Deteriorating quality of Ph D theses in India

With reference to the comments by Gurpreet Singh[1] on the quality of Ph D theses in India, we would like to add a few points to bring out the reasons and circumstances responsible for the same.

The first point that comes to our mind is the role of UGC/CSIR. Being apex bodies, they are responsible for the quality of research. It is strange that there are no rules and regulations to check the rewriting work going on in the name of research in most Indian universities. In order that our researches compete with international ones, it would be worthwhile if the UGC/CSIR makes 'one foreign examiner of repute', a rule for thesis evaluation. This would bring to an end various influences, privileges and prejudices in case of Indian examiners.

Secondly, one would like to probe into the role of the guide or research supervisor. The present UGC norms make any person with a general qualification of lecturership, eligible for guiding a research scholar. One would wonder whether having a Master's degree or even a Ph D degree is all that is needed to be a guide. Majority of the guides do not have any significant publications to their credit. Many guides/supervisors do not have any idea regarding work plan and depend mainly upon previous work. Moreover, when a student enters the field of research, he hardly knows anything about the topic or how the work is to progress, and thus is fully dependent on the guide.

Next, it is unfair to compare the work of a student from a university laboratory which is generally deprived of funds with that of a student from a well-furnished, state-of-the-art CSIR/DST/DBT or similar laboratories or institutions. But even in university laboratories there are specks of good researches amidst heaps of poor-quality ones. The examiners rarely go by the quality of theses and are rather highly influenced by friendly relations with the guide, which is also a give-and-take relationship.

It can be concluded that a quality check for thesis submission should soon come into action. Students should be considered on the basis of their research quality since, many a time, ordinary students prove to be much better researchers than NET/GATE/SLET-qualified students. The same was also noted by Srivastava[2]. It is high time that UGC/CSIR introspects to find out the reasons that have led to deterioration in the quality of Ph Ds in India. Otherwise, getting a Ph D degree would be cheaper and easier than getting a B Sc degree.

1. Singh, G., *Curr. Sci.*, 2003, **84**, 1497–1498.
2. Srivastava, G. K., *Curr. Sci.*, 2003, **84**, 616.

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NEWS

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MEMS initiative in India

Micro-Electro-Mechanical System or MEMS in short. Does one need to know more about it? Well, according to projections, what the transistor did to the latter part of the 20th century, MEMS has the potential for the 21st century. Some applications where MEMS has left its signature and is enabling new discoveries include, silicon-based pressure sensors for measuring exhaust emissions, fuel, tyre and hydraulics in the automotive industry; polymerase chain reaction (PCR) microsystems for DNA amplification and identification, biochips for identifying hazardous gases in the environment, the electronic nose, with an inbuilt array of electronic chemical sensors as well as a pattern-recognition system, capable of recognizing simple to complex odours or an electronic tongue for sensing different tastes.

MEMS includes mechanical and electrical elements that convert one form of energy into another, operating by transduction. The transducer is a device that is actuated by energy of one form and supplies energy of another form. Transducers encompass both sensors and actuators. MEMS devices are made of extremely small parts or microchips. This miniature device comprises mechanical elements, actuators and electronics on a common silicon substrate, fabricated using microsystems technology (MST). MEMS is an aggregation of parts, between which there exists a relationship, such as a microsensor (miniature device that converts a nonelectrical quantity, for example, pressure, temperature, gas concentration or magnetic phenomenon, into an electrical signal and has at least one physical dimension at the submillimetre level); and an actuator (converts an electrical signal into a nonelectrical quantity). The purpose of MEMS is to directly interact with the physical environment. Another type of device is the Micro-Opto-Electro-Mechanical System (MOEMS) that overcomes challenges posed by MEMS and demonstrates required optical performance. MOEMS devices offer higher bandwidth, lower cost, smaller size and an easier integration than similar optical devices in the macro world.

MEMS devices have to be integrated, that is, they are fabricated on the same substrate as the electronics controlling them, while taking care of compatibility issues concerning the fabrication method such as micromachining and the electronics. By integration on a microchip, the sensors collect information from their environment, the electronics processes this information and the actuators are made to respond depending upon the requirement, such as for moving, positioning, regulating, pumping and so forth. Micromechanical systems are much in demand as miniaturization reduces cost, size, weight and increases precision. They are manufactured in bulk using batch fabrication, quite similar to those used in integrated circuits. They create an effective, reliable and sophisticated link between the macro and micro world. MEMS technology enables a gateway to the world of 'smart' products (Table 1).

