MICRO STRUCTURE BULLETIN

Newsletter for Swedish Micro Structure Technology No.4 Nov 1994

Silicon Sensor Technology in Norway since 1960

A fully deployed air-bag for the driver.

An important area for MST based components is in automotive applications. Reliability, low cost, and the capability to withstand harsh environments are key features. Examples can be found in safety systems, including air-bags, ABS and ASR (acceleration slip regulation), and in pollution reduction, comfort systems (active and adaptive suspension), and engine control. Moreover, microsystems are dominating the competitiveness of automotive systems and of whole cars. The Norwegian industry is taking an active role in development and production in this area.

The semiconductor technology industry in Norway started at SI in 1960. Initially, the development of mechanical sensors was only a minor part of the total activity. In 1965, a silicon sensor with integrated piezoresistors was developed for pressure, force, and acceleration measurements. The same year some scientists left SI to establish Akers Electronics (ame) and continued the development on the silicon sensor. As a spin off from ame, SensoNor was established in 1985 as a company focusing solely on silicon sensors with emphasis on silicon micromechanics.

The silicon sensor originating from 1965 has been produced for a variety of different sensor applications. The first generation of air-bag accelerometers produced by SensoNor is one example. Orders for this accelerometer are already signed for production into the next century.

SensoNor is now supplying a variety of micromechanical sensors. The company has grown extensively in the past three years and is now the leading supplier of silicon accelerometers for automotive air-bag applications. At present they hold a share of 80% of the open world market.

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EDITOR'S NOTE

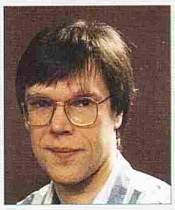
This issue ends the first full year of *Micro Structure Bulletin (MSB)*. The idea of a local MST newsletter was initiated at *MME* in September 1993. Work started immediately, and the first draft for *MicroNewsLetter,* (later changed to *MSB*), was finished within a week.

Is there a better way to celebrate the first year than to extend the authorship to other Scandinavian countries? Hence, this issue discusses Norwegian MST-activities. The success of SensoNor follows the saying "All companies start with an idea, often an invention."

The discussions at *MME '93* resulted not only in *MSB,* but also in a renewed interest in an informal meeting for those working with MST. This stimulated the creation of the first MST workshop in Sweden, *Micro Structure Workshop (MSW),* which was held this March. An important purpose of both *MSB* and *MSW* is to promote an industrial interest in MST.

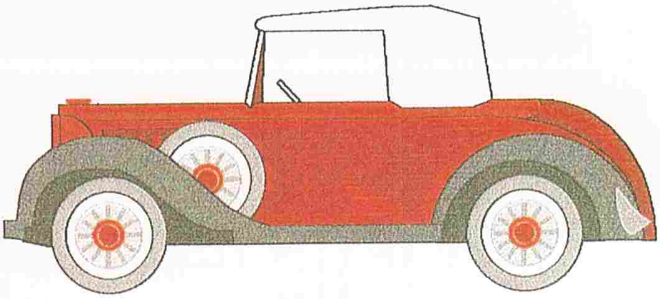
To follow up the *MSW,* Uppsala University announces two MST courses which will be held at the university in April, 1995. The European course, *Etching Technologies,* is co-ordinated by FSRM in Switzerland and *MikroStrukturKurs (MSK)* by Uppsala University.

Merry Christmas and a Happy New Year



Jan Söderkvist

SensoNor



Every year roughly 50 million cars are produced worldwide, with an estimated life of ten years. This means that, on the average, every tenth person in the world owns a car.

