MICRO STRUCTURE BULLETIN

Newsletter for Scandinavian Micro Structure Technology No.3 Aug 1995

Transducers'95 • Eurosensors IX

A piezoceramic stator intended for a miniature motor with diameter and height of 4 mm and 2 mm respective. (M. Bexell et al*, Uppsala University, Sweden).*

This conference, held at the City Conference Centre in Stockholm, was the largest sensor and actuator conference held to date, with approximately 1,200 participants from 46 countries. The hosting country, Sweden, was represented by more than 100 participants from both industry and academia.

The proximity of the center of Stockholm and the good weather made it possible for the participants to enjoy Stockholm, as well as the scientific program. The social events taking place at the City Hall and the Vasa Museum contributed further to the positive and pleasant atmosphere at the conference.

The scientific program was much larger than usual at both the *Transducers* and *Eurosensors* conferences. Four parallel oral and a continuous poster session permitted the presentation of 520 contributed and 18 invited papers. A total of 1250 abstracts were submitted, providing the three program committees in Asia, North America and Europe the difficult job in selecting among the contributions.

The various sessions at the conference were related to different aspects of sensor and actuator research. Examples include the general and theoretical aspects of sensors and actuators, micro-electro-mechanical and micro-analytical systems, mechanical sensors, gas and ion sensors, biosensors, and novel materials. The introductory plenary session started the conference in an excellent way with a summary of the essential scientific areas. An evening session, devoted to the industrialization of sensors, described different aspects of the commercialization and marketing of new sensor technologies.

Of the many highlights, the presentations by Arai *et al* (Japan) "Magnetic Small Flying Machines", Smela *et al* (Sweden) "Self-Opening and Closing Boxes and Other Micromachined Folding Structures" and Miura *et al* (Japan) "Insect-Model Based Microrobot" were especially highly appreciated as judged from the discussions during the coffee breaks. This is also the case for the entire session entitled "Micromachined Analysis Systems", including, for instance, presentations by Harrison (Canada), Manz (Switzerland) and Northrup (U.S.A.). This latter session was recognized by Swedish Radio, which made a documentary about the conference.

The arrangements during the conference were excellent. The conference facilities and the skilled staff of both the City Conference Centre and Congrex contributed markedly to the success of *Transducers'95 • Eurosensors IX.*

Ingemar Lundström, Chairman
Bertil Hök, Secretary
Jan-Åke Schweitz, Program Chairman

CONTENTS

EDITOR'S NOTE

The articles in this issue of *MSB* are related to presentations made at *Transducers • Eurosensors*. In selecting which presentations to feature here, I have attempted to demonstrate the broad range of activities in the field. Notable is the number of presentations given by industrial R&D departments. This will inspire further university-based research.

A drawback with large conferences with parallel sessions is that it is impossible to follow all the presentations which one is interested in. Of no less importance is to spend the time meeting people, to discuss new ideas, and to explore new directions. Naturally, contributions to future conferences will be affected by the many high-quality presentations at *Transducers • Eurosensors*. The next conference may even include new applications and processing steps which were not even contemplated at present.

Next large MST-event in Scandinavia will be the workshop MSW'96, March 26–27, next year. Look out for further information.

Life goes back to normal following the successful international activities. For me, it means continuing my sensor projects and consulting, and to prepare the November issue of *MSB*. Adj.Prof. Bertil Hök will help me with this issue, as a guest editor.

Jan Söderkvist

International Highlights

At *Transducers • Eurosensors*, there were numerous excellent presentations and posters. Including a short summary of each would be very lengthy. Therefore, only some of the more eye-catching international highlights are given below.

Three Dimensional Building

With surface micromachining, it is possible to deposit sacrificial layers that can easily be etched away. The proper patterning and etching of these layers enable the creation of freed structures, for instance, hinges and hubs.

N.C. Tien *et al* (Berkeley Sensor & Actuator Center U.S.A.) used the microhinge technology to achieve the vertical dimensions and functionality of optical components. Laser-beam positioning mirrors and laser-beam scanners (see figure) were designed and fabricated. Analysis showed that the stability of the mechanical structures was good under temperature changes and vibration.

The possibility to create components for articulated microrobots was described by R. Yeh *et al* (Univ. of California, U.S.A.). The cubic millimeter sized microrobots are intended for milligram payloads. A linear electrostatic stepper motor moved and rotated microhinged structures with the help of sliding shuttles and pushrods.

Energy and Data Storage

C.B. Williams and R.B. Yates (Univ. of Sheffield, U.K.) has studied the transmission of energy to completely physically isolated microsystems. One way of overcoming the lack of physical contact to the outside world is to vibrate the microsystem. Locating in the microsystem a generator that converts vibrational energy into electrical energy enables power generation in the order of 0.1 mW at 1 kHz.

