MICRO STRUCTURE BULLETIN

Newsletter for Nordic Micro Structure Technology, Vol.6, No.3, Aug 1998

MST-Friendly Environment

Today's experimental research in Materials Science often involves material manipulation on an atomic to µm scale. High quality work requires a well controlled laboratory environment, in areas such as temperature, humidity, vibration, and particle contamination. In the absence of this specialized environment, it would be difficult to reach reliable and reproducible experimental results. The newly inaugurated Ångström Laboratory at Uppsala University was projected with this in mind.

Many of the process steps used in micromachining involve wet chemical processing. Small particles in the chemical solution and, perhaps even more important, on the surface of the etch bath tend to stick to the surface of the sample as it is pulled out of the chemical bath. Even very small particles on the surface of a sample can seriously affect processing steps such as bonding. Particle contamination on the surface and in narrow gaps can also degrade the function of small devices.

Researchers does not often require as high a yield as does industry. Nevertheless, their requirements regarding the control of atomic sized contaminants can be stricter. A cleanroom is essential for controlling particles of sizes down to the atomic level.

Courtesy of IMC, Sweden.

Relative humidity, temperature and external vibration are also essential to control for the success of experiments. For example, the development of new high quality thin films with highly interesting combinations of properties requires good control of the relative humidity.

Analytical tools, such as high resolution transmitting and scanning electron microscopes (TEM and SEM), various optical and mechanical profilometers, and atomic force microscopes (AFM) are all instruments with high demands regarding a vibration free surrounding. To guarantee high resolution, their suppliers often set very specific requirements on the surroundings.

The Ångström Laboratory contains a state-of-the-art laboratory for scientists to use in their research on micromachining, microelectronical devices, and thin films. The laboratory is run by a steering committee with Dr. Anna M. Barklund as the coordinator of the common research facilities. Today, around 100 scientists from six different research groups have access to the cleanroom.

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The Ångström Laboratory Cleanroom

The major part of the 2,000 m^2 cleanroom of the Ångström Laboratory is classified as 10,000 (particles >0.5 µm per cubic foot of air). 150 m^2 is constructed as a class 100 cleanroom with unidirectional airflow from the ceiling to the floor. Smaller areas with an even higher degree of cleanliness, such as class 10 or class 1, are possible. The temperature is stable within ±1 °C. The relative humidity is held constant at 43±3 % in one third of the cleanroom. The vibration-free foundation (700 m^2), with its unique and unconventional construction, performs twice as good as specified, and is classed as BBN-E.

CONTENTS

EDITOR'S NOTE

We are all too well aware of that time passes fast. Five years have now passed since *MSB* was founded. This means that *MSB* existed before most of today's PhD students started their research. I am pleased that 19 out of the 20 published issues have included a dissertation column.

The current issue features the beginning of an article series presenting micromachining-related processing equipment. The newly inaugurated Ångström laboratory is the largest university-based cleanroom in Scandinavia that is partly targeted towards micromachining. New state of the art equipment has been installed, and the competence has been increased even further. The article series will, therefore, be presented using the Ångström Laboratory as an example.

Looking at the contents of future *MSB*s reveals that many interesting topics will be featured in the next few years. There will be an increased focus on application areas. The last issue next year (the 25th issue) will feature articles that look into the next century.

Jan Söderkvist

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Micromachining Applications Part 2:
Medical Applications of Microsystems

The current medical market for microsystems is dominated by one product: the disposable blood pressure sensor. Although there is a high level of research and development effort, the market is expected to develop slowly because of the particular problems inherent in medical applications. These include:

- Need for clinical testing
- High degree of legislation concerning manufacturing and testing of clinical products
- Threat of litigation from patients
- Biocompatibility of device packaging

Nevertheless, the potential benefits in terms of an improved quality of life and commercial returns provide a strong incentive for continuing development.

One of the key factors for success will be the formation of multi-disciplinary teams including both medical and engineering professionals. The main growth areas are projected to be in improved hearing aids (inner ear devices) and sensors for biomedical analysis, including DNA. Longer term markets (more than 5 years from now) include drug delivery systems, intravascular imaging systems and nerve stimulation (restoring limb function). Slower developing markets include cochlear implants (because of the limited number of trained surgeons) and minimally invasive surgical tools.

Key Features of Microsystems

Many new products are under development that will utilize the inherent advantages of MST:

- Low cost devices produced by mass production techniques from the semiconductor industry. Disposable products can reduce the costs of sterilization and the risks of cross infection.
- Low power dissipation. This is essential for implanted devices to give long battery life (or for the possibility of biologically powered devices). It is also beneficial for portable equipment which might be used for patient monitoring, therapy or stimulation.
- Integrated systems can be produced which have improved reliability.
- Small size and weight. This is important not only for portable equipment, but also to allow the measurement or stimulation to be carried out at the exact desired point of the patient's body, even within internal organs.

