MICRO STRUCTURE BULLETIN

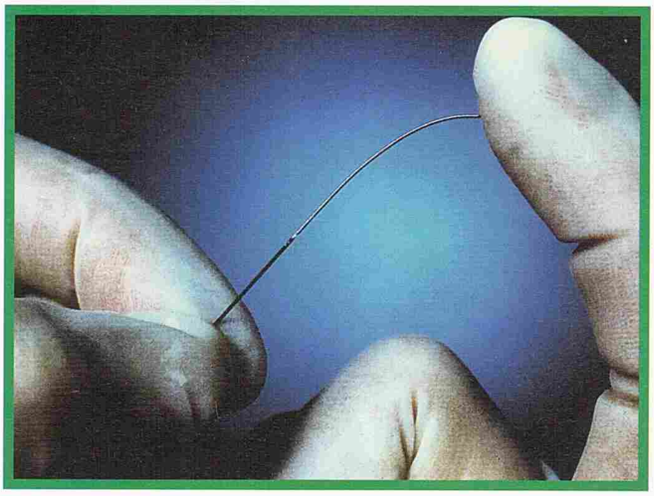
Newsletter for Swedish Micro Structure Technology No. 1 Dec 1993

Micromachining development

Sculpturing using processes originating from the semiconductor industry is a new technology which enables fabrication of very small devices. Micromachining has, since its introduction in the 1960s, developed its own arsenal of fabrication tools.

This has extended the two-dimensional world of semiconductors to truly three dimensions. The possibility to batch process with simple equipment means that the advantages of the semiconductor industry can be used to reduce the cost of each device.

Micromachining is now mature enough to meet the demands of industry. Some examples of successfully commercialised devices are resonators (e.g. watch crystals) and sensors (e.g. accelerometers for airbags). At the same time, the technology is still evolving rapidly. Future applications may contain completely miniaturised mechanical and fluid systems. All this makes MST a very interesting area, both from an industrial and from a research point of view. This is evident from the rapid industrial increase in international micromachining and MST activity. ■



An intravascular pressure sensor used for measurements, e.g., in obstructed areas of coronary arteries of the heart (see page 4). Micromechanics has made the small 0.35 mm diameter possible.

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Micro Structure Technology (MST) is the fabrication (micromaching, etc), characterisation, and use of materials and structures with dimensions smaller than for achievable by conventional machining.

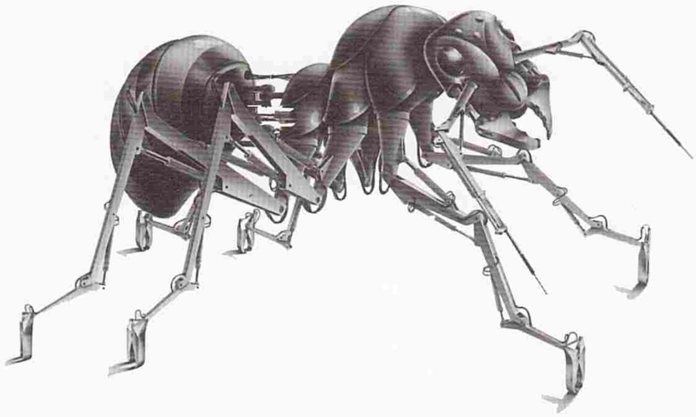
Welcome

Welcome to the first issue of *Micro Structure Bulletin*. Our aim is to describe the state of art in micro structure technology both to newcomers and to experienced readers, in industry and at universities. It is hoped that the possibilities and wonders of microfabricated devices will be revealed.

Some of the recurring topics will be: micromachining tools, applications/areas of application, micromechanical facilities, and recent R&D activities. Great care will be taken to put Swedish micromechanics in an international perspective.

As always with a new publication — its future content depends on the readers. Comments and suggestions are therefore gratefully received.