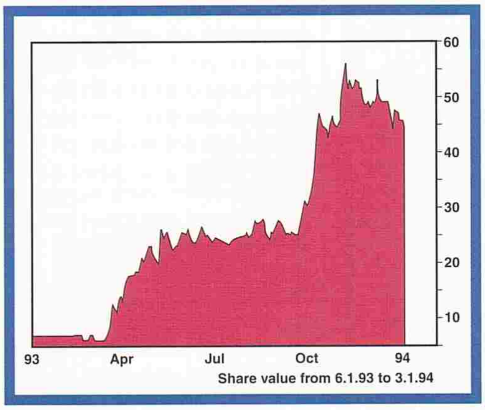
SensoNor has been involved in the development and small scale manufacturing of electronic sensors based on silicon sensor elements since it was established in 1985. In 1993, the company initiated the high-volume production of the electronic air-bag sensor, SA-20, a step that required a significant investment in equipment and personnel. The staff increased from 60 in January 1992 to 220 in January 1994. During 1993, the production rate increased with 500%. SensoNor is projected to deliver more than 5 million silicon accelerometers in 1994. Today, the wafer fab clean room facilities occupy 800 m^2, and another 200 m^2 will be added in 1995.

Although SA-20 is the major contributor to the present turnover of SensoNor, the company manufactures a large variety of electronic sensors for the measurement of pressure, force and acceleration. "SensoNor shall develop, manufacture and market sensors, preferably for high volume applications, based on silicon micromechanics technology", as expressed in their business plan. Presently, the company is developing new high volume products within their targeted market segments, the automotive and medical industries.

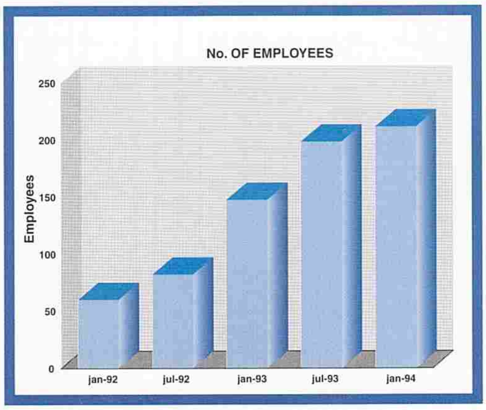
SensoNor intends to stay at the leading edge within silicon micromechanics. Important areas of competence are sensing principles and packaging. Based on a buried layer technology, SensoNor's piezoresistive pressure sensor series SP-80 excels in temperature and time stability. Within packaging, the injection molded thermo-plastic header of SA-20 was vital in the development of a competitive product.

The vigorous growth during 1993 resulted in a turnover of 13.1 million ECU, a 300% increase compared to 1992. The escalation in production, equipment, facilities, and work force resulted in a fiscal deficit in 1993 of 2.3 million ECU. Extensive resources are being put into development of new products for 1994, and the fiscal balance is expected to be already positive this year.

The laser printing of barcoded calibration data is one step in the automated production at Skoppum.



Growth in SensoNor's share value.

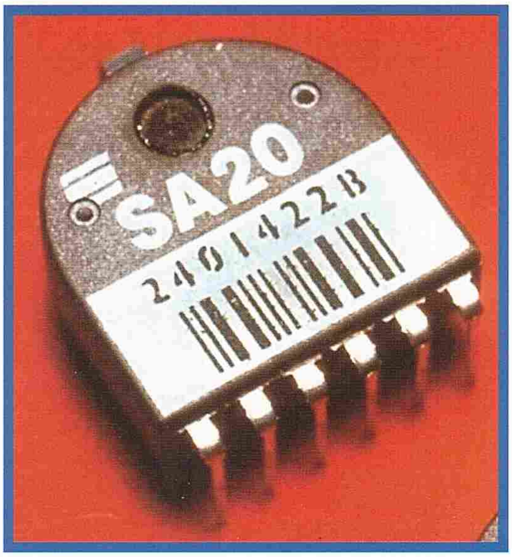


Number of employees at SensoNor.

SA-20
– a Result of 30 Years of Experience within Silicon Sensor Technology

SensoNor, a leading supplier of accelerometers for air-bag applications, is SINTEF´s major customer of micromechanical devices. The company was founded on the experience SINTEF (former SI) had obtained in the field of MST since 1960. More than 5 million SA-20 air-bag accelerometers are now in use, and so far, no malfunctions have been reported. SA-20 withstands an overload of 2,000 g, and has a ±50 g measurement range up to 400 Hz.