Applications

The main areas of application of the technology can be classified as follows:

Diagnostic systems for clinical use: This category includes both invasive devices (such as catheters, ultrasound intravascular diagnostics, and angioplasty techniques), as well as non-invasive measurements (such as electrocardiograms).

Diagnostic systems and medication management for home use: Examples are airflow measurement (for asthmatics), glucose measurement for diabetics, and other devices which can measure body fluids, electrical activity, temperature, pressure or flow. Such measurements might be transmitted for remote monitoring or used to directly control drug or medication delivery.

Drug delivery and pumping systems: MST enables the control of fluids at the nanolitre level. This will facilitate better control for external drug delivery and enable internal implantable drug delivery systems. Such internal or external systems could be controlled by telemetry or integrated monitoring/ diagnostic systems.

Monitoring and control at point-of care: This category of application includes point-of-care testing of parameters such as blood gases, pressure, control of dialysis, movement monitoring and position monitoring. The measurements could be used to control treatment.

Functional electrical stimulation: Electrical stimulation can be applied externally (e.g. for pain relief or external muscle stimulation) or internally (heart pacemaker, vagus nerve stimulation for epilepsy, bladder control, limb function restoration for paraplegics).

Prosthesis/artificial organs: Perhaps the largest application of microsystems will be in improved hearing aids (see page 4) and the restoration of hearing to those with profound deafness by inner ear implants or cochlear implants. The performance of artificial limbs can al-

Application	Estimated market size per annum	MST Advantage
Cardiac Pacemakers	$ 500 M +	Improved function
Cochlear Implants	$ 15 M +	Small size
Implanted Hearing Aids	$ 200 M	Small size
Hearing Aids	$ 500 M	Improved function
DNA Analyzers	$ 300 M +	Speed of analysis
Catheters	$ 350 M	Small size, improved function
Infusion Pumps	2 M units	Improved control
Implantable Pumps and Drug Delivery Systems	10 k units	Improved control, small size, low power
Blood Pressure Sensors	$ 170 M	Small size, accuracy
Blood Analyzers	$ 1,000 M +	Speed of analysis, small sample

Some potential medical applications for microsystems (M=million).

so be improved by active limbs which incorporate transducers and actuators.

Analysis systems: Genetic tests and a wide range of analytical measurements will be enabled or speeded up by microsystems.

Minimally invasive surgery: MST will impact both sensing (improved visual and physical sensing) as well as manipulation and surgical techniques (cutting, ablation, sealing).

Market Dynamics

The factors influencing microsystem applications in healthcare are mainly the drive to reduce healthcare costs and the need to prevent faulty diagnosis or treatment which could result in litigation. Microsystems technology and IT in general present many opportunities to address these needs, not only for the large multi-nationals (e.g. pharmaceuticals companies, pacemaker manufacturers) but also for a wide base of SME’s with innovative product ideas. The former have the resources to develop MST themselves, whereas the latter will need to adopt technology which may come from other application areas (e.g. blood pressure sensors originally developed for the automotive industry).

Overall, Europe is in a strong position to exploit MST technology in medical applications because of the solid R&D base in its institutes and universities and the leading position of many product manufacturing companies in such areas as pacemakers, hearing aids, drug delivery systems and cochlear implants.

Market Size and Factors Affecting Market Growth

Frost and Sullivan estimated that the value of the medical microsystems market was $278 million in 1993/4. This market has remained more or less static since 1993, the only high volume products being blood pressure transducers, which represent a $170 million market. However, of the $10 kit only about $1.50 is for the disposable blood pressure sensor.

There are many good ideas for new medical products, but there are many reasons why such products never get into commercial production. The medical market has many difficulties. Some of these are summarized below.

All new products have to be clinically tested. This is primarily to prove their appropriateness and safety. Such testing can take a very long time. All clinical testing has to have ethical approval from the trusts and organizations that own the hospitals and clinics where testing has to take place.

There is a huge amount of legislation relating to clinical products. This legislation concerns the way in which the devices are manufactured to ensure safety and testability. Typical of the organizations that have the powers to approve new products are the FDA in America and the MDA in the UK. From their inception, products must be designed to meet the stringent needs of this legislation.

The ever present threat of litigation from dissatisfied patients has discouraged many companies. Often the technology provider is an easier target than the medical profession. Only the very large players can weather this risk, and it is interesting to note that all existing pacemaker companies have more than $1 billion turnover.

