·|| Sūkshma ||·

A newsletter about micro and smart systems in India

Volume 3 : Number 2 : April 2008 Published quarterly by the Institute of Smart Structures and Systems

CONTENTS



# From NPSM to NPMaSS

V.K. Aatre

Among the many technologies that seem to have vast potential for application, the Microsystems Technology (MST) – microelectronics, micro machines, and MEMS (Micro-electro-mechanical systems) - seems highly promising. Coupled with the smart materials and systems technology, MST finds applications from aerospace to automobile engineering, from environmental monitoring to structural health monitoring, to biomedical and health sciences. Through the establishment of ISSS (Institute of Smart Structures and Systems) and successful completion of a National Programmme on Smart Materials (NPSM) (*see* Vol. 1, No. 1, p. 1), scientists and technologists in India have made considerable progress in this area. Based on the success of NPSM, a new National Programmme on Micro and Smart Systems (NPMaSS) has been launched (*see* Vol. 3, No. 1, p. 1).

While the basic aim of NPSM was to create awareness in India by launching HR related activities, by establishing certain basic infrastructure, and by encouraging some R&D activities, the primary goal of NPMaSS is to push this technology to products and specific field applications. Smart Materials Board (**B-SMART**), which is responsible for steering this national programme, has established five PARCs – R&D, HR, Aero, Automobile and Bio – to implement the programme.

The structure of these product oriented PARCs has made provision for advisers to guide their developmental work and for industrial representatives to define field requirements and help market the products. The role of the industrial representatives is crucial to achieve the primary goal of NPMaSS in that they must help bridge the gap between the academicians/designers and the ultimate users of the technology and products. Each of these PARCs has drawn a road map of their activities – we have broadly set a goal of at least one product per year per PARC – and we expect to periodically report on their achievements in Sūkshma. The Aero PARC mainly caters to the requirements of LCA (ADA), Saras (NAL), and ISRO and has clearly defined some end products. Potential requirements of Unmanned Aerial Vehicles (UAVs), Regional Transport Aircraft (RTA), and Structural Health Monitoring (including those for civil structures) are few other activities included in the road map of this PARC. Bio-MEMS – for diagnosis and drug delivery – is clearly a fertile area of application. Additionally, micro-fluidics, lab-on-a-chip, MEMS for environmental and food quality monitoring are areas this PARC is contemplating. The primary aim of this PARC is to complete some of the work initiated under NPSM and bring technologists and medical doctors together to define products, and hence find an R&D road map for biological and life sciences applications. Automobile industry is thriving in India and automotive electronics with sensor systems for safety, stability and comfort, and increased efficiency are becoming more of a rule than exception. This is a new area, which the National Programme is getting into, and the PARC on Automobiles is in touch with industries and other national initiatives to define a well structured programme on sensors.

While development of technologies and application specific products are a must for justifying a National Programme of this magnitude, I believe that creating a pool of young and committed researchers and technologists is of paramount importance. Indeed, it is even germane to achieving the primary goal of NPMaSS. As such, the HRD will receive particular attention of B-SMART and the HRD PARC has planned several activities. Besides establishing additional design centers and other basic infrastructure across the country, this PARC will help run workshops, training programmes, and special seminars. We are also looking into the possibility of conducting 'Student Competition Awards' to attract youngsters to make a career in this exciting multidisciplinary technology. Over the last couple of years, concentrated efforts have been made by ISSS to train a large number of teachers of the Visveswaraiah Technological University (VTU) (see Vol. 1, No. 1, p. 6 and Vol. 2, No. 2, p. 1) and introduce a course on MST in their Undergraduate Curriculum. There is even a program to write an appropriate textbook on MST. The HRD PARC would pursue such activities and buttress the ongoing efforts of ISSS.

I have often mentioned that the technology acquisition can happen through four Is – Importing, Imitating, Innovating and Inventing. The route we have to follow to excel in this MST (as in any other technology) is obvious. By and large technology seeding takes place in the academic environment; hence, there is a crying need to support R&D activities in such and other institutions. The R&D PARC of NPMaSS is in charge of the responsibility of mounting such programmes. While products are important, and indeed essential, to sustain programs like NPMaSS, the future products depends on current R&D. However, the projects supported by this PARC would be highly selective – both in content and groups performing the R&D tasks to fulfill the mandate set by the programme.

Most research and developments programs in India suffer from sub-criticality of resources – both funding and personnel power. Over the last few years the total funding in micro systems (and nano technology) in India is, in my opinion, reasonably adequate to establish the basic science and technology. However, there is clearly a shortage in the availability of adequate and specifically trained personnel. While NPMaSS cannot solve this inadequacy in the field of MST, it will make every attempt to address certain issues of this problem.

