excitation input of 20 milli-g. The work is still going on to develop an electrical model to explain few of the unpublished results. At present, a research project on energy harvester has been approved and financial sanction is awaited. Research work is also underway in collaboration with IRDE, Dehradun for designing and fabricating micromirror device for mitigating the affect atmospheric turbulence on imaging.

To conclude, efforts are being made here at our Department to work within the funding and infrastructure constraints to contribute something worthwhile to research in the field of energy harvesting and MEMS micromirror.

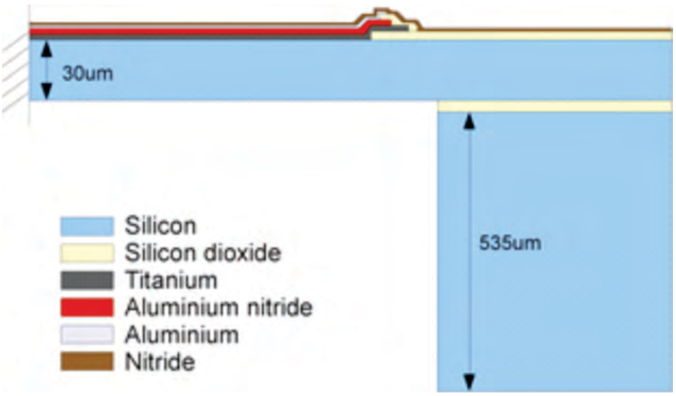


Fig 9 Schematic view of the Vibration Harvester

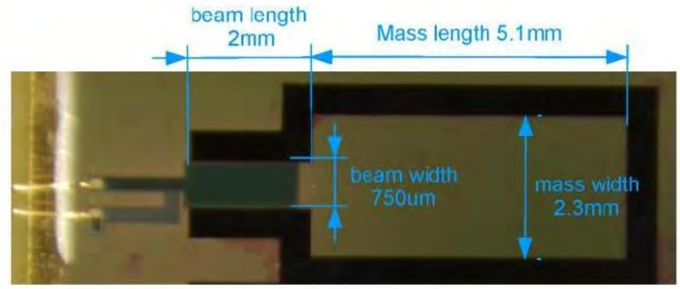


Fig 10 Top view of the fabricated device

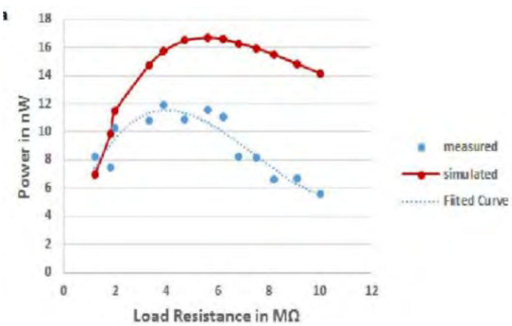


Fig 11 Resonance frequency of the three cantilevers measured using laser doppler vibrometer

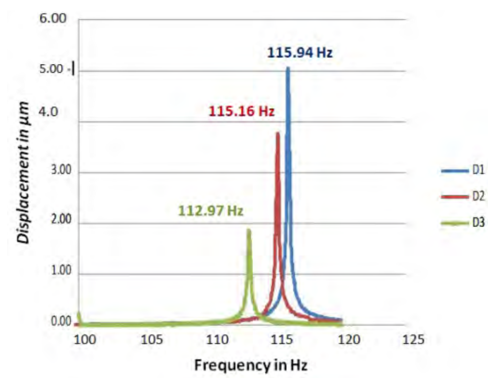


Fig 12 Power output at applied acc. of 20 milli-g

ISSS Researchers' Forum-2018: A Report

ISSS, in association with CeNSE, IISc., organized a Researchers' Forum on 27th and 28th of March, 2018 at CeNSE. The event was organized to bring together research scholars from across the country and provide a platform to share their work. Dr. Kota Harinarayana inaugurated the event and provided a key-note address highlighting the current eco-system in the country for smart systems, smart technologies, especially in the context of initiatives like 'Make in India' and smart cities development. Prof. Rudra Pratap presented a brief overview of CeNSE and INUP initiatives to provide high quality and state of the art infrastructure for fabrication and characterization of micro systems to not just the IISc students and staff, but to the community in the country at large. He exhorted the research community to make full use of the infrastructure to realize the smart devices that are developed.