Biocompatibility has to be proven for both implanted devices and for those that come in contact with the skin or other tissues.

There is a universal need to reduce healthcare costs. Markets are therefore only lucrative for products that meet specific needs and that are cost effective.

Any implanted system has to be highly reliable in an environment that is exceedingly hostile. If it needs to be powered then its power consumption must be minimized by good design, allowing for long periods between battery replacements. If communication is required with the implant then power consumption will become an important aspect of the design.

One of the greatest difficulties found by manufacturers is that of clinical acceptability. Clinicians are neither scientists nor technologists. Therefore, they often have great difficulty in accepting the advantages of a new technology, and this makes it difficult to motivate them to investigate new methodologies or even go on training courses once the methodologies have been generally accepted.

In addition, the products often need small volume production runs that are not readily integrated into the work schedules of silicon manufacturing companies.

All of the problems and challenges described above can be overcome. The specific expertise needed is available in Europe, but is spread across many different organizations.

Businesses need to be able to team work, linking the medical professions with the engineering professions. All of the various professions speak different languages. The engineer is one of the few professionals well placed to act as the link between the different disciplines and to have an in-depth understanding of the needs of the patient.

Conclusions

Although the U.S.A. has captured most of the commodity market for disposable blood pressure sensors and blood gas analyzers, our assessment is that Europe is in a strong position for the future with higher value medical microsystems. Europe is at the forefront of research into smart catheters with in-built sensors, micropumps and valves, implants for functional electrical stimulation, and advanced hearing aids. However, European companies will have to be aggressive in the move to manufacture and market such devices if we are not to see the results of our leading research exploited by others.

One important factor which could improve the European position might be the financial resources to develop medical products available from Europe’s leading pharmaceutical companies, if they decide to get involved in microsystems.

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MME ’98

The aim of Micromechanics Europe (MME) is to promote research and collaboration, and to support further industrialization. The workshop is an excellent forum in which young scientists and engineers can present new results. *MME*’s informal and inspiring nature was this year further strengthened by the beauty of the *MME ’98* workshop location. Excellent opportunities for the participants to get acquainted were available during the boat cruise to the workshop site Ulvik at the shore of the Hardanger Fjord in Western Norway.

The more than 125 participants could enjoy a high quality scientific program that featured six invited presentations and 68 posters. The trends towards international collaboration and to shift focus from the basic micromachining toolbox towards more system related challenges and manufacturing issues were noticeable at this workshop. *MME ’99* will be held outside Paris, and *MME ’00* in Uppsala.

Microsystems for Hearing Instruments

A hearing instrument is a typical space-constrained multifunctional system and an obvious candidate for the employment of microsystems. It includes a range of transducers such as a microphone, a speaker, trimmers, switches, and a telecoil, as well as a battery and a signal-processing unit. Today, all of the components are miniaturized to a level where conventional precision machining is at its limit. Furthermore, there is a trend towards fully digital hearing instruments, which suggests smart transducers with integrated electronics containing A/D conversion, signal amplification, signal conditioning, and D/A conversion.

Microphones

Extensive work has been done towards the development of a micromachined microphone for hearing instruments, this being the more straightforward component that maybe derive the most benefit from microtechnology. However, there is no commercial product available as of today. Looking at the specifications, it becomes clear that microsystems are up against a mature and cost-efficient precision machining technology.

Microphones for hearing instruments have a power consumption of less than 50 µW, a sensitivity of more than 15 mV/Pa, an equivalent input noise level of less than 24 dBA, and a volume of less than 30 mm^3. They do not require biasing and sales prices are generally less than US$ 10. All attempts of even getting close to these requirements with a micromachined microphone have failed.

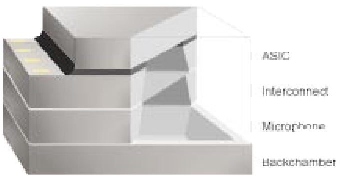
Points to Address

The two key points to be solved for the successful implementation of a micromachined microphone are to increase its sensitivity (related issues: decrease its geometric volume, noise, and power consumption) and to decrease the cost of production, including packaging. While the first point can be solved by developing new techniques, for example for controlling the membrane tension more accurately, the latter is a more complex topic involving many different aspects depending on the chosen technology and its market availability.

The high mechanical performance required excludes CMOS-based processing and pure surface micromachining. In addition, the single-chip integration of the signal conditioning circuitry is not practical since state-of-the-art ASIC technology is required as well for ultimate performance. However, the volume restriction demands tight integration, while the required low cost calls for standard processes and cost-effective packaging.