NPMaSS, like the earlier programme NPSM, is a unique program. Although they are R&D programs, they are more directed and product oriented. Though they are programs wholly supported by Defence R&D Organization (DRDO) through Aeronautical Development Agency (ADA), they are endorsed by the five departments – DRDO, DOS, DST, CSIR and DIT. They are basically run by ADA and through B-SMART with guidance from an Apex Board of all the five corresponding Secretaries to the Government of India. **B-SMART**, a multi-departmental committee with representatives from academic institutions and industrial representatives, has its job well cut out – **to run this unique program and develop this unique technology.**

Dr. V.K. Aatre, the founding president of ISSS, is a former scientific adviser to the Defence Minister and is currently a visiting professor in the ECE department in IISc.

# Update on the ISSS International Conference in 2008

**ISSS International Conference on Smart Materials, Structures and Systems**
**24-26 July 2008**
**National Science Seminar complex**
**Indian Institute of Science, Bangalore**

The preparations for the ISSS International Conference on Smart Materials, Structures, and Systems are in in full swing. More than 100 abstracts have come in from academic, government, and industrial organizations. As the full papers are arriving, the technical committee is gearing up to conduct a thorough peer review of the papers. A website has been set up wherein the authors can upload the papers, register, etc. Visit: **www.isss.in**.
Three tutorials are planned on 23 July, the day before the conference. They are on photonics, polymer electronics, and structural health monitoring.
ISSS invites all its members to take part in this conference and requests to spread the word about this conference to others who may be interested.

### Revised dates to note

(See the website for final information)

Abstract submission: (Closed)
Receipt of the full paper for review : April 8, 2008
Acceptance of the full paper after review: May 14, 2008
Deadline for receipt of the revised full paper: June 7, 2008
Last date for advance registration: June 15, 2008

### *Best paper awards at the conference*

***Student paper contest:* see website for details.**

***Best paper awards in three categories* (MEMS, smart materials, and systems) based on submitted full papers and presentation at the conference.**

***Awards will be presented in the awards function just before the Annual General body Meeting (AGM) of ISSS on the last day of the conference in late evening. Please keep this in mind when you make your travel plans.***

## ISSS News

As all members know by now, ISSS is organizing its fifth international conference this year during July 23-26, 2008, at the J. N. Tata Auditorium in IISc. This conference is jointly organized by ISAC, Bangalore-ISRO, NAL, and IISc. This conference will be of special significance due to rapid strides the country has made in the MEMS and smart systems technologies. This conference will be attended by the eminent personalities from India and from around the world. The conference details can be seen at the website: http://www.isss.in. We request all the members to attend this conference in large numbers and take advantage of the reduced registration fee for life members of ISSS. We also thank those members who have submitted abstracts. The full paper review is in progress. The members are requested to provide their help in the review process if the technical committee of the conference contacts them.

**This year, Annual General Body Meeting of ISSS will be held on the last day of the conference on July 26th. A detailed circular regarding this will be communicated to all the members in due course.**

ISSS will soon be moving over to a new website (www.isss.in). Presently, this website is the official ISSS-2008 conference website.

ISSS has been striving hard to increase its membership base. From the current year, the executive board has decided to create *Institutional Membership* to educational institutions and small R & D companies. The life-time fee for such institutional members is Rs 25,000/- with an admission fee of Rs 200/-. We kindly request all the members from educational institutions and small R & D companies to solicit membership from their organizations. The details can be obtained from the ISSS office at Department of Aerospace Engineering at IISc, Bangalore (isss@aero.iisc.ernet.in) or from krishnan@aero.iisc.ernet.in.

ISSS would like to welcome its new members.

1. Dr. Madhavan K.T., Experimental aerospace division, NAL, Bangalore (madhavan_kt@rediffmail.com)
2. Mr. Ajay Kumar Yadav, A R Division, ADE Bangalore (ajaykumar_xyz@yahoo.co.in)
3. Dr. Makharand Joshi, R &DE(Engrs), Pune, (meenmak@hotmail.com)
4. Mr. Mukesh Kumar Sharma, Biosensor Development Division, DRDE, Gwalior. (muk_drdo@yahoo.com)
5. Dr. Sanjay Upadhyay, Biosensor Development Division, DRDE, Gwalior. (sanjayupad@rediffmail.com)
6. Dr. Soma Dutta, Materials Division, NAL, Bangalore (som@css.nal.res.in)


## Editorial Team

G.K. Ananthasuresh, IISc (Editor)
S. Gopalakrishnan, IISc
J. Gurudutt, Bigtec
G.M. Kamath, NAL
K.J. Vinoy, IISc

*Art Design: G. Bharathi*

***This newsletter is sent to all ISSS members by postal mail.***


## ISSS Governing Council

**President:** A.R. Upadhya **Vice-president:** P.D. Mangalgiri
**Secretaries:** S. Gopalakrishnan and K. Vijayaraju **Treasurer:** G.M. Kamath
**Members:** G.K. Ananthasuresh, N. Bhat, S.N. Giri, J. Gurudutt, K.S. Haraprasad, S. Mohan, and the presidents of Hyderabad and Delhi chapters

To become an ISSS member, download: http://www.isss.in/membership.html and send the form with payment to: Institute of Smart Structures and Systems Department of Aerospace Engineering Indian Institute of Science, Bangalore 560012, India

ISSS admission fee: Rs. 200
Member:
Rs. 200 (annual); Rs. 2,000 (life)
Student member: Rs. 75 (annual)
Corporate member:
Rs. 10,000 (annual); Rs. 50,000 (life)
Institutional member: Rs. 25,000 (life)
Payable to "ISSS, Bangalore".