There are several technical issues involved during the design and development of both sensors and actuators. These relate to operating principle, microsystems, process modelling, circuitry design, process technology, environment during application, packaging and manufacturing system. The aim is to reach a proper balance between design, manufacture and development performance coupled with low cost.

MEMS device trendsetters are seen, for example, in space exploration where reduction in size and weight is important. Miniature satellites, less than 10 cm across, microprobes and micromachined adaptive optics (optical MEMS) that allow correction of say lens distortions. In addition, they could be used as navigation and guidance systems and in spacecraft propulsion. Microspace satellites need micropropulsion systems.

For vehicle safety, automobiles are fitted with accelerometers used for detection of collision and inflating an airbag, tyre-pressure monitoring and non-skid brake adjustments.

The medical arena has microprobes with recording tips to measure biopotentials, smart inhalers that monitor droplets inhaled by a patient, catheters with smart sensors, sensors for locally measuring temperature and pressure, microneedles and sensors for insulin drug delivery. Other examples concerning healthcare are pacemakers for adjusting pulse rate and implantable micropumps for delivering microdoses of medicine. We could, while gazing into the crystal ball, see nanorobots, of sizes less than 3 μm as futuristic workhorses in the bloodstream.

Fabrication and integration

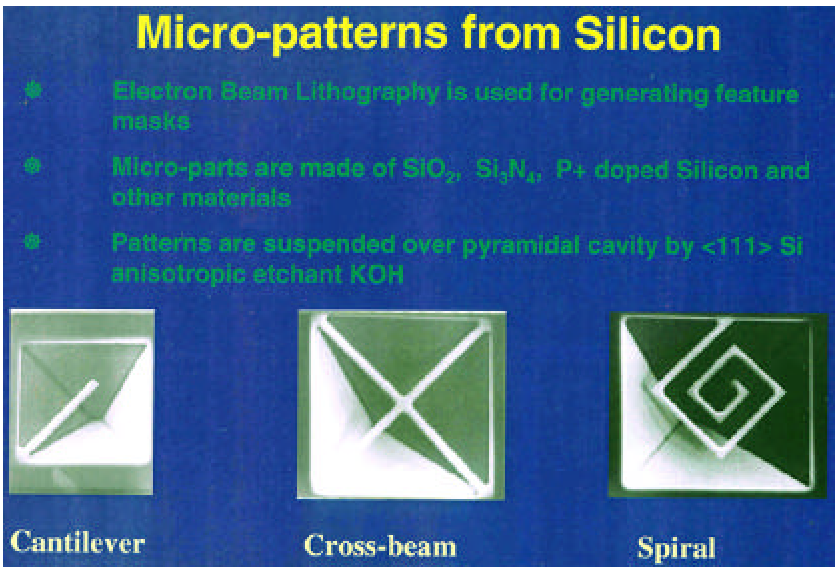
Micromachining of silicon is used for fabrication of desired MEMS structures by etching techniques, removing part of the substrate or thin film, either isotropically or anisotropically. Surface micromachining is generally used for the formation of mechanical structures in thin films on the silicon wafer. Pressure sensors may be fabricated using surface micromachining, having a membrane of the order of 100–200 μm using such techniques. Fabrication steps for preparation of MEMS devices include manufacture of the silicon wafers having high purity and precise levels of doping. Processing steps known in the electronics industry can be used for MEMS as well, such as oxidation, patterning of the wafer using lithographic techniques, etching, thermal annealing and thin-film deposition. For protection from damage, various bonding and packaging methods are needed.

Packaging

Packaging comprises the largest fraction of MEMS device costing. Packaging of MEMS devices is a critical component of the whole process. It could affect assembly, testing and output of the microsystem prior to commercialization. Packaging concerns with interaction of the device with the environment, such as vacuum sealing to protect accelerometers, standardization, acceptable electrical and magnetic interconnections, minimizing cross-talk, minimizing package-induced stress, protection from electromagnetic interference, testing and calibration, precision alignment and so on. In order to create MEMS device packages, the processes widely used include wafer bonding, wafer sawing, die attach, wirebonding and interconnections, encapsulation, trimming (minimizing effect of variation on yield loss) and testing. These processes are difficult and delicate, and require considerable expertise. Wafer bonding is found on many MEMS products and involves bonding the wafer to micromachined devices. One method is to use direct wafer bonding for microstructures such as in pressure switch, pressure sensor or an accelerometer. Microstructures

Table 1.

