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A newsletter about micro and smart systems in India

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CONTENTS

ISSS wishes Happy New Year 2008!

NPMaSS

K. Vijayaraju

With a view to harness the huge potential of micro and smart systems technologies in our country and to equip us to reach the necessary level of maturity, the National Programme on Smart Materials (NPSM) was launched jointly by the five scientific departments of the Government of India, namely, DRDO, DST, CSIR, DOS and DIT in 2000 with a funding of Rs. 75 crores over a period of six years (*see* Vol. 1. No. 1, p. 1). This programme has created a pool of scientists in IITs, IISc, NITs and other leading universities with necessary experimental facilities, and has enabled two industries viz. BEL and SCL who took up the design, development, and prototyping of MEMS related systesms. This has enabled the building up of basic infrastructure for many of these technologies, design, and development of basic devices (e.g., pressure sensors, accelerometers, patch antenna, RF devices), materials, and processes. Creating an awareness amongst our scientific community was also a major accomplishment of this programme. Another important outcome of this programme has been the realization by the industries to adopt these technologies to keep their market edge.

It is imperative now that this all-pervasive technology should be progressed further to build a variety of products and subsystems, which are of importance to both defence and civilian sectors. It is with this in mind that a **National Programme on Micro and Smart Systems (NPMaSS)** jointly by the same five departments was proposed. The lead was taken by Dr. V.K. Aatre, former SA to RM and Former Secretary, Defence, R&D and presently a Visiting Professor, ECE Department, IISc, in formulating a proposal for the national programme and submitting the same to the government for approval. The NPMaSS has now been sanctioned by the government with a budget of Rs. 195 crores spread over five years from September 2007. As mentioned earlier, it is a joint programme of the same five scientific departments of the government, namely, DRDO, DOS, DST, MIT, and CSIR. The programme is funded by DRDO and run through Aeronautical Development Agency (ADA), Bangalore.

Programme objectives: The main objective of the NPMaSS is to consolidate the gains from NPSM through the realization of products/devices/subsystems based on MEMS and smart materials technology, and their field demonstration. Various developments thus undertaken would aim to support applications in aerospace and defence areas, and to achieve commercial exploitation in the automotive, biomedical, environmental safety and food technology related sectors and in the health-monitoring of infrastructure in the civilian sector. Under this programme a component/system level characterization facility would be established to act as an interface between the developer and the user for speedy implementation of the developed devices. This programme will liaise with industries in various sectors identified and to give a major thrust in achieving significant human resource development in this important area of advanced technology. It is a 'directed programme' in the sense that projects tailored to meet the programme objectives will be sought and sanctioned to institutions having necessary expertise and facilities.

Programme management structure: The Programme has a three-tier management structure as follows:

(i) Smart Apex Board (SAB), lays down the overall policy guidelines. The Board is headed by SA to RM, Secretary, Dept. of Defence Research and Development, Ministry of Defence, as its chairman.

(ii) Board for Smart Materials Research and Technology (B-SMART) has the executive and financial authority of implementing the programme. It is headed by Dr. V.K. Aatre as chairman at the request of SAB. Project Director of NPMaSS is its member-secretary.

(iii) Project Assessment and Review Committees (PARCs) to execute the technical part of the programme (i.e., seeking and receiving, assessing and recommending, monitoring and reviewing all the projects in the specified sub-area) as per the guidelines from SAB and action plans recommended by B-SMART.

A Programme Cell at ADA, headed by a Project Director (NPMaSS) is responsible for the overall execution of the Programme as per the directives from B-SMART. Dr. K. Vijayaraju from ADA, Bangalore, has been designated as the Project Director.

Programme implementation

The B-SMART has identified five Project Assessment and Review Committees (PARCs) with a specific focus area and chairman to coordinate the activities for each of them. Focus area for each PARC with the respective chairman are also appointed (see the table on the left).

PARCs in NPMaSS

PARC 1: Research and Development
Chair: S.B. Krupanidhi, MRC, IISc, Bangalore.

PARC 2: Infrastructure and human resource development
Chair: Navakanta Bhat, ECE, IISc, Bangalore.