**SITAR** (Society for Integrated circuit Technology and Applied Research) is an autonomous Government of India society, founded with a mission to meet the microelectronic circuit requirements of various customers.

SITAR has two fabrication facilities, one in Hyderabad and the other in Bangalore. The Hyderabad facility is manufacturing MMICs. The silicon fabrication facility is located in Bangalore and is in the business of ASICs and MEMS.

SITAR has decades of experience and expertise in manufacturing high-reliability CMOS ASICs from Concept to Chip (C to C) and is armed with design, fabrication, packaging and testing facilities.

SITAR's product portfolio includes CMOS ASICs, discrete MOSFETs, and MEMS components for as diversified applications as telecommunications, computing, imaging, and sensing.

About a couple of decades ago as the microelectronics division of the premier telecommunications industry, ITI Ltd., SITAR has pioneered the five -micron CMOS process and realized products for numerous applications and migrated later to both front-end and back-end processing in three and two micron CMOS technology. The present 1.0 micron CMOS fabrication facility was established in mid 1990s, the first of its kind in southern India.

Today, SITAR routinely churns out several high-reliability CMOS products for varied applications. SITAR, while producing ASICs in the silicon technology realm is moving briskly to new frontiers such as MEMS components and integrated MEMS, to address not only the electrical but also the sensing and actuation requirements (see Fig. 1). The wafer fab is equipped with sophisticated processing equipment and clean rooms, and Class 10 and contained Class 1 along with necessary support services. The current technology is 1.0 micron technology with single poly and double level metallization. See box items for details.

The entire fab line is also capable of producing 0.8 micron devices. The salient features of the fab are:

§ Six-inch silicon wafer fabrication facility towards realization of 1.0 micron CMOS ASICS

§ Assembly and packaging facility for IC packaging needs

§ Process equipment tuning and calibration through trend charts

§ Contamination control

§ Clean environment with tight temperature & humidity control

§ Class 10 Clean Room as per US federal standard (see Fig. 1)

§ Uninterrupted clean electrical power supply

§ Bulk gases and toxic gases

§ Environmental pollution control & safety control

SITAR's major fab processes include: lithography, ion implantation, sputtering, PECVD, APCVD, diffusion, wet etch, dry etch, and characterization, in-line QC. The photolithography processing is through reduction stepper (step and repeat on wafer) and is capable of printing 14 mm x 14 mm die. For marketing and sales purposes, interested readers may use the following contact information.

**Society for Integrated circuit Technology and Applied Research**
PO Box No.1640
Off Old Madras Road, Doorvani Nagar P.O.
Bangalore 560 016, India.
E-mail: info@sitarindia.com
Tel: +91 80 25653588
Fax: +91 80 25653590

Dr. P.V.S. Subrahmanyam is the Deputy General Manager of SITAR-Bangalore. He can be reached at pvssubrahmanyam@sitarindia.com.

### Features of ASIC

CMOS digital process
Twin well
Two metal and single poly
1.0 micron Singly doped poly silicon gate
LDD
Typical gate delay of 165 ps
Library contains more than 130 Cells
5V operating voltage

### CMOS-compatible MEMS structures

Varactors
Cantilevers (e.g., 200 μm x 2 μm x 2 μ m)
Fixed-fixed beams
Metal and Oxide as sacrificial material

### Design Support

**ASIC**: CADENCE
**MEMS:** Coventorware, Intellisuite

Supports both cell based and full custom designs
Cell based design up to 100,000 gates
Customized designs of much larger gate counts and/ or specific requirements
Design support options:
- Full contract design starting from functional description
- Shared design starting from layout stage
- Full customer Design up to GDS II tape stage

Auto test vector generation capability


Fig. 1 SITAR's cleanroom corridor (top) micromachined cantilevers (bottom)

# Nanotube Composites

S. Gopalakrishnan

Late eighties and early nineties saw a big carbon revolution with the invention of fullerenes and carbon nanotubes, which gave birth to what is called the *nanotechnology*. The potential of this technology is so huge that it has applications cutting across many disciplines in science and engineering. These include energy generation, frictionless gear drive, disease diagnosis, light-weight bullet proof vests, etc. In this article, we will address how nanotechnology can be used to design new materials for structural applications, whose essential function is to carry large structural loads without failure. One way of designing such material is to reinforce carbon nanotube particles in a suitable matrix to form a nano composite structure.