Examples of smart product	Smart uses
Shape-memory alloy	A smart material
Building with an active damping system	A smart structure, such as a building that responds to changes in its surroundings
Pressure sensors	A smart sensor, like those used in automobiles
Micromotor	A smart actuator
Fuzzy controller	A smart controller
Neuronal chip	A smart electronics with intelligence
MEMS or MOEMS devices	A smart microsystem that comprises sensor, processor and actuator, all integrated in one chip



Source: NPSM

that become stuck to their substrates have to be released and the wafer has to be sawed through for die separation. Then good and bad dies are picked and placed on the assembly line to eliminate non-functional dies. Once the die is separated from the wafer, it has to be attached to a suitable substrate and then wire-bonded for electrical interconnections. The advantages of MEMS are only available when the MEMS device is integrated with electronics, presenting a challenge especially for the development of surface micromachining processes compatible with integrated circuits.

India has set-up 'design centres' at the Indian Institute of Science (IISc), Bangalore; Solid State Physics Laboratory (SSPL), Delhi; IIT Kharagpur and would also shortly do so at the IITs in Mumbai and Chennai. It is the 'same platform, same software for exchange of design' according to V. K. Aatre, Scientific Advisor to the Union Defence Minister, Government of India. At the Semiconductor Complex Limited (SCL), Chandigarh, a National Foundry for MEMS devices has been set-up (Box 1). The facility at Bharat Electronics Limited, Bangalore is also being augmented.

Industry participation in three MEMS device application areas of aerospace, civil and biomedical engineering is being explored. The aim of technology is to find products, stressed Aatre. He hoped that smart technology, as a subject would percolate undergraduate education in the country and also enter the university curriculum. Aatre was confident of Indian science and technology, but wondered 'whether we have the products'. One source said Indian industries appear reluctant to enter this arena, though we are in the process of educating industry associations of the business potential.

Vikram Kumar, National Physical Laboratory, speaking about the soon-to-emerge products from India such as surface acoustic wave sensors, titanium bolometers, nanocalorimeters, catheters for thermography, pressure sensors, vibration sensors, microaccelerometers and patch antennae, to name a few said, 'we have reached a stage where within the next year, we expect several functional devices to be available, as the design, prototyping, packaging has already been taken up, in keeping with the set target'.

Smart technology, which includes MEMS and MOEMS has attracted international attention. The current world market for MEMS according to one estimate could be around US $ 40 billion in 2003, and could grow to about US $ 100 billion in just five years. Envisaged is an enormous growth potential for optical switches in the communication industry, microfluidic systems, microturbines, microsensors, micromachines, drug-delivery systems, lab-on-chip and so on.

India has been aware of this potential, although work done previously in this multidisciplinary field was at best, unconnected individual efforts. An India-centric technology roadmap that could foster scientific exchange and focus areas for developmental research, came about only after the international conference held in Bangalore in December 1996 on smart materials, structures and systems. Following this conference, nucleation of a professional society took place, the Institute of Smart Structures and Systems (ISSS; see Box 2). Aatre, noted that the ISSS had 'triggered' the formation of the National Programme on Smart Materials (NPSM; see Box 3).

Under the NPSM, devices and materials were identified along with user agencies that formed part of the report under the chairmanship of Kota Harinarayana, University of Hyderabad. This report forms the basis of work done in India, in the area of MEMS/smart materials, particularly development of basic devices (sensors, actuators) and materials. The importance of the NPSM is that although VLSI design experience exists in the country, MEMS device design has yet to catch up,

Box 1. National Foundry for MEMS devices at the Semiconductor Complex Limited (SCL), Chandigarh

Semiconductor Complex Limited (SCL), Chandigarh was established by the Government of India in 1983 with the objective to design, develop and manufacture VLSIs and VLSI-based systems.