Micro Structure Technology



Courtesy of Ovako stål

Have we not all been fascinated by the craftsmanship of the Swiss watch makers – creating high precision mechanical systems so small that a magnifier often is needed during assembly? Today, there is a need for even smaller devices. Many such examples are found in automotive, telecommunication, medical and consumer applications, for example, accelerometers for airbags, implantable insulin pumps and ink jet printer heads. The rapidly developing Micro Structure Technology (MST) making reduced size possible, and is now being commercially exploited.

The wonders of microprocessors constantly change daily life, with things such as computers and microwave ovens. Those inventions often need information from their surroundings to function as desired. Only recently, partly due to the evolution of MST, has it become economically feasible to include sensors and microprocessors in many new applications. Clearly, the technology push for MST is now complemented by a market pull. The world market for MST is estimated to be 2.3 billion ECU in 1995.

Most of the more than 300 companies involved in MST are found in the USA (>90) and Japan (>75). The strongly increasing activity in Europe is dominated by Germany, the UK, France, Switzerland, Sweden, The Netherlands and Norway.

MST

Micromachining is the fabrication of devices with dimensions smaller than was feasible by traditional manufacturing. The fabrication of the fully three-dimensional microscopic structures includes etching, deposition, bonding, etc. Each processing step will be described in further detail in future issues of *MSB*.

Combining micromachined parts makes it possible to build complete sensor systems which can carry out complex tasks.

MST Materials

Silicon is the material most frequently used in MST. The semiconductor industry has invested extensively in knowledge and production equipment for this material. It is now possible to obtain very pure and perfect crystalline silicon wafers. This makes possible micromachined structures with highly predictable and reliable performance, and with a fracture strength higher than that of stainless steel.

Quartz is a micromechanical material which has found its own niche in time-keeping applications. Its piezoelectric effect, inertness and strongly anisotropic properties make it the unsurpassed choice. There are commercial quartz oscillators with an error of less than one second per year, independent of whether you are in arctic or desert regions. The most successful micromachined product on the market is the quartz watch crystal. It is internationally manufactured at a rate of 100,000 crystals per hour.

Other materials are also used in certain applications, although those materials are not as well characterised. For instance, GaAs has interesting optical and piezoelectric properties.

Processing steps

A key step in MST is sculpturing with wet or dry etching. Selected areas can be etched by covering the remaining areas with a material – often photoresist or oxide – resistant to the liquid etchant or to the particle bombardment. The dependence of the etch rate on the etch direction serves as an excellent method for detailed tailoring. This anisotropic effect varies with the etchant, and can be substantial for some crystalline materials. Membranes with a specified thickness can be created since the etch can be stopped at a heavily doped layer or by incorporating a slow etching layer in the material.

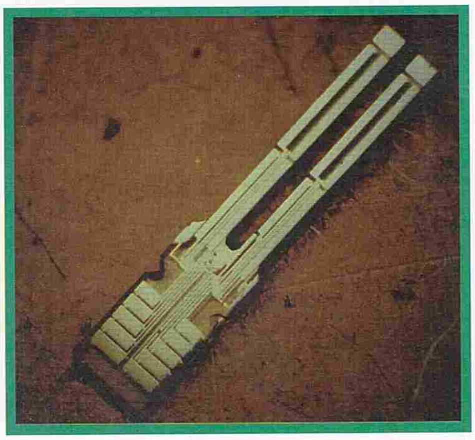
Combining etching with joining methods makes it possible to use several materials, and to form more complex three-dimensional structures. One method is anodic bonding, in which an insulator can be fused to a silicon wafer by applying a high voltage across the two materials at an elevated temperature. Cavities encountered in several pressure sensors can be formed with silicon-to-silicon fusion bonding. Bonding is also employed for packaging of the sensor chips.

Different layers can also be formed by additive steps. For instance, layers with varying characteristics can be formed by epitaxial growth and with chemical vapour deposition (CVD). Movable structures can be formed in this way by including an easily etched sacrificial layer under the structure.

Conclusion

Defining the last decade as that of *Microprocessors and Computers*, perhaps the coming decade will be that of *Multifunctional Microsystems*.

Jan Söderkvist ■



A quartz watch crystal geometry. The tines are 2.5 mm long. The electrode pattern has been changed to achieve an angular rate sensor.