Microtronic's Approach

Microtronic A/S, Denmark, which delivers conventional transducers for about 20% of the world-wide hearing instrument market, decided to pursue a stacking solution in which silicon dies are stacked to achieve high technological flexibility and tight integration. The transducer part of the microphone is made by a combination of surface and bulk micromachining using standard polysilicon, silicon nitride, and silicon oxide layers on a silicon substrate, which is bonded anodically to a silicon backchamber. This two-chip stack forms a complete condenser microphone. Next, this is bonded to an interconnect chip containing the sound inlet and feedthroughs to the ASIC chip, which is flipped onto the mechanical stack. The packaging includes a polymer encapsulation for mechanical and chemical protection and electromagnetic shielding.



Concept of an integrated micromachined microphone for hearing instruments. The stack is shown with a corner cut and without its polymer encapsulation to reveal the inner structure.

The development of this device started within the Danish collaboration project Micro Systems Center (MSC, 1995–1999), in which Microtronic is supported by Mikroelektronik Centret (MIC/DTU) and the test and design house DELTA. The production of a demonstrator microphone in an industrial process line is planned for the year 2000. For this purpose, the European collaboration HISTACK, which includes Microtronic, MIC/DTU, DELTA, the Swiss microsystems foundry CSEM, the French research institute CEA/LETI, and the Italian manufacturer of ink jet print heads, Balteadisk SpA, has been created and funded by the European Commission under the ESPRIT program.

Why Micromachining?

The above discussion demonstrates that the total effort in developing a relatively simple micromachined transducer is great compared to the development of a conventional component. And, still, the benefits are not very obvious yet. However, as the infrastructure for the industrial application of microsystems technology is becoming clearer and the foundries are becoming more focussed and documented, it will be easier for future devices to be developed. Even in a conservative market such as the hearing instrument market, micromachined transducers will eventually be introduced and will generate a faster route to the market.

The microphone is, therefore, seen as the pioneer of the micromachined transducers for hearing instruments. Trimmers and switches, which are essentially position sensors, will follow quickly because of their simple construction. The telecoil, which is an antenna for low-frequency radio signals, can only be replaced by a microsystem with difficulty. The speaker is probably the most complex transducer in this application and requires still a lot of development with respect to an efficient actuating principle.

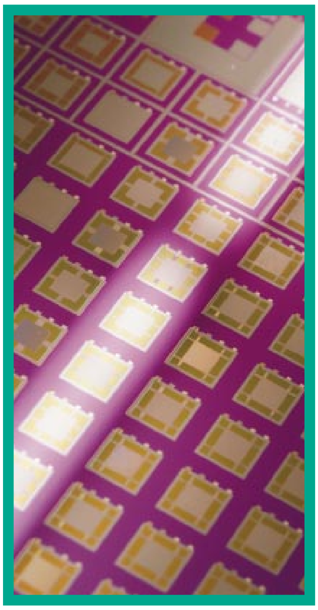


Photo of a wafer with silicon condenser microphones.

There is little doubt, however, that the future hearing instrument will contain a fully digital signal processing unit with digital connections to smart transducers which directly convert the analog environment to a digital signal and vice versa. Greater functionality will be applied to the hearing instrument e.g. by integrating sensor arrays for directional hearing. The inclusion of more powerful digital circuits will enable environmental and speech recognition that will be very useful for control purposes and communication, and for the suppression of environmental noise. The hearing instrument will definitely be more of a communication device than a prosthesis and will be empowered by microsystems, even if the development takes ten years.

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Micro Propulsion Thrusters Aim at Space

In a couple of years the first European nanosatellite will be launched. ACR Electronic and researchers within the Center for Advanced Micro Engineering (AME) at Uppsala University will contribute with microsystems to this and other space projects.

The use of microstructure technology (MST) can dramatically reduce a spacecraft's mass and volume at the same time that the technical performance in many cases is improved. As the main cost of launching satellites depends on its weight, the use of MST will also significantly reduce the cost of space systems.

The Micro Thruster Project

Satellites need stabilization to point in the desired directions for monitoring and communications purposes. Micro propulsion thruster systems will be an outstanding tool for the accurate attitude control of small satellites. They can also be used for the compensation of disturbances when very high pointing stability of a normal spacecraft is required.

A thruster project based on a system-oriented approach has been launched in Uppsala. The development project, which has a scheduled duration of five years, is financed by the European Space Agency (ESA).