The sensor element is a silicon beam with an integrated piezoresistive bridge. The functionality of the beam is monitored continuously by an integrated diagnose resistor (patented). A symmetric mass is mounted automatically on the beam. This mass results in reduced cross axial sensitivity compared to integrated silicon mass elements. The sensor element is mounted into a plastic header by soft solder die attachment and the header is automatically oil-filled and sealed in one operation. The assembly line is based on a reel to reel system with each reel carrying 1,100 units. Both assembly and testing are performed by robot handling. All sensors are screened through temperature cycling, high temperature baking, and dynamic shock testing. A vibrating system is used for dynamic testing of each sensor and static tests are performed in the temperature range of –40 to +85°C. Resulting individual calibration data are bar coded and laser printed onto the sensor header.



A fully packaged SA-20 sensor.

Air-bags and Accelerometers

Automotive air-bags have dramatically reduced fatalities and severe injuries in traffic accidents. As a result, many car makers have decided to outfit all their cars with them within the next three years. One automotive manufacturer has introduced additional air-bags for side impacts. This has resulted in a huge demand for highly reliable low-cost air-bag systems.

Currently, most air-bag systems in production use several electromechanical crash sensors, acting as electrical switches, mounted at the front of the car. To trigger the air-bag, at least one crash sensor and a "safing" sensor must close. False deployment may occur since the crash sensors have a fairly low trip threshold and can be activated by road hazards such as potholes.

The new approach is to use a single crash sensor in the form of an accelerometer mounted in the passenger compartment. Using a sensor with a continuous output enables the system to use a more sophisticated decision-making algorithm, reducing the number of false deployments. Other advantages are a significant reduction in cost and increased system reliability. Micromachined accelerometers are ideal for these requirements.

Although the crash sensor is mounted far from the impact zone, its response will be rapid enough for head-on collisions. For side impacts, the crash sensor must be located closer to the collision zone. For head-on collisions, the system's goal is to activate the air-bag by the time the occupant has moved 13 cm. Response times shorter than 15 ms are needed in some situations.

MME'94, Pisa, Italy

MME (MicroMechanics Europe) is an annual workshop which started in 1989 at the University of Twente, The Netherlands. This year's *MME* was arranged in Pisa, Italy, as a two-day workshop with about 60 participants and 40 scientific contributions. The following are a few, from my point of view, noteworthy contributions:

P. Ohlckers from SINTEF gave an inspiring invited talk entitled *Batch Processing for Micromachined Devices*. He described the micromachined device technology as having matured into a separate industrial sector. Batch processing, which heralded the rapid development of integrated circuit technology, is still a bottleneck for MST. Ohlckers highlighted the most important batch processes, and stressed that batch processing is a key factor in order to increase performance and reduce costs.

T.A. Kwa from Delft University, The Netherlands, presented the poster *Effect of Solution Contamination on Etched Silicon Surfaces*. He discussed problems with contamination from stainless steel wafer holders during KOH etching. Silicon surfaces become very rough and dull under these conditions.

S. Valette, LETI, Grenoble, France, had an invited talk entitled *Micro-optics – a Key Technology in the Race to Microsystems*. He presented recent progress, including miniaturized light sources, bulk and surface optical components and miniaturized opto-mechanical devices. He described micro-optic components as important pieces of the puzzle leading to industrial microsystems.

Info on the next *MME* is given on the last page.

Ylva Bäcklund,
Uppsala University

European MST Courses

How can Europe strengthen its position in MST? Investing in research and developmental activities is certainly an important and necessary start. But in recent years, it has become clear that education and training also must be prime objectives.

The European Community recognizes the importance of courses and personnel exchanges. To promote such activities, the COMETT program was initiated (Community Program for Education and Training in Technology). As a result, the Swiss Foundation for Research in Microtechnology (FSRM) created UETP-MEMS (University Enterprise Training Partnership for Micro Electro Mechanical Systems) in 1992.