## Why do we need composite materials?

Composites, which are formed from two or more distinct materials, have desirable combinations of properties that are not found in the individual components. For example, fibre-reinforced composites are engineered structures that commonly comprise soft matrix – typically polymer – encapsulating stiffer, load-bearing filler in the form of fibres or particles. For high-strength composites, the fibres should be stiff and have a high aspect ratio (length-to-width ratio). This allows a good transfer of load from the matrix to the filler when the composite is put under mechanical stress, in much the same way that steel bars reinforce concrete.

## What are Carbon nanotubes (CNT)?

Carbon, the sixth element in the periodic table of elements, has an electronic configuration $1s^2 2s^2 2p^2$ with two electrons in the K shell ($1s$ orbital) and four electrons in the L shell (2 in $2s$ and 2 in $2p$ orbital) with the two electrons in the $2p$ orbital providing the valence electrons. In its ground state, the $s$ orbital of the carbon atom has a spherical symmetry and the $2p$ orbital can be represented by an elongated bare bell which is symmetric about its axis. While the $s$ orbital is non-directional, the $p$ orbital has directional properties. Carbon atoms form covalent bonds in the carbon allotropes and these exist in four different forms, namely the *diamond, graphite, fullerenes and nanotubes*. These forms are shown in Fig. 1.

CNTs were discovered by Iijima in 1991. CNT can be visualized to be formed by rolling of graphene sheets in a specific direction with a specific radius for the cross-section as shown in Fig. 2. CNT exists in two different forms. If a single graphene sheet is rolled as shown in the Fig. 2, we get what is called single wall carbon nanotube (SWCNT). However, if multiple Graphene sheets are rolled, we get multi-wall carbon nanotube (MWCNT). In the nanotube form, the multiple sheets in the MWCNT are held together by van der Waals forces. The atomic structure of the nanotube is characterized by the chiral vector, $\boldsymbol{C}_h$, and chiral angle theta, and these are related by the equation: $\boldsymbol{C}_h = n\,\boldsymbol{a}_1 + m\,\boldsymbol{a}_2$. By varying $m$ and $n$, we can get different types of nanotubes. For example, if $m=0$, we get what is called *Zig-Zag* CNT and if $m=n$, we get what is called *Armchair* CNT. These are shown in Fig. 3.

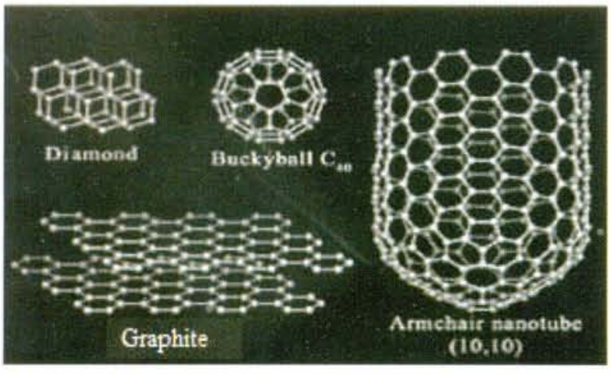



Fig. 1. Various forms of covalently formed carbon atoms

## Why is Nanotube attractive as a reinforcement material?

CNTs, due to their high aspect ratios (1000–10,000) and high intrinsic strength of the $sp^2$–$sp^2$ covalent bond between carbon atoms, have exceptionally high mechanical properties: high elastic modulus (1-4 TPa), high tensile strength (200 GPa), high fracture strain (10–30%), high thermal conductivity (stable up to 2800 °C), better electrical property (1000 times that of copper), and density one sixth that of steel. It is found that 1% by weight CNT mixed in matrix material can yield 36-42% increase in stiffness and 25% increase in tensile strength. Hence, a CNT reinforced nano composite structures will be of light weight and high strength and will be of tremendous potential to be used as structural material.

## What makes carbon nanotubes special compared with other reinforcing fibres?

The reason is the combination of their small size and particular physical properties. Nanotubes, in many respects resemble the polymer chains used as composite matrices; both have covalently bonded structures, similar dimensions, and mechanical flexibility. This makes nanotubes entirely different from traditional fibres such as carbon or glass, which are relatively large (with diameters on the scale of micrometers) and brittle. Furthermore, nanotubes can conduct heat and electricity along their long axes as efficiently as metals - a great improvement on traditional fibres.

## How do nanotubes affect the properties of composites?

Nanotubes in plastic composites - which are anticipated to be the largest bulk application of these reinforcers - would serve to increase stiffness, strength, and toughness and provide other properties such as electrical and thermal conductivity. Because, at present, nanotubes can be manufactured only at lengths up to the sub-millimetre scale (so falling into the short-fibre category), for the foreseeable future, their dominant role in composites is likely to remain as matrix modifiers and providers of multifunctional attributes. But once nanotubes can be efficiently assembled on a macroscopic scale, they could become serious competition for the continuous carbon fibres that are woven and stacked to form load-bearing elements in structural composites used in the building and engineering industries.