MST in industry

Today micromechanics is a technology available on the market. The focus has been put on microsensors in silicon – mainly pressure sensors and accelerometers. The ability to create fully integrated microsystems containing sensor, electronics, and in some applications also an actuator, has been claimed as a reason for working in silicon. However, few of these systems have yet reached the market. One reason for this is that the equipment to handle conventional microelectronics circuits or wafers is designed for handling flat or two-dimensional chips. If you wish to implement micromachining in your device this normally puts certain demands on the equipment. One example is a "smart" accelero-meter from Analog Devices which contains both the sensor element and the signal conditioning. One key to a successful microsystem is partitioning – it is not always advantageous to put everything on a single chip! The cost for redesign of a single functional block increases with increased integration.

Industry  Academy

Activities in Sweden?

On the following page the successful use of MST in a pressure sensor is described. Some other projects currently in progress in Sweden are:

- an accelerometer designed by Bofors and manufactured by Chalmers,
- a new 3D-accelerometer (Chalmers supported by Saab Combitech),
- an implantable eye-pressure sensor for glaucoma patients (Uppsala University and with Pharmacia),
- a fibre optic pressure sensor for high pressures and high temperatures (AB Volvo and Samba Sensors in Göteborg)
- a gas flow sensor SWEMA AB

How do you get started?

Once you have decided that MST is the solution to your task it can be a good thing to contact a university or a research institute for discussions about design, etc., and for prototyping. You do not have to consider mass production, as is often the case with companies involved in MST. Simulations, e.g. finite element analysis, can also be done at these facilities.

If your prototypes work as expected you can in most cases also get into a small serial production at the research facility.

A good motto for (commercial) success is: "Make things as simple as possible, but not simpler"

Hans Richert, Bofors AB ■

APPLICATIONS FOR MST

Automotive

Engine control
Pollution miminisation
Navigation
Safety systems
Anti-collision systems
Comfort

Consumer

Camera stabilisation
Remote controls
Home appliance
Burglar alarms
Sports equipment
Toys

Health-care

Health monitoring
Dosage systems
Surgical intruments
Hearing aids
Pace makers
Equipment for handicapped

Industry

Process control
Gas detection
Guided vehicles
Stabilisation
Robotics
Computer equipment

MST COMMUNITY

Previously, the development of MST was considered basic research. During the past few years, a specialised sensor industry, based on small to medium-sized companies, has evolved in several countries. Recently, large companies, e.g., in the semiconductor and automotive areas, have announced products based on their own MST activity.

At the workshop *MME'93* in Neuchâtel, Switzerland, September 1993, 52% of the participants came from research institutes, 31% from industry and only 17% from universities.

WHY MST AT ALL?

Some cases when MST is the right choice of technology are:

- to miniaturise the sensing element in an existing application
- the structure is not at all available on the market
- to optimise performance with your own design – no one knows your system better than yourself
- a sensor is available only with electronics unsuitable to your application

PUBLICATIONS

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

- A valveless diffuser/nozzle-based fluid pump, E. Stemme (CTH) and G. Stemme (KTH), *Sensors and Actuators A*, **39**(2) (1993).
- Anisotropic etching of Z-cut quartz, C. Hedlund, U. Lindberg, U. Bucht and J. Söderkvist (UU), *J. Micromech. Microeng.*, **3**(2) (1993) 65-
- Distributed sensing with grating reflectors in optical fibres, L. Wosinski, R. Stubbe and M. Breidne (IOF), *EOS Annual meetings digest, Zaragoza, Spain,* **3** (1993) 73-76.
- Flexural vibrations in piezoelectric semi-insulating GaAs, J. Söderkvist and K. Hjort (UU), *Sensors and Actuators A*, **39**(2) (1993) 133-139.
- Gallium arsenide micromechanics, Klas Hjort (UU), Doctoral thesis, Acta Universitatis Upsaliensis #465 (Oct. 1993), ISBN 91-554-3161-5.
- Kugghjul, motorer och robotar mindre än ett sandkorn (in Swedish), J.-Å. Schweitz (UU), *Forskning och Framsteg*, **8** (1993) 4-9.