The main objective of UETP-MEMS is to increase the use of microsystems in the European industry. This is achieved by offering short, application oriented courses developed by leading European universities and institutes. Target groups are R&D engineers and industrial executives. The project is coordinated by the FSRM and is co-funded by COMETT, the FSRM and the Swiss Confederation.

In 1995, there will be 15 courses offered at various locations throughout Europe. Examples are: *Application of Microsystems in Biomedical Engineering and Bioscience, CAD Tools for MEMS, Engineering of Microsystems, Hands on MEMS, Packaging,* and *Resonant Microsensors.*

Uppsala University will host two courses in 1995 — *Etching Technology* in April and *Materials for MEMS* in December.

Further information is available from Annette Locher, FSRM, Switzerland, Fax: +41-38 24 71 45.

MST at SINTEF

Today the Semiconductor Technology Group at SINTEF consists of 20 people. The activities within the group are focused in two different areas: silicon micromechanics and silicon radiation sensors. The laboratory facilities includes a full 100 mm (4"), 3 micron silicon processing lab used for processing 3,000–5,000 wafers/year. There is also a micromechanics lab with different wet etching facilities and silicon wafer bonding equipment, and a device characterization lab using IEEE-448 bus system and LabVIEW software.

Strategy

The strategy within micromechanics is to:

- concentrate the basic research activities on a few critical techniques and processes such as mounting techniques, silicon wet etching, and process and device simulations.
- identify user/producer before starting device development.
- serve as a silicon sensor foundry for small and medium scale production and the development of micromachined silicon devices.
- carry out contract research in close co-operation with producers/users.

Running projects

Packaging of micromechanical devices often represents a bottleneck for successful product development. The packaging often degrades the performance of the device and individual handling adds substantially to the production costs. At SINTEF, the packaging problems are challenged from three different angles:

1) *By moving the transition between batch processing and individual handling to a later stage through process development* —SINTEF has developed a silicon-to-silicon wafer bonding process with high potential of application for both sensors and actuators, such as the bonding of mechanical stress isolating support wafers for pressure diaphragms. A field assisted glass sealing process uses a sputter deposited borosilicate glass as the sealing material.

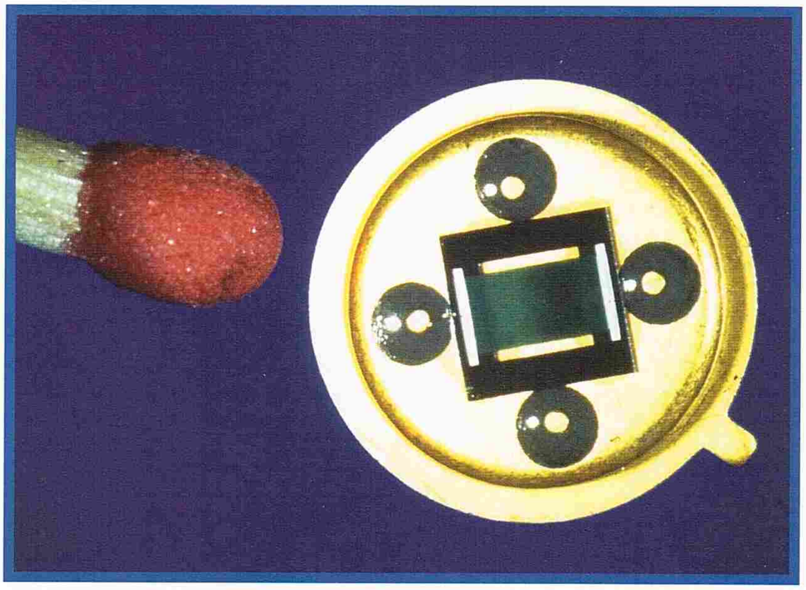
2) *By moving the transition between batch processing and individual handling to a later stage through new design* — To lower the future production costs of silicon hydrophones, SINTEF is developing a hydraulic filter using planar technology and wafer bonding.