L.-B. Fan *et al* (IBM Research Division, U.S.A.) has studied millimeter-sized motors needed for future high density data storage based on tip-based recording schemes and sub-centimeter disks. Atomic force microscope-based recording has demonstrated a data density as high as 4 Gb/cm^2.

Moving Particles

Movement can be obtained without the use of moving mechanical parts. For example, cells can be moved in small etched channels located in an electric field, due to the dielectrophoretic force. S.-W. Lee *et al* (Seoul Nat. Univ., Korea) has created a cell fusion device in which two cells can be attracted and fused on the electrodes. Experiments showed successful attraction of two radish cells to the electrodes when an AC voltage (1 MHz, 170 V/cm) was applied.

D.J. Harrison (Univ. of Alberta, Canada) described how microfluidic systems micromachined in glass chips can serve as systems for chemical analysis or sensing. With electroosmotic pumping, an applied voltage can control the direction of fluid flow without the need for valves.

Analysis Systems

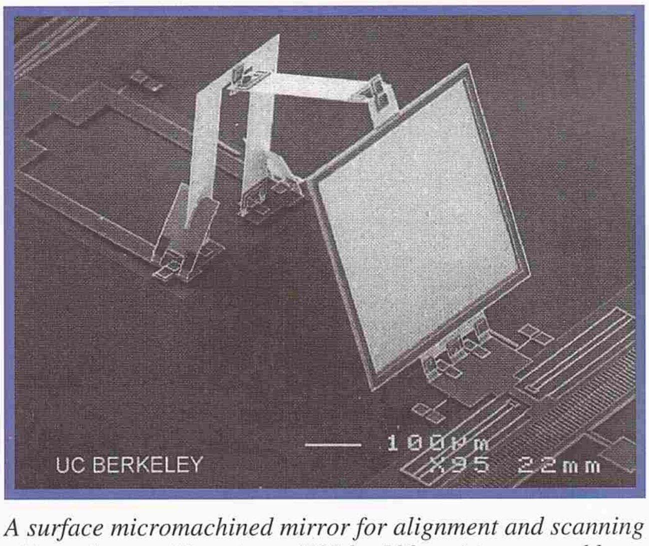
A group from Ciba-Geigy Ltd., Switzerland, in cooperation with the Univ. of Alberta, has integrated various elements of a liquid chromatograph onto a silicon microstructure. Low volume split injectors, separation channels, and optical detectors were integrated onto a chip.

The Ciba-Geigy group (D.E. Raymond *et al*) also presented a miniaturized version of a continuous electrophoretic device which demonstrates the possibilities and limitations of individual elements of a µ-TAS (Micro Total Analysis System).

M.A. Northrup *et al* (Lawrence Livermore Nat. Lab., U.S.A.) presented a miniature thermal cycling instrument for performing polymerase chain reactions (PCR). Microfabricated silicon-based reaction chambers are used in this device. Several different biological systems have been amplified and verified.

The design, fabrication, and testing of a planar microfabricated fluid filter was described in a poster by J.P. Brody *et al* (Univ. of Washington, U.S.A.). The filter can be used for separating plasma from the blood, as well as a diverse number of other functions.

Jan Söderkvist
Anna-Lisa Tiensuu



A surface micromachined mirror for alignment and scanning of laser beams. The mirror (500 by 500 µm) is actuated by two electrostatic combdrives. (Berkeley Sensor & Actuator Center, USA).

Inspired by Mother Nature

Designing a device that is simple, and that functions properly and reliably is a complicated task. An obvious, but often forgotten, place to look for ideas is in our natural surroundings. There are good reasons to look for solutions by studying natural phenomena. Performance and mechanical solutions for certain applications are often optimized since they have evolved over very long periods of time.

Insects: Flying Micromachines

Professor K.I. Arai *et al* (Tohoku Univ., Japan) presented one of the more spectacular videos during the conference. He was invited to give a talk in the session on magnetic actuators. Japan has put considerable research effort into self-running micromachines, which among other tasks, can inspect inaccessible spaces. In the introduction to his talk, Prof. Arai explained that flying micromachines are a very attractive concept since they are not dependent on surface topography and friction, as they move freely in space.

Several difficulties have to be overcome in order to realize functional flying micromachines. A remote wireless power supply is needed since cables disturb flying. The attitude of the machines should be controlled without contact guides that cause friction. Finally, it is difficult to design a simple structure with a lifting force greater than gravity.