Recently, a National Foundry for MEMS, as a national facility has been inaugurated by V. K. Aatre on 27 July 2003. This facility would provide process-development support and manufacturing facility for the product designs developed by various design houses in the country. This would enable SCL to establish the primary processes for fabricating a wide variety of products such as accelerometers, pressure sensors for industrial, health and strategic applications, IR sensors, etc. The available facilities include:

- Bulk Micro-machining
- Surface Micro-machining
- Wafer Bonding and
- MEMS Packaging.

The facility now comprises:

- Surface Micro-machining process with structural layers of silicon dioxide, poly-silicon and aluminum.
- Bulk micro-machining process with electrochemical etch stop and timed etch stop.
- Sub-micron processing (up to 0.8 microns minimum feature size) with I-line (365 nm) lithography.
- Front-to-back alignment.
- LPCVD and PECVD processes for silicon dioxide (undoped, PSG and BPSG), silicon nitride and poly-silicon deposition.
- Metal deposition by sputtering for aluminum and titanium.
- Metal deposition by e-beam evaporation for gold, chrome, etc.
- RIE for metals, silicon nitride and silicon dioxide.
- Wet etch stations for metal, poly-silicon, silicon nitride, silicon dioxide and anisotropic etching of silicon.
- Medium and high current implanters for B+, BF2, P, As implantations at different values of dose and energy.
- Anodic and fusion bonding for Si–glass and Si–Si bonding.
- Characterization facility with non-contact surface profiler, SEM, semiconductor process control system, semiconductor parametric analyser and various reverse engineering processes.
- Parametric testing with digital and analogue tester.
- Dicing process for fragile MEMS structures.
- Packaging in ceramic (DIP and PGA) and COB in various lead counts.

Source: SCL, Chandigarh

especially in integration and packaging of such devices. The NPSM promotes the setting-up of facilities for design, fabrication, integration and qualification testing as well as funding for MEMS-related projects. The idea is to strengthen and accelerate efforts, get the participation of industries and try to keep pace with rapid progress in this emerging field. In order to prioritize national needs, both in civilian and strategic sector, and channel funds for the right developmental tasks, the Government of India sanctioned the NPSM with a budget of Rs 75 crores in July 2000 spread over five years. This is a joint programme run by Defence Research and Development Organization (DRDO), through the Aeronautical Development Agency (ADA), Bangalore comprising DRDO, Department of Space (DOS), Department of Science and Technology, Ministry of Information Technology, and the Council for Scientific and Industrial Research. The NPSM currently funds about 32 projects at a total sanctioned cost of Rs 46 crores, involving more than 21 institutions. The list of projects under NPSM is given in Table 2.

The other programme run by the Government of India is DISMAS or Development Initiative for Smart Aircraft Structures, for aerospace applications. DISMAS is a five-year project, at a cost of Rs 19.26 crores, sanctioned by DRDO in April 2001. This is operated by the ADA, Bangalore. The areas of interest in about 10 projects under DISMAS are the following:

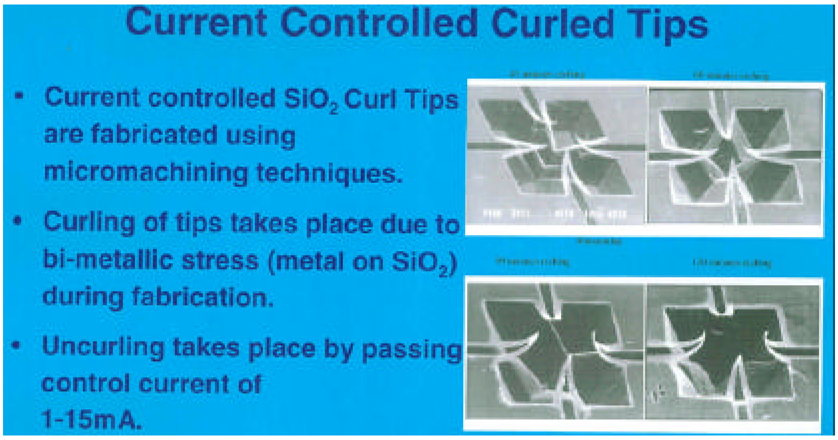
Structural health monitoring: Smart sensor monitoring of internal damage to laminated composite structures used in, for example, wing and fins, and fuselage shell of aircrafts.

Vibration and noise control: Vibration reduction in structural components of aircraft using flutter control, distributed sensors and actuators, and damping enhancement systems.