## Are nanotube composites easy to make?

Unfortunately not. The biggest challenge is to fully disperse individual nanotubes in the matrices, because nanotubes tend to form clusters and bundles. These aggregates persist unless high shear forces are applied, for example, by vigorous mixing of the polymer. But such mixing often damages nanotube structures, compromising their properties. Another issue is that the polymer-nanotube mixtures are highly viscous (owing to the large surface area of nanotubes). This creates engineering problems,because the composites do not flow easily and are difficult to mould. Processing is also rendered difficult by the poor solubility of nanotubes in most solvents and polymers. Nevertheless, several approaches have been successfully adopted to obtain intermediate mixing of nanotubes with polymer phases, including dry powder mixing, melt mixing, polymerization of monomers onto nanotube surfaces, and surfactant-assisted mixing.

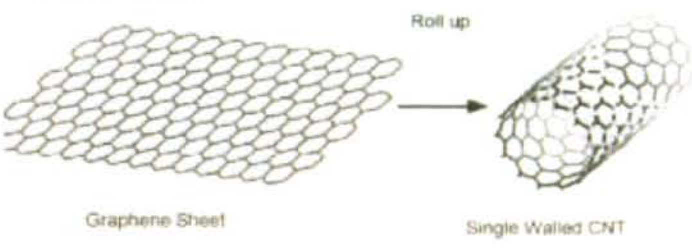



Fig. 2. A CNT from a rolled-up graphene sheet

### Does a nanotube's small size directly affect the properties of nanotube composites?

Certainly. The reinforcement effect of filler should improve markedly as its fibres get smaller because of the increased surface area (per volume of filler) available for interaction with the matrix. For example, nanotubes of about 10 nm in diameter have an interfacial area with matrices that is almost 1,000 times greater than that of 10,000 nm fibres of the same volume. This intimate contact can influence the properties of the polymer matrix, affecting its chain entanglements, its morphology and even its crystallinity. Therefore, the resulting composite can be much tougher and stronger than would be expected on the basis of the properties of the isolated filler. Furthermore, nanotubes, with aspect ratios of tens of thousands to one, can percolate: they form an inter-nanotube connective pathway throughout the matrix at exceedingly small volume fractions, and thus strengthening the composite and making it electrically conductive.

### Why aren't nanotube composites already widely available?

Because there are still a few manufacturing problems to be overcome. Initial attempts to make these materials often yielded lackluster results, mostly because of the poor interfaces that form between the nanotubes and the surrounding matrix. Strong bridges between the polymer and the nanotubes are necessary for good load transfer between the two. Such difficulties are not new, and also arose in the early days of carbon-fibre composites. However, the problem is more acute for nanotubes, both because their surfaces are atomically smooth (which results in poor matrix adhesion) and because the interfacial area for such tiny filler particles is huge.

### Are there any other manufacturing issues?

Poor dispersion of nanotubes in the matrix is also a problem. Large aggregates of nanotubes initiate cracks in composites, rather than reinforcing them. Bundle structures comprising many parallel nanotubes held together by weak bond also tend to form. Under stress, the nanotubes in the bundles can slip past each other, splitting off in layers from the host and weakening the composite. Examining the fracture surfaces of these composites can help determine whether proper load transfer is occurring. If the matrix-filler interface is strong, the nanotubes break under stress. But for poorly fastened interfaces, nanotubes are pulled out of the matrix due to interfacial slippage.

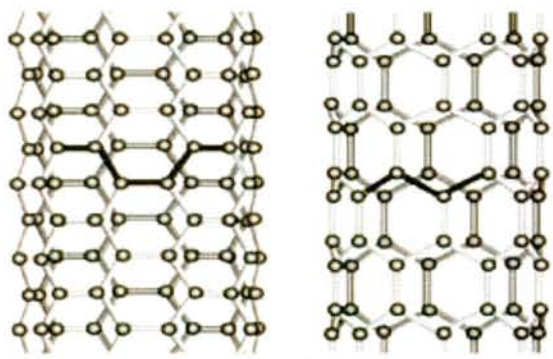


Fig. 3. (left) arm-chair CNT and (right) zig-zag CNT

### What has been done to enhance the interfacial properties of nanotubes?

Several methods have been used to modify nanotube surfaces chemically. One approach is to attach chemical groups covalently. Unfortunately, this strategy creates defects in the nanotube lattice, which can lower the electrical and thermal conductivity of the nanotubes and compromise their mechanical properties. Alternatively, non-covalent interactions can be used to either wrap surfactants or polymers around nanotubes, or to absorb aromatic structures to the side-walls. These surface-modification methods are milder than the covalent approach, and usually cause little disruption to the structure or conductivity of the nanotubes. The idea of chemically modifying fillers to increase their interfacial strength is not new. The surfaces of carbon fibres are also modified before use. But the near-perfect structures of nanotubes make the process challenging, as there are no defects on which to anchor a pendent group, and nanotubes are chemically quite inert. Nevertheless, surface modification is cleaner and more controllable than carbon-fibre modification. Although interfacial shear is detrimental to stiffness and strength, it could produce high mechanical damping, as the large number of nanotube-polymer interfaces involved in nanotube slippage creates a lot of friction and energy dissipation. Viscoelastic behavior at the interfaces causes this effect. Such damping is vital for many commercial applications, such as isolating objects from vibration. Once again, good dispersion of nanotubes in the matrices is essential to optimize this effect.