PARC 3: Aerospace applications and structural health monitoring
Chair: S. Gopalakrishnan, AE, IISc, Bangalore.

PARC 4: Biomedical, food, and environmental applications
Chair: Lazar Mathew, SBCBE, VIT, Vellore.

PARC 5: Automotive applications
Chair: N.S. Vyas, ME, IIT-Kanpur.

Project Director

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First Call for Papers for the ISSS International Conference in 2008

Fifth ISSS International Conference on Smart Materials, Structures and Systems

24 – 26 July 2008

National Science Seminar Complex
Indian Institute of Science
Bangalore, INDIA

Sponsored and Organised by

Institute of Smart Structures and Systems (ISSS)

Indian Space Research Organisation

Indian Institute of Science

The topics covered in the conference

- Adaptive materials
- Sensors and actuators
- Design, modeling and simulation
- MEMS design, electronics and packaging
- Nanotechnologies
- Signal processing techniques
- Applications

Dates to Note

Last date for submission of abstract: February 15, 2008

Receipt of the full paper for review : March 15, 2008

Acceptance of the full paper after review: May 7,2008

Deadline for receipt of the revised full paper: June 7, 2008

Last date for advance registration: June 15, 2008

The abstract should be around 500 – 800 words. The abstract should be sent in MS Word, Postscript or PDF format. The abstracts should be emailed to the conference secretariat at ***isss.psnair@gmail.com*** so as to reach on or before **February 15, 2008**.

ISSS News

The 2nd ISSS National Conference on MEMS, Microsensors, Smart Materials, Structures and Systems took place on 16th and 17th, November, 2007, in Pilani. This conference was jointly organized by the Central Electronics Engineering Research Institute (CEERI) and the Birla Institute of Technology and Science (BITS) on the CEERI campus. Several of the attendees were ISSS members. The number of papers presented in this conference has risen significantly as compared with the first ISSS national conference held in 2006 in Research Centre Imarat (RCI), Hyderabad. This shows that the efforts of ISSS and those of others in promoting research in the micro and smart systems are bearing fruits. In this conference ten invited speakers delivered talks on various cutting-edge topics. There were about 70 oral presentations and more than 40 poster presentations. The dignitaries in the inaugural function included the heads of the organizing institutions, Dr. Chandra Shekhar, Director-CEERI and Prof. L.K. Maheswari, Vice-Chancellor, BITs; ISSS President Dr. A.R. Upadhya,; Dr. T. Ramasami, Secretary, DST; Prof. V.K. Aatre, Former Scientific Advisor to Raksha Mantri, and others. Prof. L.K. Maheswari of BITS welcomed the attendees and Dr. V.K. Dwivedi gave the vote of thanks. On the second day of the conference, ISSS honored Prof. A. Selvarajan and Dr. Vikram Kumar for their contributions to the growth of their respective fields. The conference was well attended by academics including faculty and students, researchers from government organizations, and participants from the industry. The conference was organized very well for which the organizing institutions are to be congratulated.

Editorial Team

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K.J. Vinoy, IISc

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560012, India

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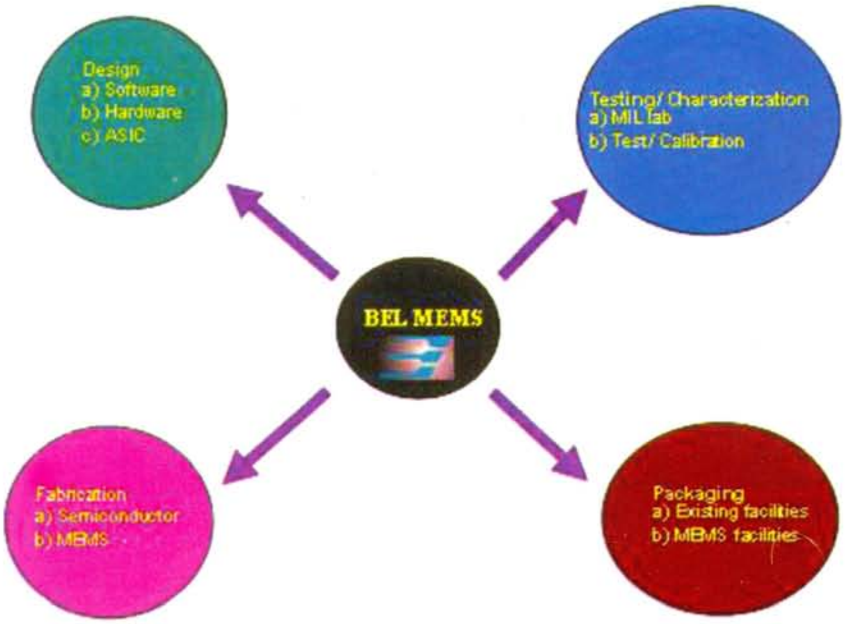
Payable to "ISSS, Bangalore".