Active shape or flow control: Changing the external contour of an aerodynamic surface for enhanced aerodynamic effects, with the help of sensors and distributed actuation.

Conformal antennae and radome: Involves development of conformal antennae for making the external contour of the aircraft aerodynamically sound.

According to ADA, Bangalore, the Light Combat Aircraft (LCA) being developed would provide a platform for incorporation of smart-technology concepts. Smart technology could be used in damage monitoring airframes made of advanced



Source: NPSM

Box 2. Institute for Smart Structures and Systems

The society comprises of all those actively working or interested in promoting smart technology in India. Founded in 1997 in Bangalore, the activities include holding workshops/conferences, bringing interested people together such as industry–R&D meets, inviting foreign speakers to deliver lectures, publishing monographs and so on. Recently, in May 2003, a series of lectures were held for the industry at Pune.

The Founder President is V. K. Aatre. The present President is Vikram Kumar and the present Secretary is P. D. Mangalgiri of the Aeronautical Development Agency (ADA), Bangalore.

The ISSS, according to Aatre is for ‘educating the educator’. He added that a monograph on MEMS technology would be available next year.

Box 3. National Programme on Smart Materials

The programme structure comprises:

Smart Apex Board (*SAB*) for providing overall policy guidelines, with V. K. Aatre heading the Board as Chairman.

Board for Smart Materials Research and Technology (*B-SMART*) for providing the executive and financial authority to run the programme and headed by Aatre.

Project Assessment and Review Committees (*PARCs*) for executing the technical components of the programmes, including assessment, monitoring of all projects funded by NPSM. Five PARCs have been constituted by B-SMART, each headed by a Chairman. These are:

- Materials and processes
- Devices
- Packaging and qualification
- Application development and demonstration, and
- Bio-medical devices

B-SMART has identified aerospace (encompassing mechanical and civil engineering as well) as a major area of application of MEMS. The devices of interest include those for sensing pressure, acceleration, rotational speed, temperature, strain, fibre-optic devices, actuators (piezo-ceramics, piezo-polymers, electro/magnetostrictive, shape memory alloys and related chemicals and materials).

An NPSM Programme Cell has been set up at ADA, Bangalore which can be contacted for further information on the programme, with A. R. Upadhya as the Programme Director.

carbon-fibre composites, better manoeuvrability of aircraft, suppression of vibrations in the fin tip and control surfaces.

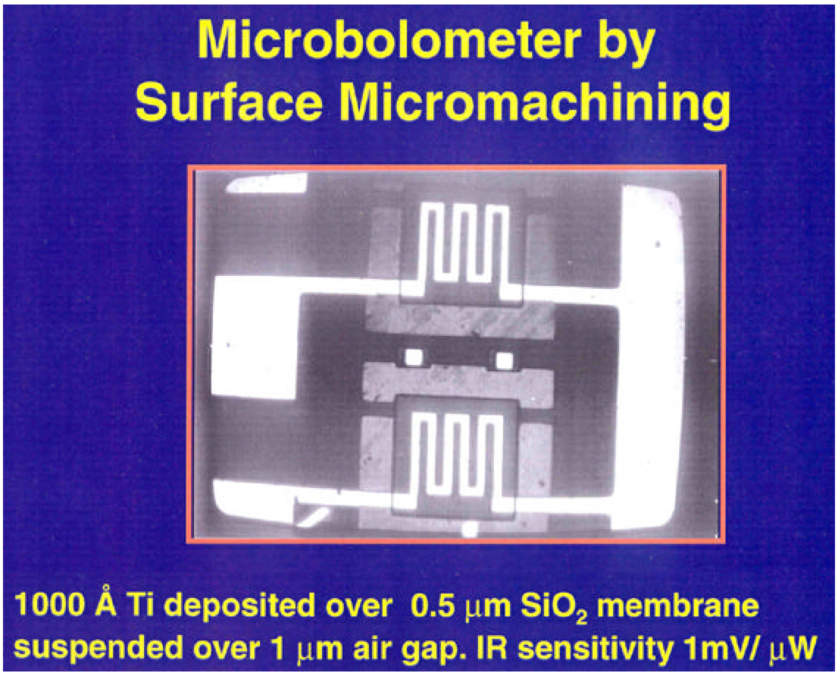
Development of some Indian smart products