More than 35 posters presentations from the students were arranged to showcase their work to the smart systems community at large. The topics ranged from Physics of Devices, Modeling and Simulation, Smart Materials, Fabrication Technologies to Systems & Applications. While a most of these posters were on sensors, a few actuators based applications development were also presented. A special feature of this event was the three panel discussions that were arranged to deliberate on some of the important aspects regarding the careers of researchers. These themes were a) career opportunities for researchers: Industry and Academia perspective, b) Funding avenues for startup and Academia and c) Career Opportunities -Research Perspective. Eminent panelists representing premier academic institutions, R&D Labs, Industries including start-ups took part to share their perspectives and respond to the questions and comments from the research scholars. ISSS wishes to thank all panelists for their support.

It was refreshing to note that quite a few of the researchers doing their Masters or Ph.Ds considered becoming entrepreneurs. Hence quite a few discussion points were on what are the support mechanisms in terms of funding, mentoring and incubation for start-ups. Another prominent topic of discussion was paucity of fabrication facilities for MEMS devices. Notably only few fab facilities exist in the country and they are already loaded with long waiting lists. In this context, the idea of community chips where multiple compatible ideas would be combined into a single device and hence have a better chance of getting the design tested and validated.

From Career development perspective, the industry expectations in terms of having a more holistic awareness of the broad domain, product and process orientation, customer or application identification and cost consciousness were amply highlighted. Awareness of Technology and Manufacturing Readiness Levels (TRL and MRL) is highly beneficial to differentiate in the industrial career opportunities realm. Overall the consensus among the panelists in different panels was that this is the right time for a budding researcher to pursue his career and blossom in this exciting technology domain.

Pitch talk sessions wherein researchers were given an opportunity to present for a few minutes to the audience a gist of their research work were also well received. Based on the posters and their presentation, two awards were given away to the presenters. Springer sponsored gift coupons for 500 Euros each for these awardees and these were given away by Prof. V K Aatre. Ms. Richa Mishra from IIT-Kharagpur received the award for her work on microfluidic drug delivery platform and Mr. Sumeet Kumar Sharma from IIT-Mandi bagged the award for his work on Deformation induced electromagnetic radiation based structural health monitoring system. ISSS expresses its gratitude to Springer for supporting these awards, and to CeNSE, IISc for cohosting the event and providing all logistic support.

Last but not the least, untiring efforts of Dr. Veda Sandeep Nagaraja, ISSS GC member and chairperson of the education sub-committee are appreciated and placed on record. Right from conception of the event to the successful completion of the same, Dr. Veda played an exemplary role and a fair share of the success of the event is due to her. ISSS is immensely grateful to her. ISSS is also thankful to several volunteers and members who strived to make this event a success.

Refresher Course on Recent Trends in MEMS, Power Sources and Electronic Packaging

Girish Phatak C-MET Pune.

All India Shri Shivaji Memorial Society's Institute of Information Technology organized a one-week refresher program on "Recent Trends in Mems, Power Sources and Electronic Packaging" between March 25 and 30, 2018. This event was sponsored by AICTE-ISTE and was technically supported by CMET and ISSS. Dr. P. B. Mane was the chief event coordinator and Mr. Jaising Pednekar (R & D E (Engg)), Dr B B Kale, Dr. Milind Kulkarni, Dr. Girish Phatak, Dr. Shany Joseph Dr. Tanay Seth (C-MET), Dr. Dhananjay Bodas (ARI), Dr. Tejashree Bhuve (DIAT) and Mr. Ramesh Singh (IIT-Bombay) were the distinguished faculty and scientists who participated as teaching faculty.

The main topics that were covered during this course were as follows.

a) Basics of MEMS Technology,
b) Miniaturized planar antenna for compact electronics systems
c) Stress management
d) Pattern Recognition and sensor instrumentation
e) Structural MEMS and their applications
f) Strategies for Li-ion batteries
g) Microfluidics
h) Plasma Techniques for nanomaterials
i) Nanotechnology for drug delivery
j) Polymer nanocomposites and batteries
k) Materials for integrated passive components in LTCC
l) Miniaturization of subtractive and additive manufacturing process

More than 40 participants attended the workshop and a visit to the Center for Materials for Electronics Technology (C-MET) at Pune was also arranged for the participants.