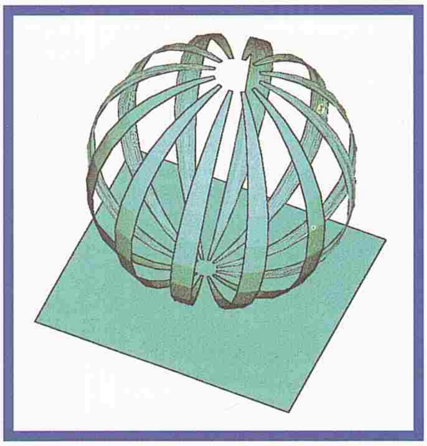
To solve these problems, a new flying mechanism was proposed using magnetic torque and elastic hinges. The auditorium was very impressed by the machines, a few centimeters in diameter, as they actually flew when a 12 Hz alternating magnetic field of more than 400 Oersted was applied.

Hands and Claws: Gripping

The hands of humans and animals serve as prototypes when developing self-opening and -closing structures (detailed on page 7) and microgrippers.

Hearing: Speech Processing

A micromechanics-based artificial cochlea (MEMBAC), presented by D. Haronian and N.C. MacDonald (Cornell Univ., U.S.A.), is an example of how nature has served as a model for the developement of a microelectro-mechanical device. The MEMBAC is composed of an array of coupled beams that operates in the manner of the basilar membrane of the cochlea in the human inner ear. This is used to mechanically filter sound into frequency bands. A physical model like this offers a promising direction for improvement of current speech processing.



A sea-anemone like micro-container, approximately 400 μm in diameter. The device is normally closed but opens upon actuation. (G. Lin et al *U.S.A., Japan).*

The conventional way of extracting information from sound is to use Fast Fourier Transformation (FFT) and Linear Predictive Coding (LPC) for achieving a frequency spectrum, which is then analyzed according to some computational algorithm. Comparisons between the physical model and conventional methods have shown that the physical model in many cases obtained better results.

Insect Model Based Microrobotics

Professor H. Miura *et al* (Univ. of Tokyo, Japan) has looked for solutions in nature at the dimensions that are to be used in microrobotics, namely insect-model based solutions. This does not only apply for mechanical solutions, as the question of robot intelligence has also led him to look into the insect world.

In his talk, he raised the question: "What is actual robot intelligence?". The research group, led by Prof. Miura, has developed several "intelligent" robots. He showed examples of robots that could learn games (intelligence for fast and accurate motion and learning), robots that could walk (biped and quadruped) and also robots that could learn by observation. However, the robots only followed the programs, that were created for them by humans. They do not, for instance, have a will to learn the games better. "Can a machine have its own will?" This is a fundamental issue in robotics and artificial intelligence. To answer this question, Prof. Miura also suggests that we look into the insect world.

As far as the mechanical solutions are concerned, he showed an example of how an insects wing functions. There is no friction since the wing is constructed of elastic hinges and elastically deformable materials.

Finally, Prof. Miura showed a true hybrid robot consisting of a control unit mounted on part of a cockroach (or the other way around?). This "robot " actually walked using the cockroach legs.

Anna-Lisa Tiensuu

POSTER AWARDS

Five posters were awarded for best technical presentation and layout. First prize was given to a late news poster from David Sarnoff Research Center, USA, with the title: "Real-Time, 3D Micro-Imaging, Visualization and Analysis of Fluid Transport in Microelectromechanical Systems". Posters from Uppsala, Linköping and Stockholm were initially excluded from the contest. However, the jury decided to award a special prize to "The Design and Fabrication of a Gripping Tool for Micromanipulation", Uppsala Univ. The poster showed in an "outstanding" way ingenious and detailed three dimensional models of the fabricated microstructures.

RETURN FOR R&D

Over the last 30 years, roughly ten billion dollars has been spent on microsystems R&D. This is a similar figure to the estimates for the market for microsystems in the year 2000 alone.

SURFING

Are you interested in purchasing literature in the field of MST? Before you do so, you may want to surf on the IMSAS homepage from the University of Bremen (http://www.zfn.uni-bremen.de/infosys/www bremen.html). There, you can find an interactive tool which allows you to retrieve a list of relevant documents. The description of each document contains additional information, such as bibliographical information and an abstract.

MAXIMA —

A European Sensor Project

The rapid development in automotive technologies has created a great need for advanced, reliable and inexpensive subsystems and components. As a consequence, the European consortia MAXIMA (Multiaxial Monolithic Integrated Accelerometer), aimed at the development of a surface micromachined accelerometer, was formed in 1992.