Shape memory alloys

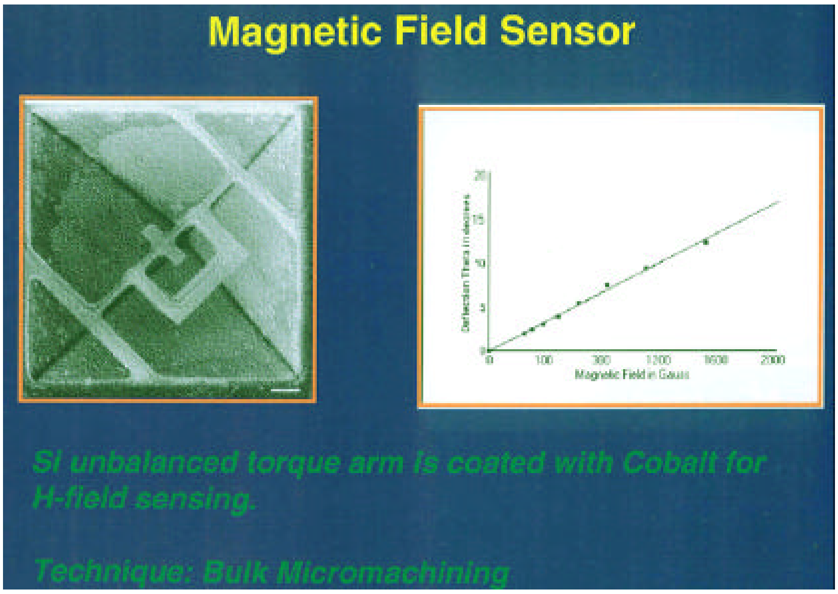
Shape memory alloys (SMAs) are thermally controllable materials producing high reversible shape changes. The effect takes place due to the reorientation of the two phases of crystalline structure such as the high symmetry austenite phase, stable at high temperature and the low symmetry martensite phase, stable at low temperature. The SMA when heated past its martensitic transformation temperature, becomes rigid austenite. The shape-memory effect is based on reversible solid-state phase transformation. Some intermetallic compounds possess the ability to undergo shape change at low temperature and retain this deformation until heated, at which point the solid returns to its original shape, which generates large forces. By changing the alloy composition, i.e. ratio of elements, the temperature of transformation can be varied depending upon applications in aerospace (embedded in composites, nickel–titanium alloys can dampen vibrations), automotive (fuel control valves), medical field (surgical equipment). SMAs are being used as actuators for manipulators in robots or in micropumps with dimensions of the order of 18 mm in diameter and 5 mm in height. SMAs are used as wires or ribbons for triggering, drive and as final control elements as well as valves and injectors, due to their force output per unit volume of any resuable microactuator technology. This force is the basis of the actuation process. In microactuators, electrical current is passed