Industry Watch: Bharat Electronics Limited

K. Natarajan

Microelectromechanical Systems (MEMS) based applications are part of an emerging market in India while some other parts of the world have established this technology with a very high growth rate. To help India initiate a major effort in establishing a MEMS market, Bharat Electronics Limited was actively involved in the National programme on Smart Materials (NPSM, *see* Vol. 1, No. 1, p. 1). The Bangalore Components Division of BEL got a grant from NPSM to the tune of Rs. 10 crores for the establishment of wafer-level MEMS processing capabilities. The major equipments obtained by this programme are a double-side mask aligner, an anodic bonder, a flip-chip bonder, a reactive ion etcher, and a network analyser. Using these, the basic technology development included bulk micromachining for the pressure sensor, surface micromachining for an RF switch, and wafer-level packaging for RF MEMS (*see* Vol. 2, No. 2, pp. 4-5) components. A separate class 100 clean room facility was established in the Silicon Building at Bangalore complex to house these facilities. The basic R & D activity started after the installation of this facility around 2004 to take up focused product development. The MEMS group has successfully developed the prototypes of (i) a low profile integrated pressure sensor for Light Combat Aircraft (LCA) applications, (ii) a force-balance accelerometer for strategic applications, (iii) LPG gas sensor chip based on silicon nitride and polysilicon technology, (iv) an SOI Technology for pressure sensors, and (v) medium pressure sensors for tire inflator applications up to 10 bar. The MEMS group is interacting with IISc, DRDL, RCI, and IITs to get the R & D support for the design and process development. It was closely interacting with IIT-Madras to develop accelerometer and pressure sensors. Prof. K.N. Bhat was guiding the BEL MEMS team as a part of the NPSM programme. With the experience gained from NPSM activities and interaction with national/international experts, a focused product oriented development programme has been drawn up as shown in Fig. 1. More details about BEL's MEMS activities and an educational pressure sensor kit developed by BEL are given in pages 4-5.



Dr. K. Natarajan is the Additional General Manager, MEMS at BEL, Bangalore. He can be reached at natarajank@bel.co.in.

Leaders of ISSS: Kota Harinarayana

Dr. Kota Harinarayana is a distinguished scientist and an outstanding engineer. He was the former Programme Director of the Light Combat Aircraft (LCA) project and the Vice Chancellor of Central University of Hyderabad. He was born in Berhampur, Orissa, in 1943, graduated from Benaras Hindu University (BHU) in mechanical engineering, and obtained a masters degree in aerospace engineering from IISc, Bangalore. He did his PhD in IIT-Mumbai, and also holds a bachelors degree in law.