Several contributions at *Transducers • Eurosensors* featured the work carried out in this project.

Background

Available micromachined silicon accelerometers normally include a bulk-micromachined sensor element consisting of a seismic mass that moves under acceleration. Piezoresistive or capacitive pickup is used to detect the deflection. Signal processing electronics, for instance for self-diagnostics and self-calibration, are normally placed on a separate IC-chip.

Surface micromachining is an important processing technology for future accelerometers. Manufacturing equipment for ordinary ICs can then be used to a greater extent. In addition, surface micromachining facilitates the integration of signal processing electronics on the sensor element chip. This can be used to generate single-chip solutions without degrading the performance.

Currently, only commercially available accelerometers from Analog Devices are based on a surface micromachined single-chip solution.

MAXIMA Approach

The overall goals for MAXIMA are:

- To develop IC compatible technologies and establish infrastructures for the fabrication of intelligent monolithic integrated sensors and sensor systems.
- To realize an integrated multiaxial accelerometer as a demonstrator.

The sensor element of the accelerometer is based on capacitive detection. To have a large capacitance variation due to acceleration, a comb structure (see figure) is used for detecting acceleration in the plane of the wafer. Thick structures and narrow gaps ensure high capacitance variations.

For optimum performance, it is necessary that the sensor element is not in a compressed stress state due to the fabrication. This avoids some nonlinearity and buckling tendencies are by that avoided.

Technological Solution

Creating low stress surface polysilicon micromachined structures in the thickness range of 10 mm cannot easily be done with conventional technologies. Therefore, an essential step in the project has been to develop processes for depositing thick and nearly stress-free polysilicon layers.

Etching out the comb structure involves high aspect ratio dry etching for creating the 1–2 µm wide gaps. The in-wafer dimensions of the sensor element is in the order of 0.5 mm.

Materials characterization has been an important tool to determine, for instance, the stress level and the fracture strength. Special test structures have been included on the wafer to help measure these parameters (see figure on page 6).

Results

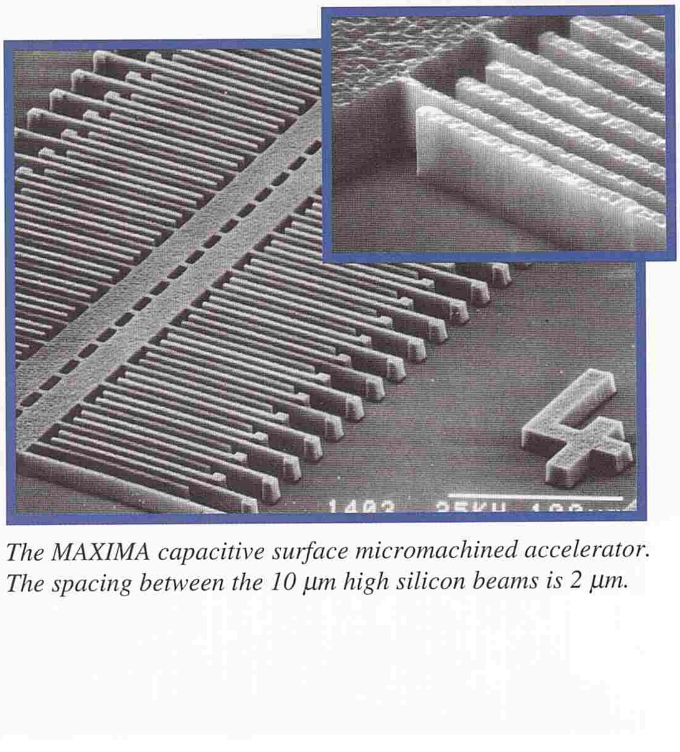
Polysilicon with a thickness of 10 µm was deposited within 20 minutes in a vertical epitaxial reactor. The surface roughness was about 3% of the thickness. Internal stress (tensile) and stress gradients were low and fit well within the requirements of the planned sensor structures. The fracture strength was good and enabled a safe realization. The applied dry etch process yielded very smooth sidewalls with a wall angle of 87°.

Organization

The project is partly financed by the European Commission under ESPRIT. The members of the project consortia are:

- FhG-ISiT, D, coordinator
- AMBIT Ltd., GR
- CNM-CISC, E
- Robert Bosch GmbH, D
- SEAT, E
- Universitat de Barcelona, E
- Uppsala University, S

Jan Söderkvist, Sweden,
Peter Lange, FhG-ISiT, Germany



The MAXIMA capacitive surface micromachined accelerator. The spacing between the 10 µm high silicon beams is 2 µm.