### Is it possible to order the arrangement of nanotubes in composites?

Certainly. Nanotubes have been aligned in composites using magnetic fields, but this is unlikely to be practical because of the very high field strengths required. One of the best ways to orient nanotubes is to put them under shear, for example, by extrusion.

### Closure

With their wide range of excellent properties, nanotubes could act as fillers in diverse multifunctional composites. Adding nanotubes to plastics provides materials that could be used to shield microelectronics from electromagnetic interference. Similarly, experiments show that the microwave-absorbing capability of nanotubes could be exploited to heat temporary housing structures, and may have applications in space exploration. Furthermore, applying mechanical stress to nanotubes modulates their electrical conductivity. This effect could be exploited in advanced materials that have embedded sensors and actuators made of nanotubes, which could be used for real-time monitoring of stress distribution and for active control of the composite structures. Finally, thin nanotube layers might also be used in transparent conducting composites. At present, the most widespread use is in electrostatic-discharge components, in which multiple-walled nanotubes slightly enhance the electrical conductivity of plastics. Some manufacturers of high-end sporting goods, such as tennis rackets, also claim to make their products from nanotube composites to deliver superior performance. In the short term, the biggest markets for nanotube composites will undoubtedly be for high-value applications that can absorb the added costs sectors such as aerospace (which needs light weight, high-strength, high-temperature-resistant composites) and energy (for example, in nanotube-reinforced rubber seals for large oil-recovery platforms). These are exciting times for nanotube composites.

### Further reading


1. Ajayan, P.M., Schadler, L.S., Giannaris, C. and Rubio, A. Adv. Mater. 12,750-754(2000).
2. Hariis, P. J., Inter. Mater. Rev. 49, 31-43 (2004)
3. Breuer, O. and Sundararaj, U. Polym. Composites 25, 630-645(2004). Dyke, C.A&Tour, J.M. J. Phys. Chem. A 108, 11151-11159(2004).
4. Yarkobson, B.I. and Couchman, L.S.J. Nanoparticle Res. 8, 105-110(2006)
5. Tasis, D., Tagmatarchis, N., Bianco, A. and Prato M. Chem. Rev. 106, 1105-1136(2006).


Dr. S. Gopalakrishnan is a professor of aerospace engineering in IISc. He can be reached at krishnan@aero.iisc.ernet.in.

The department of electronic science at the University of Pune is engaged in training the post-graduate and doctoral students in the field of semiconductor science and technology since 1984. The department focuses its research activities in the field of sensors and sensor instrumentation. The topics of research include semiconductor sensors, fiber optic sensors, inorganic and polymer based sensors, neural networks, embedded systems for human pulse detection, sugar production process control, etc. The development of MEMS-based sensors started in 2000. The department is also identified as a MEMS Design Center in the NPSM program (*see* Vol. 1, No. 1, p. 1). The laboratory has research-grade equipment for fabrication of sensors. The equipment include: vacuum evaporation, sputtering systems (DC, RF and Magnetron), photolithography exposure system, in-house developed e-beam lithography system based on SEM-S120 from Cambridge Instruments, diffusion and oxidation furnaces, DI water plant, Class 100 clean and chemical benches, spin coater etc. In addition to their own, the research group also uses the microfabrication facilities of Bharath Electronics Limited (BEL) (*see* Vol. 3, No. 1, p. 3-5). The lab has ANSYS, Coventorware, EM3DS, IntelliSuite, Matlab, and MEMSPro for carrying out the simulation and design work.

One of the completed MEMS projects of the University of Pune is a piezoresistive accelerometer funded by ARDE, Pune. As shown in Fig. 1, it consists of a large plate (which serves as a proof-mass) suspended with a narrow flexural beam. This was simulated using Coventorware software. Several designs were analysed to ascertain different parameters such as sensitivity, resonant frequency, cross-axis sensitivity, maximum stress, proof-mass displacement, etc. The values of stress, bandwidth and displacement for a finalized design were found to be 81.2 MPa, 1513 Hz and 16.25 mm respectively. The sensitivity was calculated as 53.63 mV/V/g. This work was reported in the Ph.D thesis of B.P. Joshi, a student who finished in 2007 (see the list of publications in the box). A new idea of adding an additional mass and locating it suitably to maximize a performance factor (which is the product of sensitivity and bandwidth) was also attempted.

A design of this accelerometer was fabricated on n type, double-side polished 3" silicon wafer with thickness of 225 um, using silicon bulk micromachining. The boron-implanted resistors were used for stress measurement. The Wheatstone bridge structure was fabricated on the device in order to compensate for change in resistance measurement. Figure 4 shows the SEM image of the completed accelerometer. The fabrication work was carried out at BEL, Bangalore, and was funded by ARMREB, DRDO.