Dr. Kota Harinarayana started his career in 1967 at Hindustan Aeronautics Ltd. (HAL), Bangalore. He moved to the Defence Research Development Organisation (DRDO), Government of India head quarters in 1970 and stayed there until 1982 holding various positions. He rejoined HAL in 1982 as the Chief Designer in Nasik Division. He was deputed to DRDO in 1985 and assumed charge as Director, ADE, Bangalore. He was appointed LCA Programme Director in December 1985 and he was concurrently holding the post of Director, ADE, till 1986. During 1995 he was elevated as a Distinguished Scientist by DRDO. As Programme Director and Chief Designer of LCA, he successfully directed the project leading to flight-testing and clearance for limited series production. Thanks to his efforts, India succeeded in developing a state-of-the-art, high-technology fighter aircraft of the world class. Dr. Harinarayana played a key role in life extension and determination of components of the MiG 21 aircraft, and indigenisation of components, spares, and consumables of aircraft during his tenure as the Chief Resident Engineer, Nasik. New aerodynamic device vortex plate was flight-tested on a MiG 21 aircraft for the first time in the world. He is currently the Raja Ramanna Fellow at the National Aerospace Laboratories (NAL) and is pursuing his vision of developing an indigenous 70-seater passenger aircraft for India.

As the former programme director of LCA at ADA, he worked actively for the creation of National Programme on Smart Materials (NPSM), which was the nodal agency for implementing this programme. He headed a committee, which drew up the specifications for various smart materials, sensors and devices for various applications. His committee report formed the basis for all the devices and materials developed under NPSM (*see* Vol. 1, No. 1, p. 1)

Dr. Harinarayana also served as the President, Aeronautical Society of India; Chairman, Technical Committee of ARDB; Fellow, Aeronautical Society of India and Indian Academy of Engineering. He received distinguished alumnus award from aerospace department, IISc, Bangalore in 1993 and from IIT-Bombay in 1995. He is the recipient of the *National Aeronautics Prize*, *FIE Foundation Award-1996* and *SBI-Pragna Puraskar-2001*. He received the Dr. Y. Nayudamma Memorial Award for 2001. He received the DRDO Technology Leadership Award for 2001. He was honoured with Padma Shri by the Government of India in 2002.

MEMS Activities of BEL

K. Natarajan

The microelectromechanical systems (MEMS) group of Bharat Electronics Limited (BEL) has set up the infrastructure for designing, fabricating, and prototyping MEMS devices. Based on a market survey, it was found that MEMS-based pressure sensors and related systems got the highest market potential in India compared to other devices such as accelerometers and gyroscopes. In order to reach the market fast, in addition to setting up a design centre and fabricating facility, a core R & D center for packaging was initiated with an investment of Rs. 5 crores with the approval of BEL management during 2005 and was implemented during 2006-07. The major equipment installed in the project include: a special dicing machine, an E-beam welder, a laser welder, a capacitive discharge (CD) welder, and some testing facilities. Some of these are depicted in Fig. 1. The facilities required for the MEMS-based high-pressure sensor were completed by March 2007 and the critical process parameters for the process development of pressure sensors was completed soon after. The major process developments are: special design for header/ diaphragm SS316/304L, glass to metal seal/gold plating, E-beam welding of SS diaphragm, oil filling of the cavities, embedded electronics for voltage amplification with temperature compensation. The first prototype was successfully developed during April 2007. Figure 2 shows calibration and output characteristics of the pressure sensor intergated with electronics on an ASIC.

Some of the strategic partners have shown very keen interest in the MEMS group activities and products. BEL has already supplied 100 pressure transducers for strategic applications during June 2007. With the experience gained from this development, further product development for the pressure sensor with media isolated diaphragm for the pressure ranges of 0 – 10 bar, 0 – 100 bar, 0 – 200 bar, and 0 – 400 bar are underway. The first batch of 100 will be delivered at the cost of Rs. 30 lakhs as a sale value. Other products under development are a digital pressure indicator, a tire inflator system, and a digital pressure gauge.

Other major activities of the MEMS group are the development of RF-MEMS (*see* Vol. 2, No. 1, pp. 4-5) components such as series and shunt switches, resonators, and filters in the frequency range up to 20 GHz. The actual chip photographs are shown in Fig. 3. These components are part of a smart phase shifter for radar and communication systems. MEMS based devices/systems are already deployed globally in aerospace, strategic, automobile, and industrial and consumer applications. The number of applications which are listed are more than 10,000 and the turnover is more than 30 billion US $ (Rs. 1,20,000 crores) per year, and it is growing at the rate of 15–18% per year. The market size in India is around Rs. 600 crores and this is expected to grow around 20% in the coming years. BEL is bracing up for this challenge.