Accelerometer Workshop

A NEXUS workshop covering the frontiers of the silicon accelerometer development was organized in Uppsala on June 22–24. The 30 participants from twelve countries had the opportunity to attend the oral presentations, experimental activities, social events and many stimulating and lively discussions.

The presentations given by seven invited international experts gave a well balanced overview of topics such as accelerometer principles and fabrication techniques. One presentation also covered the related topic of angular rate sensors. The keynote lecture by Eric Peeters, from the Xerox Wilson Center for Research & Technology in the U.S.A., started the workshop in an excellent way.

The workshop took place during the Swedish Midsummer weekend, and as a result, an extensive and very well received social program could be arranged. The participants enjoyed a visit to a typical Swedish midsummer festivity. The social highlight was a boat cruise to the Skokloster Castle area on Midsummer Eve. On board, an extensive smörgårdsbord was served. As a surprise, the boat company had invited the famous botanist Carl von Linné, impersonated in an excellent way.

The workshop was organized by Prof. Bob Puers (K.U. Leuven, Belgium) in collaboration with Jan Söderkvist. We really appreciate all the positive comments from the participants.

Jan Söderkvist

Industrial Session

A popular industrial session was organized at *Transducers • Eurosensors* in the evening of the second day. The purpose was to create a forum for the discussion of possibilities and problems related to the industrialization of sensors and actuators. After five presentations given by invited speakers, a lively panel discussion followed.

The five invited speakers represented both small and large, as well as general and specialized, companies from Europe, Asia and North America. The session was chaired by I. Lundström, Sweden, and S. Middelhoek, The Netherlands.

Microelectronics vs. Micromechanics

Kurt Petersen from Lucas NovaSensor, U.S.A., pointed out that there are both similarities and differences between the microelectronics and the MST-based industry. Both use similar production techniques and equipment. However, the competition on the market is very different. For electronic products, there exist very few alternatives. For micromachine-based products, there are many conventional "macrofabricated" alternatives.

There has to be a notable advantage, for example, in price, performance, reliability, availability or strategic aspects, before a switch to a new technology is motivated. Initially, this prolongs the decision time for providing the necessary investments in production facilities. Foundry service possibilities, which are currently in the start-up phase, are created first when there is a market.

Time-to-Market

The time-to-market can be substantial for a new technology that has to compete with existing technologies. A typical example is the micromachined printer head in which developmental activities started in the early 1970s. Currently, commercially available printer heads are based on machining processing steps only to a minor degree, although research efforts are increasing. The competition from conventional fabrication methods is significant. Another example is a display based on a silicon chip consisting of more than a million small electrostatically movable mirrors. Texas Instruments started their research in this area in 1977. In 1993, they presented a prototype, and the first product is expected in 1996.

The long time-to-market was also discussed by Sverre Horntvedt from SensoNor, Norway. They expect a ten-year period from development until profit. Traditionally, these first ten years are the "easiest", and the next ten years are the most "difficult" for a new industry that is based on a new technology. Two general observations he made regarding the international accelerometer industry were to "never promise too low prices too early", and that the acceptance of industrial failure varies between the continents, with a resulting difference in the availability of venture capital.

Concentration

The micromachining industry is slowly adopting to the transformation of MST into a myriad of separate subspecialities. A result is a concentration on product areas, instead of on fabrication processes. This trend reduces the temptation to apply MST to too many areas too quickly. However, if diversified, an under-critical development and marketing effort for some products may result.

Each subspeciality may require totally different technical solutions. Development efforts for microfluidics concentrate on, for example, bulk micromachining, deep RIE-etch, and wetting properties, while surface micromachining with integrated electronics are of higher interest for inertial sensors. The packaging problems are also very different for various application areas. For microfluidics and pressure sensors, contact with the surrounding media is necessary, while inertial sensors can be kept well isolated from a hostile surrounding. Also, the need for hermetic sealing varies between applications.

Applications

Isemi Igarashi from Toyota Central R&D Labs. Inc., Japan, shared his experience from the automotive industry, an application area which has probably best accepted components based on micromachining. Reliability, cost-reduction and more advanced functions are a few driving forces.

Lars-Göran Andrén from Pharmacia Biosensor, Sweden, shared his experience of managing issues related to the development of their biosensor. How to optimize the development effort is a complicated issue. For instance, should internal or external resources be used, and how to transfer from being development oriented to starting the manufacturing phase. Launching a new type of product means that the marketing department has initially to concentrate on technology push instead of listening to the market pull. In the second case, there may not be any market shares left to fight about. The time-to-market for their biosensor was 6–8 years, and to break even, 10–12 years.