Table 2. Current NPSM-funded projects

Project	Institution	Cost (lakhs)	Project duration
Development of constitutive models of smart materials	IIT, Chennai	24.15	2 years
Development of ceramic-oxide magnetic materials for magnetostrictive sensors and actuators	NCL, Pune	45.69	3 years
Development of Ni–Ti-based shape memory alloys for actuator application	NAL, Bangalore	69.60	3 years
Development of multilayer piezoelectric actuators	CGCRI, Kolkata	42.07	2 years
Development of magnetic oxide for sensor application	IISc, Bangalore	22.20	2 years
Integrated piezoelectric/electrorestrictive films onto MEMS for microsensors and microactuators	IISc, Bangalore	79.51	2 years, 6 months
Development of electroactive polymers for actuators	NCL, Pune	63.10	3 years
Development of PZT and PMN materials and fabrication of sensors/actuator devices	NAL, Bangalore	24.67	2 years
Development of magneto-electric composites for sensors and actuators	Osmania University, Hyderabad	29.92	3 years
Development of multilayer PMN–PT electrostrictive activator	C-MET, Trissur	24.39	2 years
Nanoporous titania films	IIT, Kharagpur	19.45	2 years
Ferroelectric thin films for RF MEMS	University of Hyderabad	57.25	2 years
Design and development of MOS-integrated piezoresistive pressure sensor	IIT, Chennai	233.86	2 years
Development of silicon micro-mechanical accelerometer for aircraft motion sensing	IIT, Kharagpur	212.70	2 years
Development of MOEM pressure sensor	IISc, Bangalore	14.95	2 years
Development of MEMS-based microswitch	IIT, Delhi	14.95	2 years
Millimetre-wave antennas using MEMS	IIT, Delhi	11.50	1 year
Design centres for MEMS devices	IISc, Bangalore; IIT Kharagpur; SSPL, Delhi	139.70; 43.12; 182.82	4 years
Development of combtype accelerometer using MEMS technology	SSPL, Delhi	433.00	2 years
Design and development of MEMS capacitative pressure sensor chip	CEERI, Pilani	453.85	2 years
Development of plasma etching process for high aspect ratio structuring for MEMS application	CSIO, Chandigarh	95.20	2 years
Silicon MEMS foundry services	SCL, Chandigarh	1278.00	1 year, 3 months
Design and development of low pass filter based on MEMS technology	BEL, Bangalore	232.00	1 year, 8 months
FBGs and LBGs for structural health monitoring	CSIO, Chandigarh	122.00	2 years
Active millimetre wave antenna	IIT, Delhi and SSPL, Delhi	22.42; 8.60	1 year, 6 months
Packaging of pressure sensor and accelerometer	BEL, Bangalore	344.00	1 year, 3 months
Active noise control device	NAL, Banglaore	28.26	2 years
Structural health monitoring of pre-stressed concrete bridge girder	SERC, Chennai	36.00	3 years
Development of catheter-end temperature probe for arterial plaques	IIT, Delhi; AIIMS and SSPL, Delhi	32.97	2 years
Bio-MEMS based micro-clinical diagnostic kit for tuberculosis	CSIO, Chandigarh	61.00	2 years, 6 months
Bio-MEMS for cardiac diagnostics	IIT, Mumbai	264.55	2 years, 6 months
Smart vest	DEBEL, Bangalore	55.00	1 year, 6 months



Source: NPSM



Source: NPSM

through the SMA element to induce temperature change. Examples of SMAs are nickel–titanium alloy, copper–zinc–aluminium alloy, copper–aluminium–nickel alloy. At the National Aerospace Laboratories (NAL), Bangalore, indigenous alloy fabrication, wire-drawing with controlled microstructure is underway.

PZT actuators

The piezoelectric effect can be observed by applying either compressive or tensile stress to the opposite faces of a piezoelectric crystal, resulting in electric charges on the surface of the crystal and a change in polarization in the material. Piezoelectric ceramics produce a small shape-change from an applied voltage. MEMS devices based on this effect are used as sensors or actuators. Bulk piezoelectric ceramics such as lead zirconate titanate (PZT) and more recently, thin-film piezoelectric materials from zinc oxide and aluminium nitride are used. Surface and bulk micromachining can be used to build complex microstructures with features such as large force generation, high frequency responses and stable motion control at moderate voltage levels. At the Central Glass and Ceramic Research Institute (CGCRI), Kolkata compositions are being made along with multi-stacking of actuators.

Magnetostrictive materials

Magnetostrictive material under the brand name Terfenol-D®, is an alloy of terbium, dysprosium and iron. Magnetostrictive composites are made by embedding magnetostrictive particles in a host polymeric material. These particles undergo elastic strain when subjected to external magnetic field. This property can be used in distributed actuators or as discrete-point strain sensors. At the National Chemical Laboratory, Pune an import substitute composition has been generated whose material performance is 80% of that observed for the expensive Terfenol-D®. Magnetostrictive materials may be used in aerospace applications for vibration control, improving pointing accuracy of airborne antennae and sensing damages in laminated composites.

Constitutive modelling

This project at IIT Chennai deals with constitutive modelling for reliable operation by mapping stress and strain variations in different kinds of actuators.

Magnetic sensor materials

Magnetic microsensors for measuring magnetic flux density can be classified on the basis of principles such as galvanic (Hall device), conductimetric (magnetoresistor), voltaic (magnetodiode, magnetotransistor) and acoustic (surface acoustic wave or SAW device). Magnetic sensor materials are being formulated at IISc, Bangalore, which show significant currents under applied magnetic fields.

Electroactive polymers

Polyvinylidene fluoride (PVDF) is an important ferroelectric polymer, useful as sensors that are piezoelectric and pyroelectric (electrical variation with pressure). At NCL, Pune conventional PVDF is converted to usable actuations and newer polymers for ultrafine actuations.