3) *By developing and evaluating new materials and concepts for packaging of micromechanical components* — A plastic header formed in one piece, filled with oil and hermetically sealed, has been developed by SINTEF and SensoNor for use in SA-20.

An increasing effort is now being made in the mechanical

From the pioneer-period showing a home made diffusion furnace.

SINTEF as a Silicon Sensor Foundry – An Electrically Chopped IR-Source



Electrically chopped solid state IR-source.

SINTEF serves as a silicon sensor foundry for national and international customers. One example is an unique solid state IR-source that is produced for Simrad Optronics. The device is used for detection of CO_2 and hydro carbon gases for offshore applications and N_2O for medical applications. The gas sensors are able to detect concentrations of a few ppm. Rapid response of the gas detector is obtained by a high frequency electrical chopping of the source. With an emittance of 0.2 W/cm^{2}µm, a 20% modulation is obtained at 100 Hz. The source has a maximum emittance in the wavelength region of 2–4 microns.

simulation of silicon devices. One example is the design of a pressure sensor made for the range of 0 – 2,000 bar. The use of finite element analysis (FEA) has been a critical tool to optimize the performance of this device. The sensor is based on the Bourdon-tube principle using planar silicon technology (patent pending).

Silicon etching using EDP and KOH with electrochemical passivation is part of the standard process used by SINTEF in the production of micromachined silicon IR-sources for a Norwegian gas-sensor producer. New etches and methods are evaluated continuously to serve as alternatives to established procedures.

In condenser microphones, etched silicon diaphragms make it possible to produce microphones that have very small acoustic distortion. By controlling the initial mechanical stress by doping the material, 4x4 mm^2 diaphragms of thickness 1 µm have been made with resonance frequencies of 10–13 kHz for an initial stress of 10–15 MPa.

Anders Hanneborg

PUBLICATIONS

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

- A Light Controlled Optical Modulator in Silicon; Z. Xiao and O. Engström (CTH); *Proc. ESSDERC'94,* Edinburgh, U.K. (1994).
- Buried Cobalt Silicide Layers in Silicon Created by Wafer Bonding; K. Ljungberg, A. Söderbärg, A.-L. Tiensuu (UU), S. Johansson, G. Thungström and C.S. Petersson (KTH); *J. Electrochem. Soc.,* **141** (10) (1994) 2829–2833.
- Continuous Ink-jet Print Head Utilizing Silicon Micromachined nozzles; L. Smith, A. Söderbärg (UU) and U. Björkengren (LU); *Sensors and Actuators A,* **43**(1–3) (1994) 311–316.
- GaAs Low Temperature Fusion Bonding; K. Hjort, F. Ericsson, J.-Å. Schweitz (UU), C. Hallin and E. Janzén (LiU); *J. Electrochem. Soc.,* **141** (11) (1994) 3242–3245.
- Hardness, Internal Stress and Fracture Toughness of Epitaxial $Al_xGa_{1-x}As$ Films; K. Hjort, F. Ericsson, J.-Å. Schweitz (UU), C. Hallin and E. Janzén (LiU); *Thin Solid Films,* **250** (1994) 157–163.
- Piezoresistive Silicon Microphones for Turbulent Measurements; E. Kälvesten (KTH); Licentiate thesis, *TRITA-IL-9402* (Sept. 1994).
- Silicon on Aluminum Nitride Structures Formed by Wafer Bonding; S. Bengtsson, M. Choumas, W. Maszara, M. Bergh, U. Södervall, C. Olesen (CTH) and A. Litwin (Ericsson Comp.); *Proc. IEEE Int. SOI Conf.*, Nantucket Island, MA, U.S.A. (Oct. 1994) 35–36.

SINTEF

The SINTEF Group performs contract research and development for industry and the public sector. The Group is the largest independent research organization in Scandinavia with a turnover of 184.5 million ECU in 1993. It's projects are primarily in the technological fields. Nevertheless, it is active also within the natural sciences, social sciences and medicine. The Group serves both Norwegian and foreign clients.