In another project, the non-availability of a facility for silicon nitride deposition has prompted the Pune MEMS group to work on the development of low-temperature masking materials. The work was undertaken as a PhD Project. Poly tetrafluoro ethylene (PTFE) and poly methyl methacrylate (PMMA) were chosen as masking materials. These materials were deposited by DC & RF Sputtering and plasma polymerization techniques, and their performance as masking materials was evaluated. The measured etching characteristics show that the materials chosen are suitable for the development of various MEMS structures.

The group has also undertaken the design of a DC-contact RF MEMS series switch for DC to 3 GHz applications. The fabrication of the switch will be done in collaboration with the Indian Institute of Technology, Bombay. The work of this MEMS group has published in national and international journals (see box).

Dr. S.A. Gangal is a professor in the department of electronic science in the University of Pune. She can be reached at sag@electronics.unipune.ernet.in.

### Selected publications of the U. Pune MEMS group


1) "Study on performance enhancement and Design of MEMS Piezoresistive acceleration sensor with a special consideration to Sensitivity and Bandwidth optimization" B.P. Joshi, Ph.D thesis, University of Pune, 2007,

2) "Optimising performance of a cantilever type microaccelerometer sensor", B.P. Joshi, A.S. Chaware, S.A. Gangal, Defence Science Journal, 57(3), 2007 pp. 261-269.

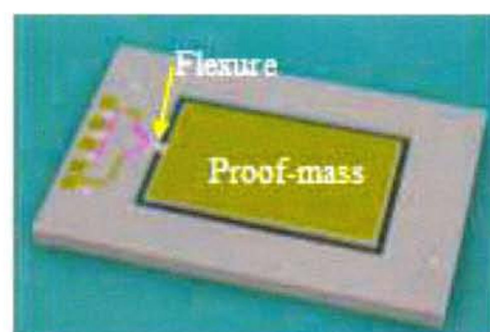
3) "Performance improvisation of cantilever type silicon microacceleration sensor using stress concentration regions", B.P. Joshi, Aditee Joshi, S.A. Gangal, Defence Science Journal, 57(3), 2007, pp. 271-279.

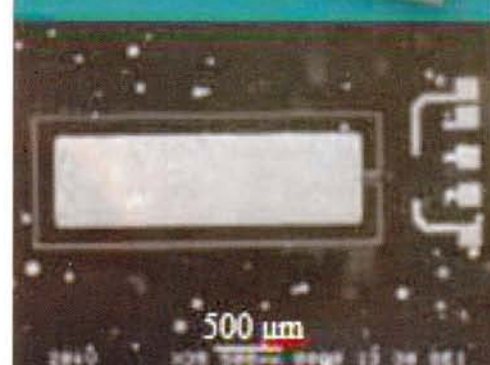
4) "RF sputter deposition of polytetrafluoro ethylene films as masking materials for silicon micromachining," Dhananjay S. Bodas, Sheetal J. Patil, AB Mandale and SA Gangal, , J. Appl. Polym. Sci., 91, 2004, p. 1183.

5) PTFE as a masking material for MEMS fabrication, Dhananjay S Bodas and S A Gangal, J. Micromech. Microeng, 15, 2005, pp. 802–806.

6) "RF sputtered polytetrafluoroethylene—a potential masking material for MEMS fabrication process," Dhananjay S. Bodas, S.A. Gangal, , J. Micromech. Microeng. 15, 2005, pp. 1102–1113.

7) "Comparative study of spin coated and sputtered PMMA as an etch mask material for silicon micromachining," Dhananjay S. Bodas ,1, S.K. Mahapatra, S.A. Gangal, , Sensors and Actuators A 120(2), 2005, 582-588.

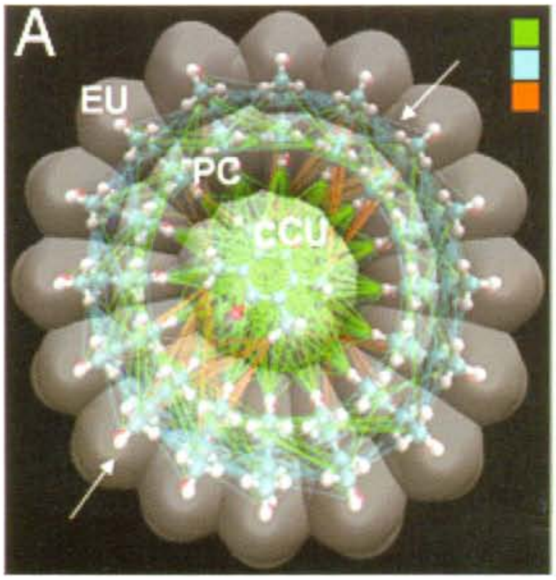

Piezoresistive accelerometer (top) Fig. 1. schematic, (bottom) Fig. 2 SEM image.