(Top) Fig. 1. Micromachining facilities of BEL

(Left) Fig. 2. BEL pressure senor with integrated electronics

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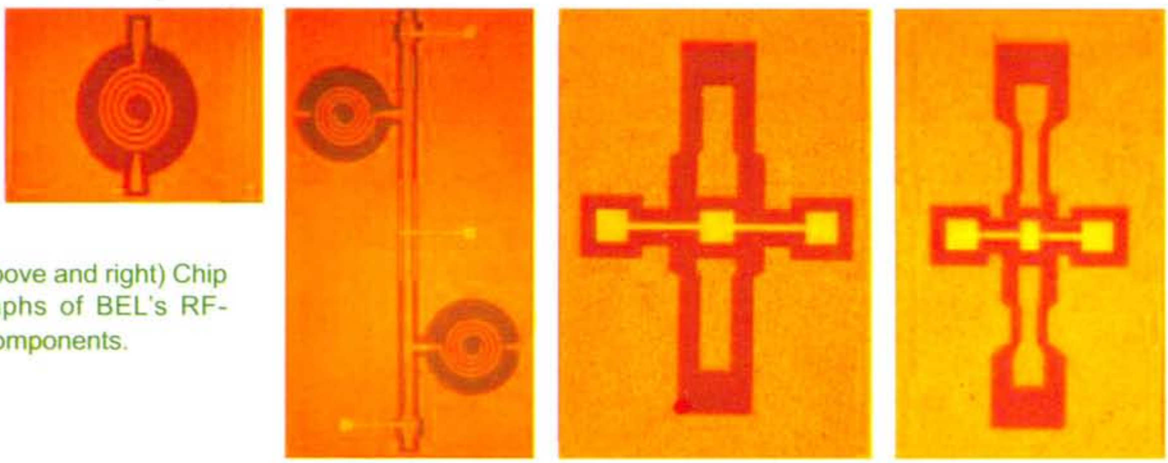

Fig. 3 (Above and right) Chip photographs of BEL's RF-MEMS components.

MEMS Activities of BEL

K. Natarajan

The MEMS group of Bharat Electronics Limited (BEL) has designed and built a "pressure sensor college kit" to enable college and university students understand and appreciate micromachined sensor technology. The picture of the kit and its contents are shown below. A number of experiments can be performed using this kit. The includes many accessories as indicated below. Thus, the students will be able to perform the experiment in the laboratory of a typical engineering college. Those interested in this kit may contact the author of this article.

Pressure sensor college kit

1 bar TO-8 sensors (#2)
2 bar TO-8 sensors (#2)
10 bar TO-8 sensors (#2)
Nozzle for TO-8 sensor (#1)
Compensated sensor (#1)
Nozzle for compensated sensor (#1)
Bulk micromachined Si wafer (#1)
Test jig (#1)
Digital pressure indicator (#1)
PVC hose pipe (2 m long)
User's manual
MEMS product information

Possible experiments with the pressure sensor college kit

* Characterization of the uncompensated pressure sensors to understand parameters such as offset, span, linearity, etc.
* A study of the effect of temperature and pressure to obtain the temperature coefficient of the offset, span, etc.
* Studying the methods of compensation for adapting the uncompensated sensors for compensated output.
* Comparing the ASIC compensated pressure sensor, which can be characterized with two temperatures and different pressures, with the one compensated in the lab.
* A study to distinguish between gauge and absolute types of pressure sensors.

A silicon wafer with bulk-micromachined pressure sensor diaphragms helps the student understand how the mechanical element of the pressure sensor is made and it gives an idea of the size of the sensor element. By testing the uncompensated pressure sensors, students can appreciate the effect of temperature on the output. This output is a few mV as can be seen in Fig. 1. The variation seen in Fig. 1 is due to the temperature coefficient of the piezoresisters in the sensor. An ASIC included with the compensated pressure sensor of the kit not only adjusts for temperature variations but also amplifies the output to 0-5 V range (see Fig. 2). The digital pressure indicator enables viewing the pressure reading directly in pressure units rather than as a voltage. The LCD display on the indicator has the provision to show the pressure in psi, kPa, or bar.