The last speaker, H. Meixner from Siemens, Germany, described the history and status of the development of metal oxide sensors.

An observation is that some customers hesitate to use semiconductor sensors. Further R&D is needed, for instance on studying new metal oxides, before gas sensors can be cheap enough to be made mandatory in every private household.

Jan Söderkvist

Local Highlights

Several contributions to *Transducers • Eurosensors* came from the Nordic and Baltic countries. The following highlights represent a small number, of the many, interesting contributions:

Baltic States
There were three contributions from the Baltic states. A. Kruusing *et al* (Tallinn Technical Univ., Estonia) have studied flexible permanent magnetic beams for pumping and flow sensing. The excitation was studied both analytically and experimentally.

G.Vaivars *et al* (Univ. of Latvia, Latvia) showed how thin gas sensitive films can be obtained using sol-gel and laser evaporation methods.

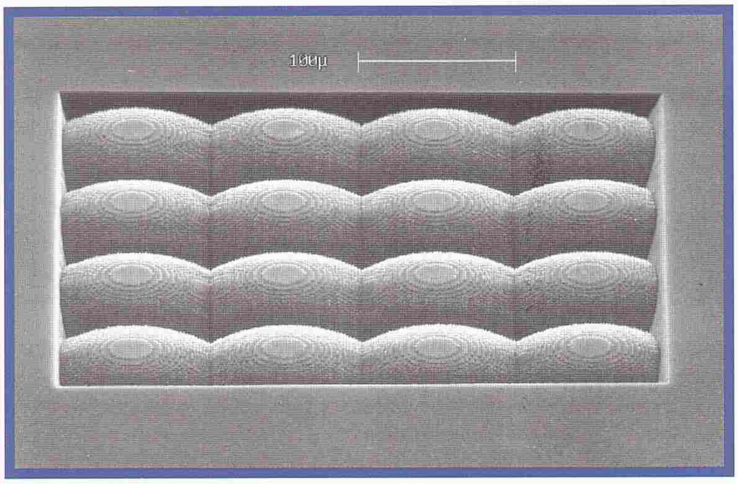
V. Snitka *et al* (Vibrotechnika Res. Inst., Lithuania) have developed a bimodal ultrasonic actuator with about a 10 nm positioning resolution.

Denmark
Denmark showed a strong position in optics. M. Müllenborn *et al* (MIC) presented their results on etching silicon with the help of a laser. This technology has been used to create demonstrators in the form of lenses, diffusers, nozzles, etc (see figure). This etching procedure involves the local melting of the material in a chloride atmosphere, in contrast to the ablation technique presented in *MSB 94:3*. Etch speeds in the order of 10^5 µm^3/s were obtained for a 488 nm laser. An 800 nm spot size generated an 1 µm melting zone.

T. Storgaard-Larsen *et al* (Brüel & Kjær / MIC) demonstrated a new accelerometer design based on a Bragg grating as the strain sensing element. The acceleration induced deflection of the seismic mass stretches a thin wave guide microbridge. This changes the distance between the gratings on the wave guide, which can be detected as a shift in wavelength of the reflected light.

Finland
T. Veijola *et al* (Helsinki Univ. / Nokia / Vaisala Technologies) presented a model for studying the effect of air damping in narrow gaps between two moving surfaces. The resulting mechanical force was derived using an electrical circuit representation. The model was successfully applied to a capacitive accelerometer from Vaisala Technologies. Narrow gaps are frequently found in micromachined capacitive devices, for which the electrode distance is preferably small.

M. Huotari *et al* (Univ. of Oulu) presented a study on insect biosensors. The work was stimulated by the rapid speed of response, that insects possess towards various chemical stimuli, such as some diamines and alcohols. Measurements were carried out using blowflies. Some of the parameters studied were the response time, specificity and inhibitory effects for various gases.



A lens array in silicon machined by 3D laser micromachining. (M. Müllenborn et al, *MIC, Denmark).*

Norway
M. Nese *et al* (SINTEF) presented a method for testing the hermiticity of bonded wafers. This method is based on measuring the gas concentration within the enclosed cavities with the aid of Fourier transform infrared spectroscopy. In the tests, N_2O was used as the testing gas. The detection limit was estimated as 1 to 2 mbar.

E. Steinsland *et al* (Univ. of Oslo / SINTEF / SensoNor) has studied the possibility of creating an etch stop effect when etching silicon in tetramethyl ammonium hydroxide (TMAH) solutions. An etch ratio of 1:40 between silicon areas with high (up to $4 \cdot 10^{20}$ cm^{-3}) and low boron concentrations was obtained. No significant dependence with etchant concentration in the range of 15-45 wt% was observed.