Intravascular p

The search for a miniaturised sensor for medical use is based on a desire to minimise trauma for the patient. This interest from the medical field has resulted in our project – to miniaturise a pressure sensor for measurements inside the coronary vessels (arteries of the heart). To simplify the procedure and to minimise the added obstruction to blood flow in the vessel, the diameter of the sensor had to be smaller than 0.46 mm (0.018"). To achieve this, we decided early in the project to use a single optical fiber and a micromachined sensor element.

The project was initiated by RADI Medical Systems when we contacted the micromechanics group at Uppsala University. In the beginning the project was financed by Nutek and LFTP (Landstingets Fond för Teknikupphandling och Produktionsutveckling).

Balloon Dilatation

A narrowing in a coronary vessel that obstructs blood flow may cause the patient chest pain and could eventually lead to more serious consequences. One way to treat this condition is balloon dilatation, that is, to place a "balloon" in the narrowing, inflate it and thereby press out the walls of the vessel.

To get the balloon in place, entry into the blood vessel is made using a catheter introduced by way of a puncture to an artery in the groin. The arteries and the instruments inserted into the body are visualised via X-ray. After one dilatation procedure has been completed, an X-ray view of the artery is analysed to see whether or not a second dilatation should be performed.

Improvements by adding a pressure sensor

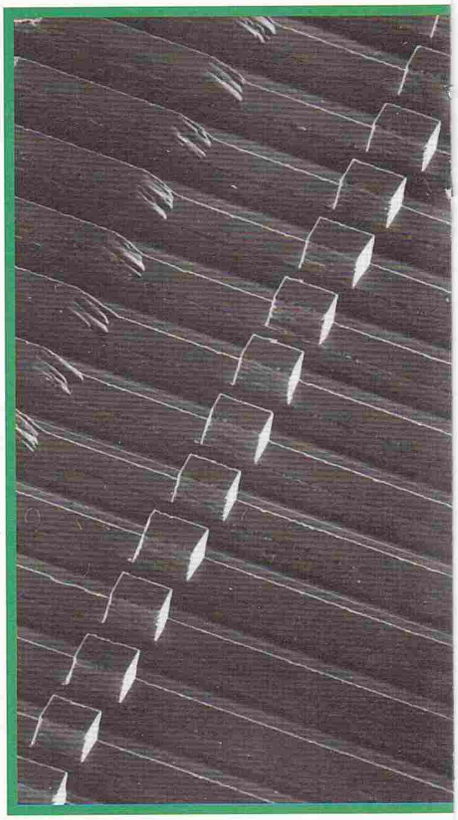
A limitation of X-ray, however, is that it provides only a subjective 2-dimensional view of the artery. The pressure gradient across the narrowing is, on the other hand, an objective characteristic parameter of the vessel. This additional information can be very helpful.

The difference in pressure measured over the narrowing will help to reveal whether or not additional treatments are necessary. Whereas small geometrical obstructions, such as a torn-off flap of the vessel wall that affects flow, will be shown as a pressure gradient, they might not appear on the X-ray image.