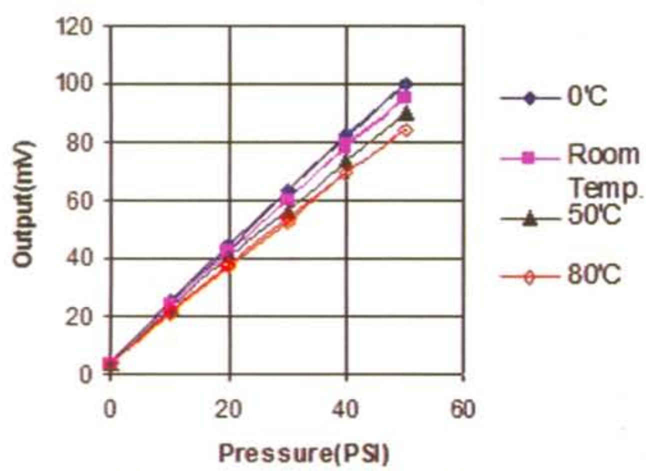

Fig. 1. Uncompensated "raw" sensor

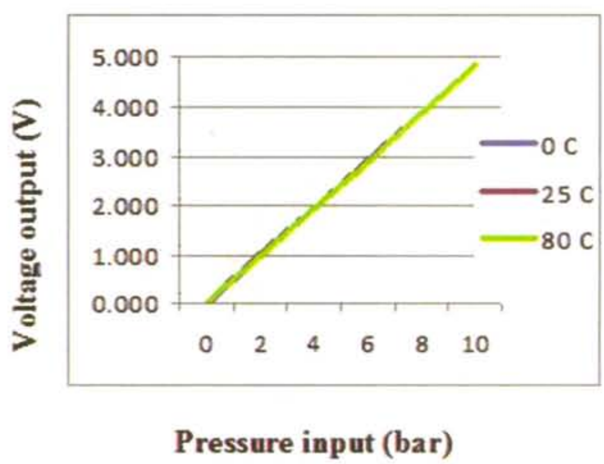

Fig. 2. Compensated sensor with an ASIC

Shape Memory Alloy (SMA; *see* Vol. 2, No. 3, pp. 4-5) thin film has been recognized as a promising and high-performance material for microelectromechanical systems (MEMS) applications because it can be patterned with standard lithography techniques and can be fabricated in a batch process mode. The phase transformation in SMA thin film is accompanied by significant changes in the mechanical, physical, chemical, electrical, and optical properties. These changes can be exploited in the design and fabrication of microsensors and microactuators. The Nanostructured Thin Film Research Lab at the Indian Institute of Technology-Roorkee (IIT-Roorkee) is actively involved in the fabrication of high-quality titanium-nickel (TiNi) shape memory thin films and heterostructures for MEMS applications. Proper passivation to prevent surface layer degradation and nickel releasing into the environment has been considered crucial for the medical applications of TiNi based shape memory alloys. The surface properties and corrosion resistance are important material characteristics that enable the use of TiNi for surgical devices in the human body. Therefore, a stable, biocompatible and corrosion resistant passive layer is required. The present research at IIT Roorkee deals with the deposition and the effect of nanocrystalline TiNi protective layer on TiNi thin films prepared by dc magnetron sputtering (see Fig. 1) to improve the surface properties and the biocompatibility of SMA thin films. The goal of this research is to investigate the influence of the size and preferred orientation of grains in the passivation layer on the mechanical, chemical and functional properties of TiN/TiNi heterostructure and to investigate the critical thickness of passivation layer up to which shape memory properties can be retained.

The group is also involved in the synthesis of nanostructured materials by physical vapour deposition (PVD) processes such as RF/DC magnetron sputtering system with the facility to deposit nanocrystalline powder, thin films, and multilayers by varying the substrate temperature from –150 °C to 850 °C with a base pressure of about 10^{-8} Torr and multi-chamber Excimer based pulsed laser deposition (PLD, Lambda Physik, KrF; see Fig. 2) for multilayers and heterostructures of functional nanomaterials. A number of other new research projects have been taken up by this group. The notable ongoing research projects include Functional Nanocomposites: Synthesis, Characterization & Applications (DST, India), Functional Nanostructures for MEMS & Optoelectronic devices (DIT, India), and Development of Super-hard Nanocomposite Coatings (DRDO, India).