SINTEF (Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology) merged on January 1, 1993 with SI (Centre for Industrial Research) in Oslo. SI is now an integrated part of SINTEF. The Semiconductor Technology group at SINTEF is located in Oslo, at the former SI site. It's focus is on microsystems together with the ASIC (application specific integrated circuit) and microsystem packaging groups.

Micromachining Basics Part 5: Simulations

Reliable components are essential for the industrial development of MST. Understanding the functionality and optimizing performance are other key factors for success. Unfortunately, necessary testing and visualizing with standard diagnostic methods are difficult on a small scale.

To reach desired behavior, effort must be spent in the design phase on making the structure tolerant to parameters whose effects are difficult to test. In addition, parameters which are feasible to test in the macro world should be identified. Therefore, simulations and model testing are essential tools for MST.

Similar reasoning applies to very large structures. The well-known failure of the Tacoma Narrows bridge in Washington State, U.S.A. is an excellent example of this.

Simulation Programs

There are many modern software tools well suited for simulations. An advantage, as well as a disadvantage, of their user-friendliness is that they often can be used with little or no prior knowledge of the underlying phenomena.

For microelectronics design, the use of the programs Spice (electric circuitry) and Suprem (semiconductor process simulations) is well-established. There are ongoing developmental efforts aiming to improve etch simulators for mask design. A complication in MST is that etched structures often differ significantly from the pattern on the mask (*MSB 94:1*).

Some software tools specialize in differential equations, such as Matematica and Matlab. They can be used for most applications that can be described in terms of equations, for example in control systems.

An excellent complement is symbolic math software tools, such as Derive, Macsyma, Maple and MathCad. For instance, MathCad offers a user-friendly windows-based environment which is literally an advanced and well-organized scratch paper with the potential to use electronic versions of scientific handbooks.

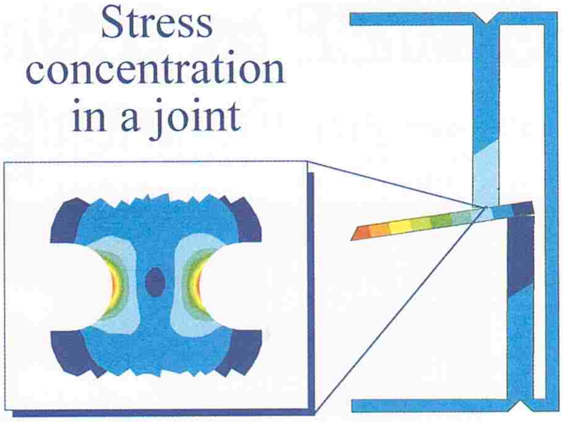
Simulations are of interest not only in the design phase. Commercial software packages are emerging that enable you to design and simulate semiconductor factories in your computer. Such models can be used for everything from making daily operational decisions to convincing upper management how to build the next module.

Finite Element Analysis

Finite element analysis (FEA) is more general, involving the division of a complex structure into many small elements. The governing equations for the desired phenomena are then applied to each element. This transfers the problem into standard algebra with numerous similar equations. Obviously, this technique has only become practical with the advent of modern computing systems.

There are several commercially available FEA programs, such as Abaqus, Ansys, Cosmos and Nastran. They provide sophisticated modeling capabilities for structural, thermal, electrostatic, magnetic, fluid and other problem applications. Additional capabilities, include dynamic simulations and design optimization on anisotropic and nonlinear materials.

An important step towards the user-friendliness of popular Windows-based programs is to improve the user-interfaces of FEA programs. As an example, a new graphical user interface based on the X/Motif and Windows NT environment was recently presented for Ansys. The interface, multiple capabilities, and reliability are some reasons why Ansys is one of the most widely used FEA programs.



FEA used to evaluate stress concentration in a micromachined structure

Clearly, FEA is no longer a tool used only for special applications by a limited number of experts.