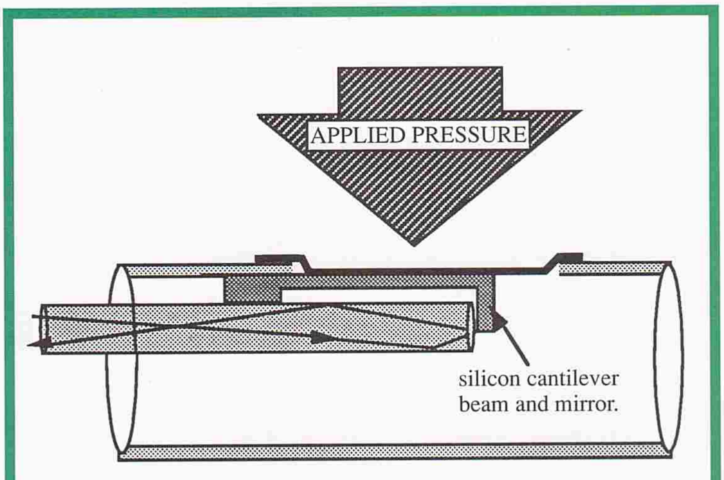
The Pressure Guide System

The *Pressure Guide* system from RADI Medical Systems is an entirely new concept in pressure measurement, integrating a miniaturised pressure sensor into a guidewire which can be introduced into coronary vessels. This makes it possible to easily obtain a measurement of the pressure gradient. The technique is to compare the pressure gradients before and after balloon dilatation.

To measure the pressure gradient over a narrowing in a vessel, the sensor element of the guidewire is first positioned behind the narrowing, and then drawn back until the sensor element has passed the narrowing. The difference between these two measurements is the gradient, and indicates how obstructive the narrowing is to blood flow. After a balloon dilatation has been performed, the *Pressure Guide* is still in place and the



Silicon cantilever beams with dimensions 5



pressure sensor

0 x900 µm, fabricated in (100)-silicon with anisotropic wet etching.

pressure gradient can easily be measured once again.

To make recording of the results as easy as possible, we have developed the *Pressure Gradient Analyser (PGA)*. It consists of a light source, a detector, and the necessary electronics. It also includes a computer which records the pressure difference over the narrowing and calculates the diastolic, systolic and mean pressure gradients.

The technical solution

The pressure sensor is fiber optic and intensity modulated. An advantage of fiber optics is the possibility of transmitting information in both directions using a single optical fiber. This is important in order to maintain the small dimensions of the sensor. Light emitted from a diode in the PGA enters, via a beam splitter, the optical fiber leading to the sensor. The sensor reflects part of this light back to the PGA, via the same fiber, in a pressure dependent way. The beam splitter in the PGA transmits the returning light to a photo diode which detects the intensity of the reflected light.

The sensor element modulates the intensity of the reflected light via the lateral movement of a micromachined silicon cantilever beam. The silicon beam contains a mirror positioned in the beam of light from the optical fiber. The beam and the optical fiber are assembled inside a tube which is sealed by an elastic membrane. Changes in the blood pressure in the artery deflect the cantilever beam, via the membrane, so the amount of light reflected by the silicon mirror changes.

The silicon beam is fabricated by micromachining. The vertical walls are anisotropically etched utilising the low etching (100) planes. It is possible to etch thousands of sensing elements on each wafer. The sensing element is 50 µm wide and 900 µm long. This makes it possible to assemble the sensing element and the optical fiber inside a tube having an inner diameter of 0.13 mm. The *Pressure Guide* has been made with an outer diameter of 0.46 mm (0.018") and 0.35 mm (0.014").

Commercial results

RADI Medical Systems' *Pressure Guide* and *PGA* are now being sold in Europe and Japan, and we expect to introduce the product in the USA during 1994. We have sold approximately 1,500 sensors to date. Although some alternative uses have also been found for the product, it has mainly been used to measure pressure gradients in the coronary arteries.