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Fig. 1. RF/DC magnetron sputtering system

Fig. 2. Pulsed laser deposition system

Technology News

MEMS Innovation Fest in Bangalore

"The MEMS INNOVATION FEST 2007 was organized by Step Electronics Pvt. Ltd. along with Karnataka Hybrid Micro Devices Ltd., & Jain Group of Institutions at the Central Power Research Institute (CPRI), Bangalore, on 9th & 10th Dec 2007.

The conference focused on bridging the gap between design and product through innovation, which was well-received and appreciated by the participants. The MEMS conferences held in India thus far focused on sensitising the academic community. The theme of the MEMS Innovation Fest falls beyond the academic realm and hence was organised focusing on industrial community.

It was interesting to note that the participation was from all the quarters of academics, industries, and government sectors. There were more than 25 papers presented covering micro sensors and actuators, RF MEMS, energy harvesting using MEMS as well as MEMS in agriculture. The technical sessions were well attended. Participants benefited from the MEMS course conducted by Prof, Chengkuo Lee Vincent of IME - A*STAR, National University of Singapore." (Contributed by V. Janardhan and S. Pamidighantam)

Fatigue in silicon?

A recent article in *Applied Physics Letters* (**91**, 201902, 2007) by S. Bhowmik et al., reports that bulk silicon is susceptible to cyclic fatigue. It was a matter of debate because no evidence was reported earlier. The experiment that provided this counter evidence to the established theory involved indentation of a bulk silicon surface with micro spheres. The paper presents the details and discusses its possible inmplications in silicon based micro devices.

The first of this two-part article focused on the materials research and MEMS device development being carried out in National Aerospace Laboratories (NAL), India's premier civilian laboratory for aeronautical and aerospace R&D (website: www.nal.res.in). The aerospace applications research using smart materials are covered in this second and concluding part.

Shape Memory Alloy (SMA) Applications: The important achievements in the SMA applications area relate to exploiting the basic material properties (both thermal and stress induced) of NiTi SMA (*see* Vol. 1, No. 3, pp. 4-5) for aerodynamic morphing (shape change). Conventional aircraft control surfaces such as flap (which are movable) are housed in fixed lifting surfaces such as wing. The smart SMA based control surface has no distinct moving parts as the entire lifting surface can be made to undergo shape changes. This works like the wing of a bird, which generates the required control force by flexing the wing appropriately. Towards this goal, a smart control surface was built incorporating SMA elements (Fig. 1). The model has been successfully tested in the wind tunnel up to a maximum speed of 160 km/hr. Successful SMA applications have also been evolved in NAL for innovative SMA-based repair technologies and energy absorption mechanisms.

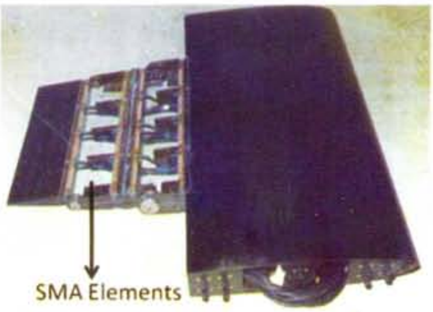

Fig. 1. Adaptive control surface using SMA actuators.

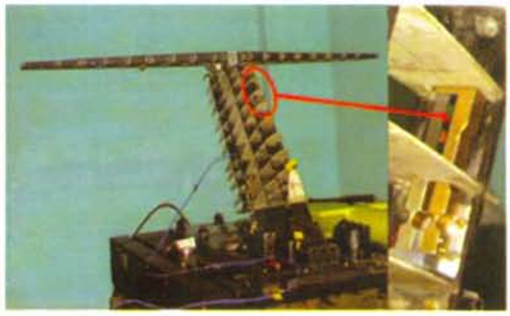

Fig. 2. Vibration control of a T-tail.