When to Use Simulations

There are many situations in which simulations are useful:
- to understand functionality
- to study design alternatives
- to determine performance
- to optimize performance
- to determine reliability
- in troubleshooting

For feasibility studies, it is important to obtain a rapid response. The question is more *if,* rather than *how well,* the structure works. Rough approximations and coarse models are therefore appropriate. A more accurate model may be needed once the proper design is identified.

The change in output resulting from small variations in the input can be used for numerical variational analysis. An indication of the reliability of the component can thus be found. Including a temperature dependence of the material constants reveals the temperature behavior of the device.

Simulations can be used for testing almost any feature. Another example which may be of interest involves the simulation of nonlinear effects. The effect of large deflections and compressive stresses, and the dependence of resonance frequencies on the loads can thus be determined.

Thermal and electrostatic simulations are also of interest for MST components. Some examples are: thermal gradients, capacitances, leak currents, and nonlinear deflections induced by electrostatic forces.

Guidelines

It is important that simulations are calibrated with experimentation or with "handbook solutions". This process not only increases the confidence in the model, but also usually improves one's understanding of the operation of the device.

A model should not be built with higher accuracy than needed. This makes the simulations more time-efficient. For instance, less active geometric areas can often be identified. In addition, it is not advisable to strive for higher accuracy than the accuracy of the input, including the material parameters.

For FEA, an understanding of FEA techniques is helpful in obtaining accurate results within a limited budget and time-frame. This is in contrast to many other types of programs for which it suffices with a knowledge of how to run the program.

Summary

If correctly carried out, simulations can dramatically increase understanding, reduce the number of experimental steps, reduce cost, and increase reliability and performance. If not, the least damage is a reduced confidence in simulations at the management level.

At last, do not forget that pen, paper and common sense can solve more problems than you expect!

Jan Söderkvist

Research Funding

Europe

In December, EU is expected to announce the 4th framework program for 1995–98. It will provide a sum of 10.7 billion ECU for R&D in areas such as information and communication technologies, industrial and materials technologies, and life science technologies. The deadline for proposals is expected to be in mid-spring.

The opportunities for support to MST are manifold. Three main objectives will be: stimulation of microsystems applications, enhancement of the technology base, and long term research.

As for previous calls, it is important that the proposals involve geographical and industry-academia well-balanced consortia. NEXUS, the European network for MST, provides one possibility for finding suitable partners. NEXUS will be presented in next issue of *MSB*.

Japan

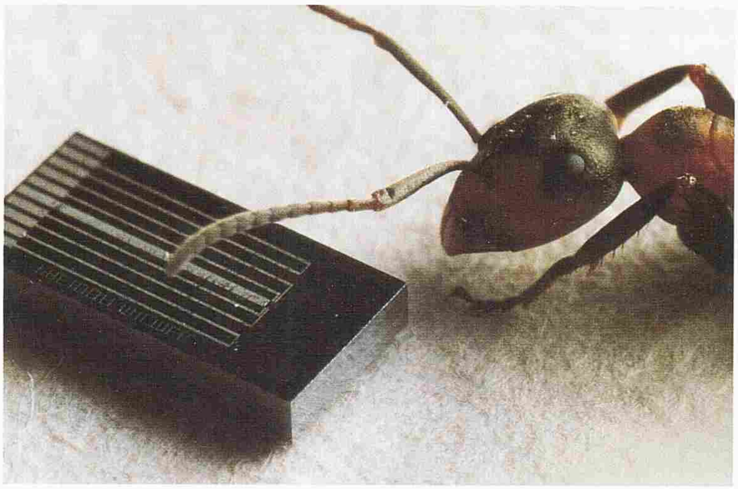
The market for sensor systems in general is considered as one of the most dynamic ones. The overall market volume was estimated to be more than $15 billion in 1991. This figure is expected to triple by 1995.

To meet this rapid increase in demand, the Ministry of International Trade and Industry (MITI) in Japan launched the "Micromachine Technology" program in 1991. This is a ten-year R&D project, under the Industrial Science and Technology Frontier Program, with a total budget of about $250 million. Funding also comes from the Ministry of Education and the Micromachine Research Center (MMC). Together with MITI, these sources amount to $25 – 35 million annually.