Lars Tenerz
RADI Medical Systems ■

Eurosensors VII

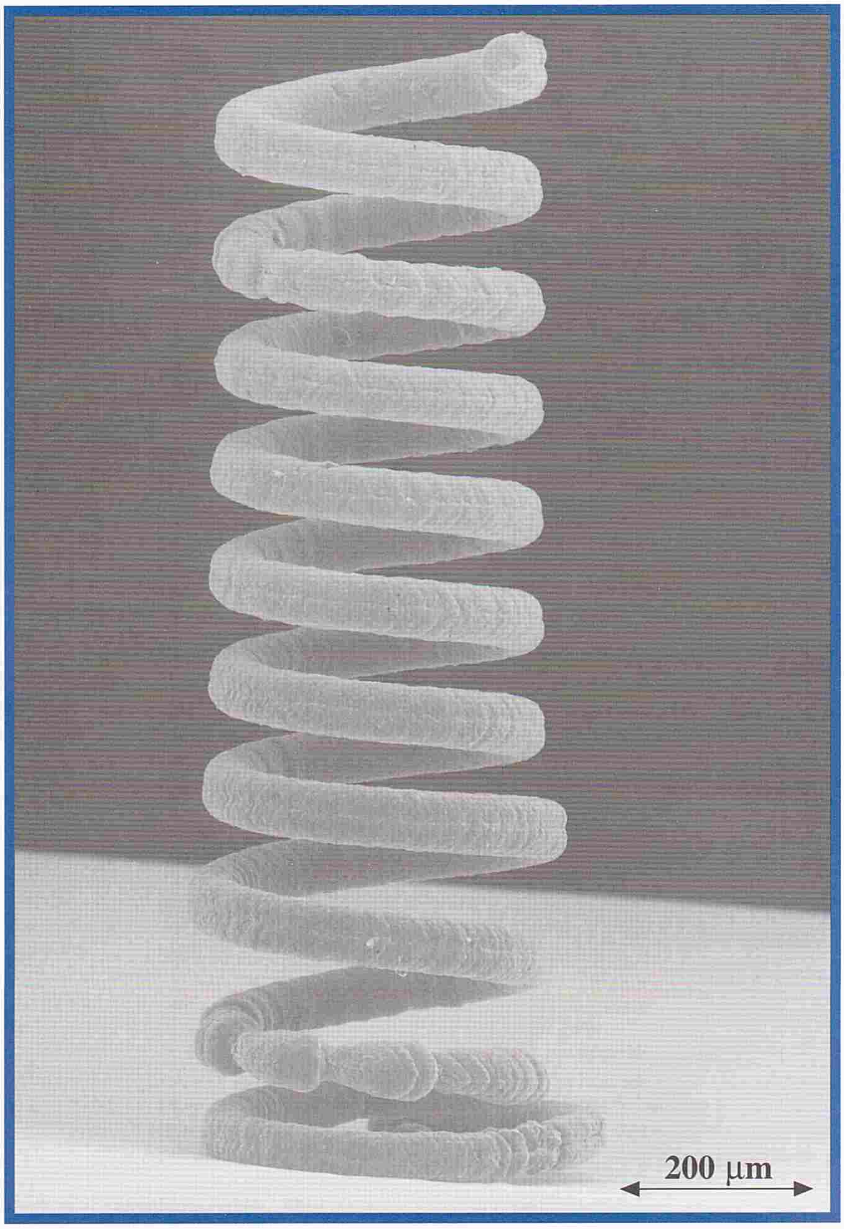
Eurosensors, the annual european conference on physical and chemical sensors, was this year held in Budapest, Hungary. This was the first time the conference was hosted by a former eastern country. Ever since the start in 1987, *Eurosensors* has grown each year. This time 145 oral presentations and over 300 posters were accepted. Two reasons for this large amount of contributions were that *Eurosensors* this year opened its arms to the former east, and the fact that almost every single contribution was accepted.

Many excellent sessions were held on topics such as micromachining, optical and radiation sensors, chemical and electrochemical sensors, biosensors, intelligent sensors, and pattern recognition.

Next year the conference will be held in Toulouse, France. The year after it is combined with *Transducers '95* in Stockholm, Sweden.

All contributions from Sweden (7 from Uppsala, 1 each from Chalmers, Chalmers/KTH and LiTH) were accepted at Transducers '93 in Japan. The total acceptance rate for Europe was 49%.

MST at Uppsala University



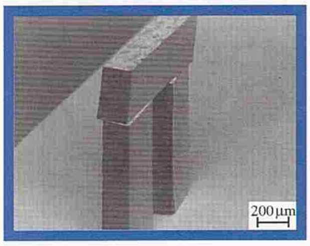
Boron helix grown by local chemical processes

Uppsala University started working with micromechanics in 1984, when Prof. Bertil Hök joined the Department of Technology. The MST-program now involves 1 Prof., 1 Assoc. Prof., 5 full-time PhDs, 3 part-time PhDs, and 9 graduate students, and is the biggest and most well-established MST-research team in Sweden. The team represents more than 100 years of full-time MST-experience, out of which some 70 years are MST-research. This has resulted in more than 80 publications in scientific journals, 55 conference contributions, 10 PhD theses and 4 MSc theses since 1988.