The aim of the project is to manufacture thruster modules, each module containing four complete independent thrusters with a thrust-range from 0.1 to a few mN. The complete system will be accommodated on seven small circular wafers inside a pressure-tight housing in the shape of a 40 mm sphere. Four wafers are hermetically bonded together to a gas-handling module. In the module some micromachined components are integrated together to perform a system function. The total mass of the module is estimated to be below 10 grams. The other three wafers, which mainly contain control electronics, are in close but dismountable contact with the gas-handling module.


A nanosatellite in close encounter with an asteroid.

Gas Module Design

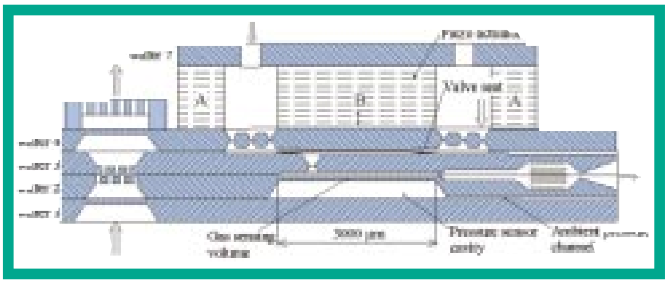
Each thruster contains a filter stack, a proportional valve, a nozzle, alignment structures and the interconnecting channels. All parts are micromachined using different methods as there is currently no other way to produce these miniature high precision components with the accuracy required (~1µm).

Five piezoelectric elements act as valve actuators in each valve. A center element (B in the figure) is bonded to the valve cap, which is a suspended part of wafer 4. The other four elements (A in the figure) are bonded onto wafer 4 in a ring configuration around the center element. The cap is lifted and the valve opens when the central part contracts.

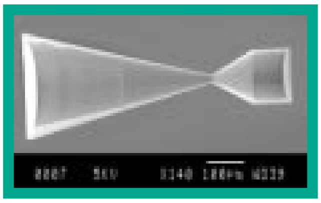
The gas flows through a short channel directly to the nozzle, on the way passing a small cavity that reduces the flow velocity across a differential pressure sensor. The pressure sensor signal is used in a closed loop in order to control the proportional valve.

No on/off switching is employed in the system due to pointing stability reasons. Thus, there is no such thing as a digital minimum impulse bit noise. Instead, the thruster noise depends mainly on the quality of the analog control signal.

The small top wafer (wafer 7 in the figure) contains some of the actuator control electronics.



Cross-section through the gas-handling block.


Laser-induced etching gives fine 3D-structures with high-precision and acceptable surfaces.

Nozzle

To deliver precise momentum, the thrusters exhaust minute amounts of cold gas through an exactly defined nozzle. This nozzle should be perfectly smooth and cone-shaped, not trivial requirements for silicon microstructures.

As the nozzle is the most critical part of the system several micromechanical methods have been tested, including anisotropic wet-etching, diffusion limited isotropic etching, and laser-induced etching.

Nozzles made at the Mikroelektronik Centret (MIC) in Denmark by laser-induced etching of a (100)-silicon surface in a chlorine atmosphere clearly gave the best result. The laser was used to locally heat and melt the silicon surface (see *MSB 96:3*).

The advantage of this technique is that it is independent of the crystal orientation and is not inhibited by the native oxide. The process is only limited by the gas-phase mass transport of the reactants and reaction products, and thus permits true 3D-structures to be crafted.

Nozzle Heater

According to the common gas theory, the thruster specific impulse can be increased significantly if the gas temperature is increased. The increased complexity of the nozzle when heaters are included is more than well motivated, in particular for interplanetary probes where every gram of saved fuel is of the greatest importance.

Conclusions

As we ponder the requirements for new types of miniature spacecraft designed to orbit around earth or to travel throughout our solar system and beyond, it is obvious that we must explore the full range of micro/nano technologies where the key technology is MST.

Once a few MST-devices have demonstrated success in real space missions, several more will follow enabling the possibility to create a new generation of small, but able, spacecraft. These vehicles will permit us to explore space much more efficiently and much more in depth than ever before.

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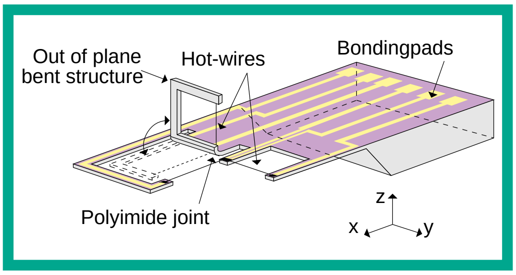
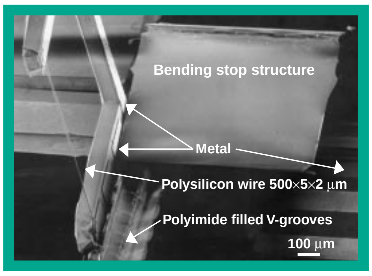
3-D MST Using Polyimide Joints



The 3-D hot-wire probe. The silicon chip size is 3.5 × 3 × 0.5 mm and the three wires are 500 × 5× 2 µm. The polyimide joint consists of 70 µm wide and 30 µm deep polyimide filled V-grooves.