Japanese industry is also very interested in MST, and spends between 45 and 70 million dollars per year on this sector.

DISSERTATIONS

MSB congratulates Edvard Kälvesten on successfully having defended his work for the degree of Technical Licentiate on September 16 at the Royal Institute of Technology (KTH).



The silicon microphone beside a wood ant – formica rufa (Photo: Hans Sohlström).

The area of Kälvesten's work is well described by the title of his thesis, *Piezoresistive Silicon Microphones for Turbulence Measurement.* This piezoresistive microphone, with a diaphragm side length and thickness of 100 µm and 0.4 µm, is equipped with a special vent channel for equalization of the static pressure between the cavity and ambient. The small diaphragm makes it possible to resolve and measure the smallest pressure eddies in a turbulent flow. The acoustic sensor shows a pressure sensitivity of about 0.9 µV/Pa and a corresponding noise level of 90 dB(A).

Center of Surface and Microstructure Engineering

Sweden must concentrate on the creation of R&D environments which strengthen our industrial life. Such environments can benefit from the EU programs, and also enable strong new areas to develop. This is how the deputy director of the Swedish National Board for Industrial and Technical Development (NUTEK), Christer Heinegård, describes the intentions behind the proposal of thirty *centers of competence* put forward to the Swedish government. Universities, research institutes and industry must co-ordinate R&D activities in order to keep down costs, which are often substantial in areas of high technology. The basic idea of a center of competence is that the desires and needs of industry should have a strong influence on the work at the center.

One of the proposed centers is the Center of Surface and Microstructure Engineering which is a joint proposal from Uppsala University and the Royal Institute of Technology (KTH). Interested parties from industry include Ericsson, Pharmacia and Sandvik Coromant. According to NUTEK's recommendations, the Center should focus on microstructure engineering. The overall goal is to establish and maintain Swedish competence within the area of surface and microstructure engineering and to facilitate the implementation and use of new technologies. The Center will formally be affiliated to Uppsala University and also have a geographic center of gravity in Uppsala. Of course, a center of this kind, being based in the university world, must rest firmly on basic research. How this is planned to be carried out, and in which specific areas the Center will be working, will be reported in future issues of MSB.

Anna-Lisa Tiensuu,
Uppsala University

POSTTIDNING B

MICRO STRUCTURE BULLETIN NO.4 NOV 1994

Interested in MSB (✉ or ✂)?

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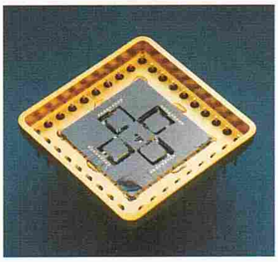
NEXT ISSUE



Some topics covered will be:

- MST at Chalmers University of Technology (CTH)
- The Samba Sensor
- Bonding
- The European MST-network NEXUS

FUTURE EVENTS

MEMS '95 (Micro Electro Mechanical Systems) in Amsterdam, The Netherlands, Jan. 29–Feb. 2, 1995. For information contact: Ms. J. Spierenburg, BASICS, Fax: +31-53 356 770.

Transducers '95 • Eurosensors IX, see separate note.

MME '95 (MicroMechanics Europe) in Copenhagen, Denmark, Sept. 4–5, 1995. For information contact: Prof. Otto Leistiko, Fax: +45-45 88 7762.

MSK '95 (Mikro Struktur Kurs) in Uppsala, Sweden, April 27, 1995. Language: Swedish. For information contact: J. Söderkvist, Fax: +46-8 510 116 15.

Etching Technology (course), Uppsala, Sweden, April 25–26. For information contact: FSRM, Switzerland, Annette Locher, Fax: +41-38 24 71 45.

Sensor 95, Nürnberg, Germany, May 9-11, 1995.

49th IEEE Int. Frequency Control Symposium, San Francisco, USA, May 30–June 2, 1995.

THE AIM OF the *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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