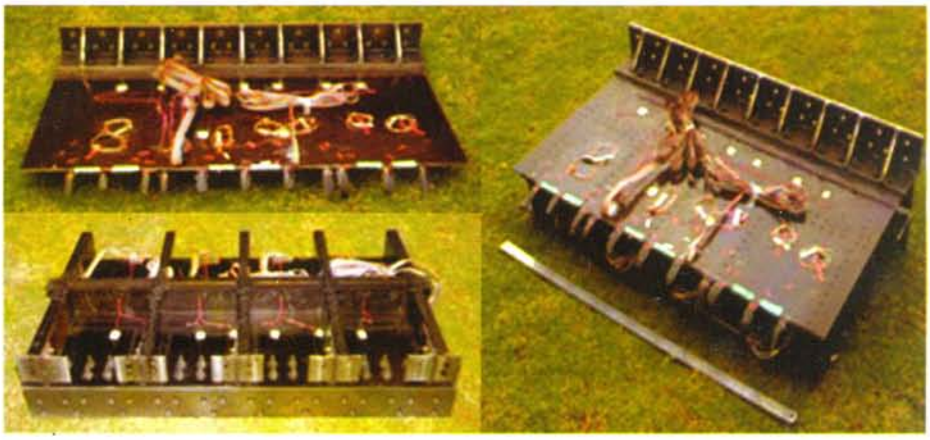

Fig. 3. A composite structure with embedded fibre optic sensors for health monitoring.

Vibration and Aeroelastic Applications: Aircraft structures are susceptible to vibration due to the nature of the air flow around them. Moreover, the coupling of the structural vibration with the aerodynamic forces often results in undesirable phenomena termed as aeroelastic instabilities. One way to mitigate these problems is to use active control techniques using smart actuators. A successful wind tunnel demonstration of active flutter control technology on a composite wing using a trailing edge flap acting as an aerodynamic effector has been demonstrated at NAL. NAL has also designed, developed, and successfully tested amplifiable piezo mechanisms for structural control applications. The necessary in-flight electronics has also been developed. A laboratory level demonstration of vibration control experiment using distributed PZT stacks on a composite T-Tail structure has been planned under the simulated aircraft power environment (Fig. 2). Vibration control of full scale fin-tip structure of LCA has been achieved using a system built around Texas Instruments 6711 floating point Digital Signal Processor board in a Pentium 4 host PC. The control law implemented in C++ is based on the well known computationally efficient & simple Filtered – X Least Mean Square(LMS) algorithm. The control actuators can be PZT patches, bimorphs or stacks. Sensing is by PZT patches or accelerometers.

Structural Health Monitoring: Health monitoring of aircraft is gaining increasing importance due to significant cost benefits. The cost benefits accrue by dispensing with routine maintenance and inspections, and replacing with a 'maintenance-on-demand' concept. Efforts at NAL have been to develop the necessary system to monitor the health of a typical aircraft composite structure using fibre optic sensors. Towards this end, the technology for embedding Fibre Bragg Grating (FBG) sensors (*see* Vol. 1, NO. 1, pp. 4-5) into composite structures has been developed, and study of associated issues, including sensor characterization, certification requirements, etc., have been done. Constant upgradation of the requisite instrumentation and software for data acquisition, processing and interpretation of sensor data is also being done. The design, fabrication and testing of typical composite structures to study the effect of damages on static strain patterns have been carried out (Fig. 3). These structures were also used to validate the SHM methodology developed. An SHM methodology based on artificial neural networks has been developed for load monitoring and damage detection. The focus now is on developing systems that can be flight tested on an aircraft. The platforms currently being studied are the Unmanned Aerial Vehicle, *Nishant*, the Light Combat Aircraft, *Tejas*, and the Light Transport Aircraft, *SARAS*.

The author, G.M. Kamath who is a scientist in NAL, acknowledges the inputs of his colleagues for this article. Oversights, if any, are that of the author. Queries may please be sent to director@css.nal.res.in.

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