SEM-photo of the z- hot-wire which has been out-of plane rotated by a three V-grooved polyimide joint. A bending stop structure rotated 180° stops the z-wire at exactly 90°.

Today we can see a rapidly growing interest in silicon micromachined sensors and actuators. Silicon micromachining offers possibilities for low-cost and highly miniaturized sensors. However, the planar nature of the photolithography technique makes it very difficult to realize three-dimensional (3-D) sensors with detailed features in all three directions. Batch and mass fabrication of true 3-D silicon structures is a key factor in future micromachining technology that could enrich the world with new 3-D sensors and actuators.

The MEMS-group at KTH-S3 has developed a new technique to fabricate true 3-D micro structures. To create a well controlled, out-of-plane rotation of a silicon structure a polyimide based micro-joint is used. The main advantage with this approach is that it utilizes conventional high-resolution surface lithography (with sub-micron features) while providing access to the third dimension. Other quasi 3-D techniques (e.g. anisotropic etching) usually have high resolution in the plane, but the resolution in the direction normal to the surface is poor. Different devices have been fabricated as demonstrators showing the potential of the new polyimide technique.

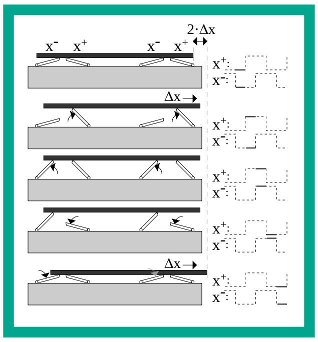
Polyimide Joint Principle

The basic principle of the new micro-joint is illustrated in the figure bellow. The absolute contraction length of the polyimide is larger at the top of the V-groove than at the bottom ($\varepsilon \cdot a > \varepsilon \cdot b$), which results in a rotation of the free standing structure out of the wafer plane. Different curing temperatures gives different polyimide shrinkage and different static bending angles, α.

The rather high thermal expansion of the polyimide together with the current through an integrated heater in the joint is used to achieve a dynamic movement of the structure.

3-D Flow Sensor

To demonstrate that the fabrication technique is compatible both with IC-based surface micromachining and with batch fabrication, a 3-D hot-wire sensor has successfully been fabricated. The miniaturized 3-D hot-wire probe is schematically shown above. The x- and y- hot-wires are located in the wafer plane and the third z-wire is rotated out of the plane using a robust, small radius polyimide joint. Flow measurements of the hot-wire have been performed showing attractive flow sensitivity and high signal to noise ratio. The hot-wires are sufficiently small to resolve the small eddies in a turbulent gas flow and the smallness also means small thermal mass and, therefore, fast response time.



Operation principle for the bi-directional 1-D micro conveyer with two sets of legs rotating in different directions, x^+ and x^-. A displacement equal to $2\cdot\Delta x$ is obtained during one period.

Actuators

By using the polyimide joint in the dynamic mode a variety of actuator applications are conceivable. For example, micro-motion systems, micro-robots, micro-motors, micro-grippers, micro-manipulators and micro-optical systems are possible examples.

Experiments of movable flat “medium sized” objects in the mm range have been performed with a one-dimensional demonstrator conveyer based on the polyimide joint actuators.

Conclusion

Extensive experimentation has shown that the polyimide joint technique works very well in both the static and dynamic modes. The new polyimide joint gives robust, self-assembling, small radius joints with well controllable bending angles. It is also easy to realize electrical interconnection to the assembled 3-D structure, which is not affected by the out-of-plane rotation. Today, we can see feasible applications in several different fields ranging from medical, military, and household equipment to pure research tools.