Relaxor-ferroelectrics

Relaxor-ferroelectric materials such as lead magnesium niobate–lead titanate (PMN–PT) with large electrostrictive strain near the Curie temperature are used in actuators having advantages such as low hysteresis and a return to zero displacement when voltage is removed. At C-MET, Hyderabad actuators based on multilayer relaxor materials are being made.

Other projects include integrating ferroelectric thin films on MEMS structures, for the development of RF MEMS, useful in microwave applications at the University of Hyderabad; and nano porous materials such as nano-titania integrated onto MEMS for use as chemical sensors at IIT, Kharagpur. Work is being done on multilayer-stacked ferroelectric-relaxor-based actuators at NAL, Bangalore.

Finally, smart technology has been identified as an important tool for development in India. The national programme aims to coordinate a national effort for optimally using limited resources for critical segments contributing to technological growth and self-reliance.

Fabricating MEMS devices is a field of research with huge potential and is all set to develop rapidly with the arrival of more sophisticated micromachines. The only limiting factor would be the level of smart thinking of humans to stretch the extent of creativity for developing smart MEMS devices. Being multidisciplinary and the products permeating our lives so inextricably, it is apparent that India needs a lot more 'hands' working in areas of both strategic and civilian interest. An exciting field indeed to enthuse young scientific minds!

ACKNOWLEDGEMENTS. I thank all those who contributed insights into recent Indian developments in this area and especially V. K. Aatre, who loaned books on this subject from his personal collection that made background reading for this article both pleasurable and informative.

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RESEARCH NEWS

Neutron scattering, quantum entanglement and chemical formula of water*

K. R. Rao

Even after nearly 50 years since neutron scattering came up as a bouquet of powerful techniques to unravel structure, magnetism and excitations of solids and liquids, new findings continue to be announced making the neutron a very unique and useful probe. As the flux of neutrons on the samples moved up by nearly four/five orders of magnitude during this period, techniques became powerful to elicit new information. One such technique is Neutron Compton Scattering (NCS), often referred to as 'deep inelastic neutron scattering'.

Compton effect, first observed in 1923 by A. H. Compton, relates to reduction in energy of high-energy X-ray or *g*-ray photons when they are scattered by free electrons in solids or liquids. When a photon of energy E_o and momentum p_o collides with an electron, the electron of initial energy E and momentum p recoils with energy E_e and momentum p_e. By conservation of energy and momentum, one can show that there will be a shift in the wavelength of the photon after scattering with the electron. The shift in wavelength is given by, $l - l_o = (\hbar/mc)(1 - \cos q)$, where q is the scattering angle of the photon. One can derive from detailed measurements the momentum distribution of the electrons as it was before scattering. Hence X-rays/*g*-rays (and so also high energy electrons) are used to derive momentum distribution of electrons in atoms and molecules in solids.

NCS from atomic nuclei is analogous to X-ray or *g*-ray scattering from electrons of atoms. During the scattering process, at large momentum transfer, the neutron effectively interacts with the nucleus of a single atom. The scattering process is subject to usual conservation laws of momentum and energy transfers. Hence from measurement of scattered neutron intensity as a function of momentum transfer $\hbar\mathbf{Q}$ and energy transfer $\hbar ù$ during the scattering process, the momentum distribution of the nuclei before scattering can be derived. NCS and high-energy electron Compton scattering (ECS) are being used as complementary techniques for study of momentum distributions of nuclei/atoms in a variety of solids and liquids.

The electron-volt spectrometer (eVS) based on time-of-flight (TOF) technique at ISIS spallation neutron source in UK is being extensively used for these studies. In this instrument one makes use of epithermal neutrons for scattering experiments. The eVS at ISIS has undergone significant modifications, resulting in better resolution during 2001 and is rechristened as VESOVIO.

The NCS technique has been used by a number of scientists at ISIS for momentum distribution studies in a variety of materials. Amongst them Chatzidimitriou-Dreismann from Technical University of Berlin and his collaborators have studied protonic motions in various systems like water, liquid H_2O–D_2O mixtures, metallic hydrides, all at room temperature. The experimental results from H_2O–D_2O mixtures[1] are believed to show an anomalous effect, namely the scattering cross-section from hydrogen nuclei was less than expected values.

*Dedicated to Prof. S. Ramaseshan on his 80th birthday.

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