Sweden
G. Andersson (CTH) presented a 3-axis monolithic silicon accelerometer, which has been described in *MSB 95:1*.

A planar pump without any valves has been realized in silicon and was presented by A. Olsson *et al* (KTH). This pump is based on the diffuser/nozzle principle. It is shown to function at very small dimensions in the order of 30–100 µm.

E. Kälvesten *et al* (KTH) presented an integrated pressure-flow sensor for measurements in turbulent gas flows. The pressure sensor is based on polysilicon diaphragm technology and the flow sensor on the cooling of a polyimide-insulated heated mass.

H. Elderstig *et al* (IMC) presented a poster on a mechanical splice for fiber ribbons. This structure will be described in a future issue of *MSB*.

The performance of a Metal Oxide Silicon Carbide (MOSiC) sensor was investigated and reported by A. Baranzahi *et al* (LiTH). The device has potential for application as a fast responding high temperature sensor for combustion control.

F. Winquist *et al* (Linköping Univ.) reported a study in which an electronic nose had been used for screening of irradiated tomatoes. They concluded that electronic noses could be of great value for certain applications, for example, the screening of shipments to detect both damaged and irradiated products. Other presentations treated additional application areas for the electronic nose.

A micromachined flow-through cell for liquid sampling was presented by L. Wallman *et al* (LTH). Small drops with a volume of 34 pl are formed using a piezoceramic disc-shaped actuator. The described device can be used in a wide range of applications where negligible sample take-out volume is a requisite and still continuous sampling is desired.

The self-opening and closing structures presented by E. Smela *et al* (Linköping Univ.), work related to the MAXIMA-project, presented by S. Greek *et al*, and F. Ericson *et al* (UU) and in-situ investigation of high strength microassembly using Au-Si eutectic bonding, presented by A.-L. Tiensuu *et al* (UU), are all further described in this issue of *MSB*.

Jan Söderkvist
Anna-Lisa Tiensuu

Micromachined Folding Structures

The electronic properties of conducting polymers can be varied between insulating and metallic by altering the doping level. Under certain conditions, mobile ions from an electrolyte in contact with the polymer can travel in and out of the polymer, with a resulting change in the volume of the polymer. This process can be controlled by the application of a small voltage. By using a conducting polymer as one layer of a bilayer, a large degree of bending can be achieved as its volume shrinks. Hinges made from such bilayers can be used to rotate rigid plates.

Surface micromachining was used to fabricate such actuators. Several rigid elements were connected together with the bilayer hinges. Activation of the hinges caused the microstructure to fold and assemble into predetermined shapes, such as the box shown in the figure.

These devices were operated in an aqueous salt solution, and the potential between the devices and a reference electrode was varied between -1.0 and +0.35 V. When positive potentials were applied, the volume of polymer contracted and the bilayer bent, folding the structures. These structures folded in 0.5 to 10 seconds, depending on the polymer thickness. Applying a negative voltage caused the structures to unfold again.

Bilayer cantilevers are a common feature in micromachined structures. However, conducting polymers undergo much larger volume changes than solid state materials, and smaller voltages and currents are required for operation. By controlling the bending of the hinges rather than the position of the plate, folding of more than 180° can be achieved. Another feature of these devices is that the plates can be held in any position by fixing the voltage to maintain a certain doping level. This permits one to do delicate manipulations or, with separately addressed plates, complex folding sequences. More details can be found in a recent issue of Science (see "Publications").

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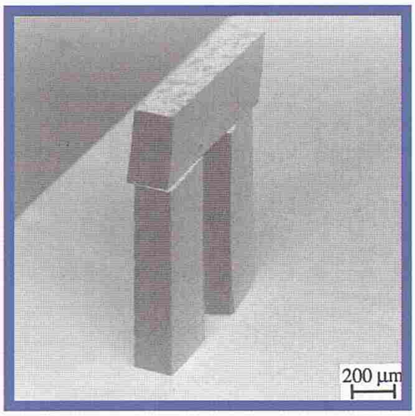
Self-opening and -closing boxes. Each of the six sides is 300 µm x 300 µm.

Dissertations

MSB congratulates Anna-Lisa Tiensuu, Uppsala University, on successfully having defended her Technical Licensiate thesis, *Investigation of Silicon bonding with Metal interlayer for Assembling Microsystems*, on June 6. This thesis reports on two methods for joining silicon with the aid of a metal inter-layer. The two methods that are investigated are gold-silicon eutectic bonding and bonding of silicon through cobalt silicidation.



A three-dimensional microstructure assembled using gold-silicon eutectic bonding.