## Marching Towards Nano Brain

Recently, scientists at the International Center for Young Scientists, National Institute for Materials Science, Ibaraki, Japan, have reported the realization of a multi-level switch in 2,3,5,6-tetramethyl-1–4-benzoquinone (duroquinone, DRQ) which generates four logic states (0, 1, 2, and 3) when instructed by a scanning tunneling microscope (STM) pulse. This is the latest example of a *molecular machine*, which is a system that generates physical motion of its components at the atomic level, controlled by an external stimulus. DRQ alkyls rotate like machines with change in logic states 0 to 1, 1 to 2, and 2 to 3. DRQ single molecule demonstrates double negative differential resistance (NDR) peaks, which creates four different states.

Several nano machines have been realized over the last two decades by rearranging the constituent naturally occurring materials such as proteins and DNA. The emphasis has been to increase the number of versatile instructions and generate multiple operations by increasing the complexity of design by various assembly approaches. The machine in this case, has a molecular assembly consisting of 17 identical molecules of DRQ. The DRQ at the center of a circular ring formed by 16 other DRQs, upon excitation by the STM pulse, controls the operation the 16 others in parallel through hydrogen-bond channels. Each molecule is a logic machine and generates four instructions by rotating its alkyl groups. Therefore, a single instruction can be executed in four billion ($4^{16}$) different ways.

The authors of this article (see ref. below) believe that this invention has the potential to realize remotely operated nano robots that may be used for treating diseases or to remotely operate on a tumor. The logic machines invented could one day guide themselves through the blood flow in the body and control their functions.




**Molecular model of the architecture inside its van der Waals sphere (white color) showing the Central Control Unit (CCU), hydrogen bond-based Communication channels and Execution Units. Three different communication channels are used: internal oxygen atoms of DRQ and CCU, orange lines connect external oxygen with CCU, and blue lines are the intermolecular coupling between EU DRQs.** (Figure taken from the reference.)

**Reference:**

A. Bandyopadhyay and S. Acharya, "A 16-bit parallel processing in a molecular assembly," Proc. Nation. Acad. Sci., vol. 105, pp. 3668-3672, Mar. 11, 2008)

Professor K.J. Vinoy can be reached at kjvinoy@ece.iisc.ernet.in.

## In Memorium: Professor Santiram Kal

Professor Santiram Kal was born on March 9, 1952, in Galia, West Bengal, India. He received his M.Sc. degree in physics from Burdwan University in 1975, and Ph.D. degree in Electronics and Electrical Communication Engineering from the Indian Institute of Technology, Kharagpur, India, in 1983. He was a faculty member in West Bengal Education Service, Govt. of West Bengal, during 1980-83. He joined the Microelectronics Center of IIT Kharagpur in 1986 as a lecturer. Since 1999 he had been a professor in the Department of Electronics and Electrical Communication Engineering of the same institute. He visited Ruhr University, Bochum, West Germany, as a DAAD fellow during 1983-1985. As a post-doctorate fellow, he worked in the University of Erlangen-Nuernberg, Germany in 1993 and again in 1996. He also served as a visiting professor at the Asian Institute of Technology Bangkok in 2004, at the University of Southern California, Los Angeles USA in 2005, and as a research professor for a short period in 2006 at the University of Illinois at Urbana Champaign, USA. He was a Guest Scientist at the Technological and Scientific Research Center, Trento, Italy, form May – July, 2005 and May – June 2006.

9 Mar. 1952 - 31 Dec. 2007

Prof. Kal published more than 100 research papers in international and national journals and conference proceedings. He had written a few books in the field of microelectronics, devices, circuits, and MEMS. He was actively involved in many research and consultancy projects funded by various government agencies and industries in the country and abroad in the areas such as ASICs, special semiconductor films, micro sensors and MEMS. He was a member of the National Advisory Committee for Indo-US, Indo-Italy and Indo-China collaborations in the areas of MEMS and microelectronics. He was a life fellow of Institution of Engineers (India) and a Senior Member of IEEE. Apart from being an excellent academician, he held key responsible administrative positions viz., the chairman of IEEE Kharagpur section (2002), Vice-Chairman of GATE-2003 and Chairman of GATE-2004. During 2002 – 2007, he was the Chairman of the Advanced Technology Centre, IIT Kharagpur.

Prof. Santiram Kal was a source of inspiration and motivation and was a role model for many students. With his gentle and caring attitude, Prof. Kal led the students to produce extraordinary work in the emerging and cutting-edge technologies such as MEMS, Bio-MEMS, microelectronics and VLSI.

Prof. S. Kal is survived by his wife Mrs. Sompa Kal, son Mr. Subhadeep Kal, and daughter Ms. Subhashee Kal.

May his soul rest in peace.

This memorium is prepared by Professor Samit Ray, Physics, IIT-Kharagpur. He can be reached at physkr@phy.iitkgp.ernet.in.

*S Ū K S H M A*
**Institute of Smart Structures and Systems**
**Department of Aerospace Engineering**
**Indian Institute of Science**
**Bangalore - 560012**
**India**