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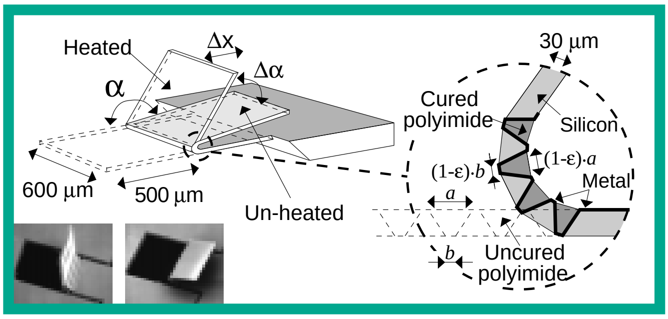
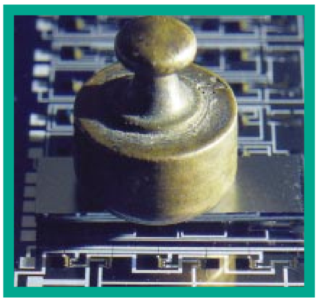


Schematic view of a 3-D test structure consisting of a four V-grooved polyimide joint. Static bending angles, α, from 20° to over 200° (max 35° per V-groove), have been obtained by varying the curing temperature for joints with 1 to 7 V-grooves. The metal wires through the polyimide joint are used as electrical heaters to achieve dynamic movements. Dynamic bending angles, $\Delta\alpha$, of 5° per V-groove (Δx up to 200 µm) and cut-off frequencies ranging from 1 to 10 Hz have been measured.



The micro-conveyer during a load test. The 2 g weight shown in the photo is equivalent to 350 mg on each leg or 16,000 times the weight of each leg shown in the SEM-photos to the left. Measured convey velocity is 1.3 mm/s (at 50 Hz and 90 mW/leg).

Dissertations

MSB wishes to congratulate the following individuals on successfully having defended their theses.

Elin Steinsland, U. of Oslo
Her Dr. Scient. thesis, *Characterization of Crystalline Silicon for Micromachining*, reports on etching experiments performed on single crystal silicon using tetramethyl ammonium hydroxide (TMAH), and on measurements of the temperature coefficients of the elastic constants of silicon.

A method for monitoring the etch rate of silicon during wet etching (*in situ*), has been realized by laser reflectance interferometry. This enables real time monitoring of how the etch rate depends on variations in the etchant and the sample. *In situ* measurements in TMAH etchants on different silicon crystal orientations have been performed.

The surface topography of the sample can affect the intensity of the reflected laser signal. Computer simulations have been used to study this for typical surface topographies that may evolve during etching.

Accurate values of the temperature coefficients of the elastic constants of silicon have been calculated from frequency-temperature measurements and from finite element simulations on three specially designed silicon resonators. This part was performed at the University of Neuchâtel, Switzerland, in co-operation with CSEM SA, Switzerland.

Mats Bexell, Uppsala Univ.
His PhD thesis, *Microfabrication and Evaluation of Piezoceramic Actuators*, focuses on miniaturized motors and the micro-processing of piezoceramics.

A piezoelectric miniature motor (∅ 4 mm) has been developed and characterized. The maximum output torque and rotation velocity was 3.8 mNm and 65 rpm, respectively. These values are among the highest reported for miniature motors of this size. An analytic model has been derived whose results give reasonable agreement with measurements.

A new technique for the high resolution patterning of electrode layers on ceramic green bodies is presented. By embossing, line widths and spacings down to 20 µm have been accomplished. To comply with the embossing technique, a wet building process for multilayer ceramics has been developed.

Thierry Corman, KTH
His Licentiate thesis, *Low Pressure Encapsulation Techniques for Silicon Resonators*, focuses on wafer level encapsulation techniques. Special attention is paid to techniques enabling high quality factors for the resonator.

The thesis deals with anodic bonding, metal deposition sealing of small channels used to evacuate residual gases, and getter materials placed inside the cavities to absorb residual gases. Both vertical and lateral electric feedthroughs, which are used for electrically contacting the enclosed device, are addressed. As an illustration, a silicon resonator derived from a liquid density and mass flow sensor design has been encapsulated inside a low pressure cavity.

Thorbjörn Ebefors, KTH
His Licentiate thesis, *Three-dimensional Microstructures based on Polyimide Joints*, originates from a desire to fabricate robust 3-D structures with sensor features in all three directions. The final goal is to fabricate a fast and accurate triple hot-wire sensor for the simultaneous measurement of three perpendicular velocity components in gas flows. The sensor should be small enough to enable measurements of the smallest eddies in a turbulent gas flow. The article on page 6 presents more details.

STANDARDS

Further penetration and use of microsystems technology is currently hampered by the lack of standardization, e.g. in the design, production, packaging, testing and use of microsystem devices. The European Commission supports the creation of industrial standards for MST. As part of this work, a workshop of European experts was held earlier this year aimed at identifying industrial standardization needs.

Internationally, standardization issues is one topic addressed at the yearly World Micromachine Summit (see *MSB 97:3* and *98:4*). As a result, Tokyo hosted the world's first international MST standardization workshop in October 1997.