PUBLICATIONS

The following list shows some MST-related results published during the last months:

- Small Piezoresistive Silicon Microphones Specially Designed for the Characterization of Turbulent Gas Flows; E. Kälvesten, L. Löfdahl and G. Stemme (KTH); *Sensors and Actuators A*, **46**(1–3) (1995) 151–155.
- Controlled Folding of Micrometer-Sized Structures; E. Smela, O. Inganäs and I. Lundström (LiTH); *Science*, **268** (June 1995) 1735–1738.
- Improved Direct Bonding of Si and SiO_2 Surfaces by Cleaning in H_2SO_4:H_2O_2:HF; K. Ljungberg, U. Jansson and A. Söderbärg (UU); *Appl. Phys. Lett.*, **67**(5) (1995) 650–652.
- Investigation of Silicon Bonding with Metal Interlayer for Assembling Microsystems; A.-L. Tiensuu (UU); Licensiate thesis, *Uptec* (May 1995), ISSN 0346-8887.
- Spin Deposition of Polymers Over Holes and Cavities; H. Elderstig and P. Wallgren (IMC); *Sensors and Actuators A*, **46**(1–3) (1995) 95–97.

S&A

A conference proceeding is available which includes the abstracts from the more than 500 presentations given at the conference. Each abstract in the proceedings was limited to a maximum of four pages. Despite this, the proceedings weighs more than four kilos. A shipping service, therefore, was available at the conference.

For those that are interested in more information, the journal *Sensors and Actuators* will publish extended versions of most of the conference contributions.

POSTTIDNING B

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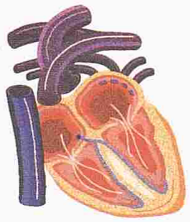
MICRO STRUCTURE BULLETIN NO.3 AUG 1995

NEXT ISSUE

The next *MSB* will feature a special issue on medical applications of MST.
Guest editor: Adj. Prof. Bertil Hök.



MSW '96 Call for Contributions

The second Scandinavian Micro Structure Workshop will be held in Uppsala in late March 1996. The purpose of MSW is to stimulate the use of Micro Structure Technology and to bring together in an informal way those in Scandinavia interested in MST. MSW is a complement to scientific conferences, which are primarily forums for the latest scientific results. The first MSW held in 1994 had 70 participants. The official language is "Scandinavian".

Some provisional topics that will be covered during MSW are: design and fabrication services for MST, overviews of process steps, application oriented presentations, and how to market an MST-based product. A poster exhibition is planned. Ample time will be given for informal discussions during and between the presentations.

You are invited to submit suggestions for contributions before December 31 to Jan Söderkvist. Feel free to choose from additional subjects not covered in the above list.

For more information, please contact Jan Söderkvist (Fax: +46-(0)8-510 116 15, address given in the editorial column).

MSB subscription (✉ or ✂)?

Micro Structure Bulletin is distributed free of charge within Scandinavia and to a limited number of international experts. Please contact the Editor-in-Chief if you wish to receive a personal copy of *MSB* on a regular basis, or if your address label is incorrect. In response, a ✉-sign will be included on your address label.

A ✂-sign on your address label means that there is a 20% risk for each issue of you being removed from the mailing list.

The editors also encourage you to put *MSB* on circulation.

FUTURE EVENTS

Laser Microengineering (course), MIC, Lyngby, Denmark, Sept. 12–13, 1995. For information contact: FSRM, Fax: +41-38 200 990, or Matthias Mullenborn, Fax: +45-4588 7762.

microSIM 95, Southampton, UK, Sept. 26–28, 1995. For information contact: Sue Owen, Fax: +44-170 3292 853.

Microfabrication Technology for Research and Diagnostics, San Francisco, U.S.A., Sept. 28-29, 1995. For information contact: CHI, Fax: +1-(617) 630-1325.

Materials for Microstructures (course), Uppsala, Sweden, Dec. 5–6, 1995. Registration deadline Nov. 17. NEXUS may pay your registration fee. For information contact: FSRM, Fax: +41-38 200 990, or Jan Söderkvist, Fax: +46-(0)8-510 116 15.

MEMS '96 (Micro Electro Mechanical Systems), San Diego, U.S.A., Feb. 11–15, 1996. *Abstract deadline: Sept. 15*. For information contact: Preferred Meeting Management Inc., Fax: +1-(619) 298 3459.

MSW '96 (Micro Structur Workshop), Uppsala, Sweden, March, 1996. See separate note.

Actuator 96, Bremen, Germany, June 19–21, 1996. For information contact: Dr. H. Borgmann, Fax: +49-421-17 16 86.

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