Organisation

Micromechanics at Uppsala University takes place primarily within the Departments of Electronics (Adj. Prof. Bertil Hök, phone: 021-80 00 99, fax: 021-80 10 09) and Materials Science (Assoc. Prof. Jan-Åke Schweitz, phone: 018-18 30 89, fax: 018-50 55 95). The two departments collaborate extensively and usually appear as one entity within the field of MST. They also work together with other related departments in their immediate vicinity.

The multidisciplinary nature of MST implies that R&D in materials and processes are natural components in the development of all devices/ systems.



Micro arch bonded in-situ in an SEM.

Research Targets

The fundamental research targets at Uppsala University involve: 1) basic physics and technology of microfabrication, 2) characterisation of material properties relating to mechanical microstructures, and 3) theoretical modelling of micromechanical elements and micromachining processes. Bulk and surface micromachining of silicon dominates, but in some major projects within the group, microstructures in gallium arsenide and quartz are also being investigated.

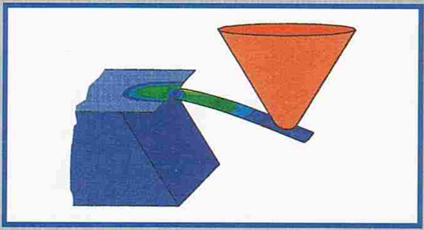
The applied research activities focus on physical sensors for biomedical applications, microfluidics, and optronics. Speculative device concepts are pursued by theoretical analysis, prototype implementation, experimental verification of basic characteristics, and field tests. The laboratory is adequately equipped for prototype fabrication, and experimental device evaluation.

External Contacts

Collaboration takes place with several other Swedish and foreign universities, both in terms of project activities and in terms of exchange of research personnel. Numerous Swedish companies and industries are involved in project activities within the group. The group is also involved in two EEC collaborations, and NUTEK has recently granted funding for the planning of a Center of Excellence in Micromechanics at Uppsala University.

The Micromechanics group is amply represented in the steering and program committees of international conference series, as well as in the editorial boards of international scientific journals. The most prestigious international conference within MST, the biannual *Transducers*, will be arranged in Stockholm in 1995, with the Uppsala group heading the Program Committee. ■

RESEARCH PROFILE



Materials characterisation in-situ in an SEM, evaluated by FEM.

Materials technology and analysis

- Cross-sectional TEM investigation of surface layers and interfaces.
- Testing mechanical micro-strength in-situ in an SEM, e.g. bond strength.
- Microtribology testing in-situ in an SEM.
- Determination of thin film properties by micromechanical technique.
- Simulations by FEM technique.

Process technology

- Voltage controlled, dopant selective etching of silicon.
- Field-assisted (anodic) bonding of glass/Si and ceramics/Si.
- Direct Si-to-Si (fusion) bonding, aiming at lower process temperatures.
- Bulk micromachining of quartz.
- Surface and bulk micromachining of GaAs.
- Sacrificial layer technique in the GaAs-AlGaAs system.
- Truly 3-dimensional microstructures by laser-assisted CVD (selective deposition and etching).

Device technology

- Fiberoptic beam splitting and multiplexing.
- Ultraminiature pressure sensor for intravascular use (0.35 mm outer diameter).
- Capacitive pressure sensor for intraocular measurements.
- Non-return microvalves for pumps and other microfluidic applications.
- Angular rate sensor and resonance structures in micromachined quartz.
- Sensor and actuator structures in GaAs.
- 3-dimensional micro-electromagnet by LCVD technique.
- Development of a generic microrobot system for use in-situ in an SEM (probing, testing, assembly, repair...).

DISSERTATIONS

Recent Dissertations

MSB congratulates Klas Hjort on successfully having defended his thesis *Gallium Arsenide Micromechanics* on October 8th, 1993.