JAPAN

The Micromachine Center (MMC) in Tokyo and KTH in Stockholm organized a one-day seminar in Stockholm in June. Six speakers each from Japan and Sweden/Finland gave their views on the status of R&D in their regions.

A systems view is favored in Japan compared to the bottom-up view predominantly used in Europe. The need to improve existing machines and devices is in Japan taken as a reason for entering new technological areas. In Europe, we often focus on developing process steps before considering simple devices and systems. Consequently, Microsystem Technology is in Japan denoted as Micromachine Technology.

Japan believes that the best way to promote the development and implementation of a new technology is to enable as many people as possible to understand it and its usefulness. To pick up new ideas from children, MMC has created a micromachine textbook that is used by approximately a quarter of a million fourth graders each year. There are also MST-focused drawing contests for elementary and junior high school pupils.

www.mst.material.uu.se

Interested in learning more about the wonders and possibilities of MST? Both general and tailored presentations ranging from less than an hour to several days in length are offered by Uppsala University at your choice of location. You are also invited to visit the Ångström Laboratory to see how micromachining is carried out.

POSTTIDNING B

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MICRO STRUCTURE BULLETIN NO.3 AUG 1998

FUTURE EVENTS

Conferences:
Eurosensors XI, Southampton, United Kingdom, Sept. 13–16, 1998. For info.:
Univ. Southampton
Fax: +44-1703-595791
diana.ecs.soton.ac.uk/~aht/EurosensorsXII

MEMS '99 (Micro Electro Mechanical Systems), Orlando, U.S.A., Jan. 17–21, 1999. *Abstract deadline: Sept. 14*. For info.: Preferred Meeting Management, Inc.
Fax: +1-(619) 298-3459
www.eecs.umich.edu/mems

Transducers '99, Sendai, Japan, June 7–10, 1999. *Abstract deadline: Nov. 30*. For info.: Transducers '99, Attn.: J. Echizen
Fax: +81-3-3299-1361
www.com.cas.uec.ac.jp/trans99.html

Deep Wet Etching of Borosilicate Glass Using an Anodically Bonded Silicon Substrate as Mask; T. Corman, P. Enoksson and G. Stemme (KTH); *J. Micromech. Microeng*., 8(2) (1998) 84–87.

FSRM-courses:
Fax: +41-32 720 09 90
www.fsrm.ch
- *The Challenges of Microsystems Technology*, Copenhagen, Denmark, Sept. 17, 1998.
- *Micro Devices for Fluid Handling*, Stockholm, Sweden, Sept. 28–29, 1998.
- *Manufacturing Processes for Micromechanical Components*, Copenhagen, Denmark, Nov. 19–20, 1998.

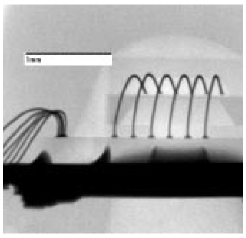
PUBLICATIONS

- Characterisation of Crystalline Silicon for Micromachining; E. Steinsland (Univ. of Oslo); *Doctoral thesis*, (1998).
- Dynamic Actuation of Polyimide V-grooves Joints by Electrical Heating; T. Ebefors, E. Kävesten and G. Stemme (KTH); *Sensors and Actuators A*, 67(1–3) (1998) 199–204.
- Low Pressure Encapsulation Techniques for Silicon Resonators; Thierry Corman (KTH); *Licentiate thesis*, TRITA-ILA-9801, ISSN 0281-2878 (1998).
- Measurement of Package-Induced Stress and Thermal Zero Shift in Transfer Molded Silicon Piezoresistive Pressure Sensors; J.B. Nysæther (Univ. of Oslo/SINTEF), A. Larsen, B. Liverød and P. Ohlckers (Davis A/S); *J. Micromech. Microeng*., 8(2) (1998) 168–171.
- Microfabrication and Evaluation of Piezoceramic Actuators; M. Bexell (UU); Doctoral thesis, *Acta Univ. Ups*. 360, ISBN 91-554-4187-4.
- Silicon Microphones – a Danish Perspective; S. Bouwstra, et al (MIC); *J. Micromech. Microeng*., 8(2) (1998) 64–68.
- Three-dimensional Microstructures based on Polyimide Joints; Thorbjörn Ebefors (KTH); *Licentiate thesis*, TRITA-ILA-9802, ISSN 0281-2878 (1998).
- Using FEA to Treat Piezoelectric Low-Frequency Resonators; J. Söderkvist (Colibri); *IEEE Tr. Ultrasonics, Ferroelectrics and Frequency Control*, 45(3) (1998) 815–823.

NEXT ISSUE

Some topics covered will be:

- Markets analysis
- Metal microstructures on CMOS
- Packaging



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