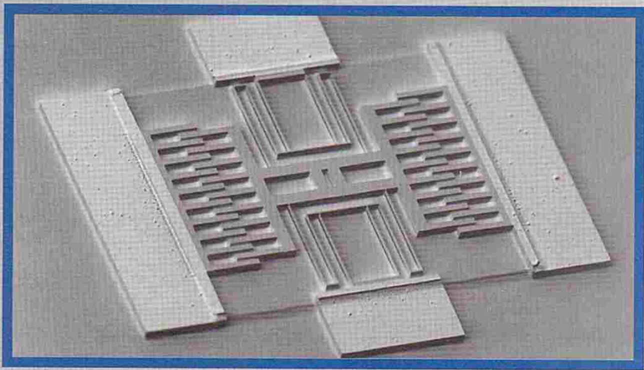
Hjort's thesis comprises studies on GaAs micromechanics, from basic materials studies and microprocessing to device technology. The main objective of the thesis is to demonstrate that most structures achievable by micromachining in silicon are also achievable in GaAs, and that GaAs offers superior possibilities in some applications. The thesis gives comprehensive surveys over GaAs as a mechanical material, and microprocessing of GaAs. In a series of papers, some mechanical properties and microprocessing techniques of GaAs are specially studied to provide necessary information for micromechanical design in the material.

Coming Dissertations

Two additional dissertations in the field of MST was held in Uppsala on December 10th, 1993:

- Silicon microstructures: fabrication techniques and applications, by Leif Smith.
- Micromechanics – fabrication processes and fluid components, by Ulf Lindberg.

Their work will be presented in the next issue of *MSB*.



Surface micromachined actuator in GaAs

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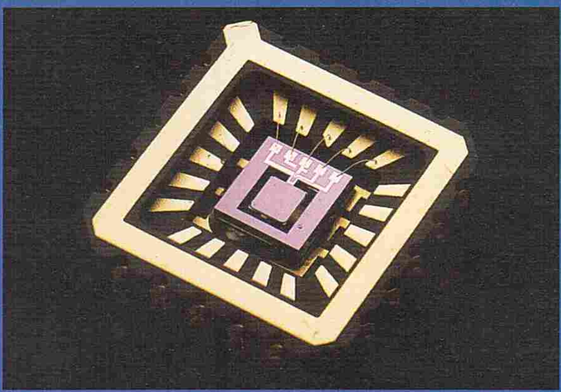
NEXT ISSUE



Some topics in the next issue will be:
- a micromachined silicon accelerometer
- basic etching techniques
- Industrial MST

NEXUS

NEXUS, the European MST-network for universities and industry, has produced a 12-minute video introducing MST.

FUTURE EVENTS

MSW '94 (Micro Structure Workshop) in Uppsala, Sweden, March 1994. A Swedish informal workshop for MST. For information contact: Jan Söderkvist (+46 (0)8-510 116 49) or Ylva Bäcklund, Uppsala University (+46 (0)18-18 30 23, Fax: +46 (0)18 55 50 95).

Eurosensors VIII, in Toulouse, France, 25-28 September 1994. *Abstract deadline: January 15.* For information contact: Eurosensors VIII Secretariat, CNRS/ LAAS-7, Fax: +33-61 33 62 08.

MEMS '94 (Micro Electro Mechanical Systems) in Oiso, Japan, January 25-28, 1994. For information contact: IEEE MEMS-94 Workshop, c/o MESAGO Japan Corp., Fax: +81-3-3359-9328.

MME'94 (MicroMechanics Europe) preliminarily in Pisa, Italy, September 7-8, 1994. Organiser: P. Dario, ARTS Pisa.

Transducers '95 in Stockholm, June 25-29, 1995. For information contact: Carin Palm, Phone: +46 (0)18-18 31 48, Fax: +46 (0)18-55 50 95.

The aim of *Micro Structure Bulletin* is to promote micromechanics and micro structure technology. It constitutes one part of Uppsala University's effort to share scientific and technological information

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