MICRO STRUCTURE BULLETIN

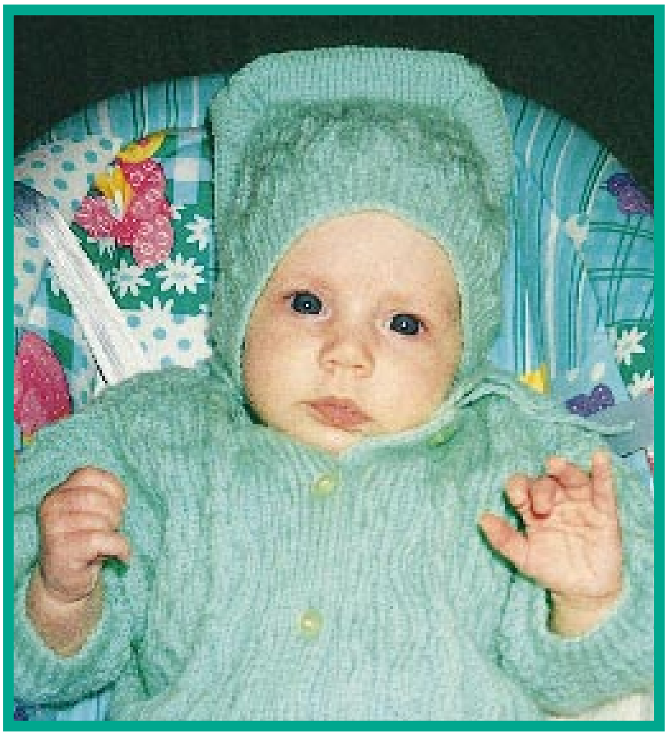
Newsletter for Nordic Micro Structure Technology, Vol.5, No.2, May 1997

MST – for All of Us

In the fall of 1992, a little girl and her parents came by to the Micromachine Center (MMC). Her father, finding out on TV that micromachine research was being carried out for medical applications, had apparently inquired here and there before being directed to us.

The girl was suffering from Peutz-Jeghers Syndrome, a disease in which numerous polyps form in the stomach and intestines. "When the doctor first found polyps in our daughter's stomach and large intestine, he removed them by endoscopic surgery," her parents explained: "yet, a polyp in the small intestine can cause intussusception – the intestine folds up inside itself. Well, about two years ago, this is exactly what happened. The doctor had to open her abdomen to extract it. Then, last summer, she had to have polyps removed from her large intestine again. The doctors says that polyps in the large intestine can usually be removed by endoscopic surgery but, depending on where they are, even a first-rate surgeon would have a hard time extracting them all, because the highest technology is required for this."

I listened sympathetically. When they had finished speaking, I gave them an outline of the national large-scale project called "Micromachine Technology" that was being advanced at the MMC. I explained that yes, we were conducting research work on the future application of micromachines to various fields including medicine, but that the technology was still in an infant stage and would require much time to develop. Even with this, her father was elated – "Just the fact that there is a project, that there are people working on this, gives us hope for the future."



The girl shown in the figure, which is the Editor-in-Chief's proud contribution, is not connected with the girl in the text.

The little girl, who had been quietly listening all along, suddenly spoke up. "Please mister," she said, "please invent a robot that will fix my tummy without another operation."

The MMC has notified such wishes like this little girl's to researchers around the world, and has stressed the necessity and importance of micromachine technology.

Micromachine technology is neither just for eminent researchers in special fields nor individual companies. It is for people, people who are aware of what we are doing and are waiting for us to help them. We must keep this in mind as we endeavor in promoting research and development to be able to put micromachines to practical use as soon as possible.

This text appeared in the July 1993 edition of the Japanese magazine **Micromachine** *that is published by MMC. The permission to reproduce it here is greatly appreciated.*

CONTENTS

EDITOR'S NOTE

Almost everyone owns devices that include micromachined components, of which watches are a prime example. Despite the perceived unimportance of how components are manufactured, the general population is slowly becoming aware of micromachining and its possibilities. Articles on this subject are appearing in technical weekly newspapers and in monthly popular science magazines. Recently, micromachining was shown on the Swedish TV-program, *Hjärnkontoret*, which addresses questions from children.

In Japan, it is not only the R&D in the MST area that is stimulated. It is also considered important to promote a better understanding of micromachines in society, as well as to pick up novel ideas among people in various fields. The text on the front page of this issue is one example of this interaction. "Micromachine Drawing Contests" for primary and junior high school students are held to increase awareness of MST, and the winning contributions are used to promote this area.

An important purpose of *MSB* is to increase awareness of MST and its possibilities. Subscription fees are, therefore, not charged within the Scandinavian countries. The generous support from the many companies and organizations supporting *MSB*, including Uppsala University, is greatly appreciated.

Jan Söderkvist

The Ångström Laboratory at Uppsala University

The official inauguration of the Ångström Laboratory on April 18 by His Royal Majesty the King of Sweden, marked the end of the largest construction project in the 520 year history of Uppsala University. It also marked the start of a new era of advanced materials research and micro engineering at Uppsala University.

At the Ångström Laboratory, physicists, chemists, materials scientists and engineers work together in one of Europe's most modern centers for research and education on materials. Some 250 researchers from many different disciplines contribute with their special knowledge and talents in a variety of cross-disciplinary projects.

At their disposal are premises well adapted to their purpose, advanced scientific equipment and powerful tools for computing. Basic science, as well as applied research, find a dynamic environment with rich opportunities for cross-fertilization.

Several of the research groups belong to the world elite within their fields. Some examples are thin film science, advanced micro engineering and solar energy research. Much of the research takes place in close collaboration with industry and other universities in Sweden, as well as abroad.

The activities at the Ångström Laboratory have a pronounced international character with an extensive exchange with the world-wide research community. Some one hundred different projects are performed on an international basis.

The largest cleanroom facility in Sweden (some 2400 m^2) constitutes the "heart" of the laboratory. Part of the cleanroom (700 m^2) is constructed on a devibrated fundament of concrete which is separated from the rest of the building. On this area it is possible to perform 0.1 µm lithography and atomic resolution microscopy.

During the inauguration of the Ångström Laboratory, His Royal Majesty the King of Sweden received the first copy of the new biography "Ångström father and son" from Prof. Emer. Olof Beckman. Photo: Teddy Thörnlund.

Several materials related undergraduate and master programs are located in the Ångström Laboratory, for example the master program in Engineering Physics, as well as ten different research groups: Materials Science, Solid State Electronics, Solid State Physics, Inorganic Chemistry, Ion Physics, Solid Mechanics, Soft X-ray Physics, Analytic Electron Microscopy, Materials Physics and the ESCA-Laser Laboratory.

There is not space enough here to present all research activities going on in the Ångström Laboratory. However, the titles of some of the externally financed research centers and consortia might give a good indication: Competence Center for Surface and Micro Structure Technology (SUMMIT), Strategic Center for Advanced Micro Engineering (AME), Ångström Solar Center, Center for Batteries and Fuel Cells for Better Environment, Energy Systems Center, Ångström Consortium for Thin Film Processing, and the Consortium for Clusters and Particles.

Jan-Åke Schweitz
Uppsala University
Fax: +46-(0)18-18 35 72
E-mail: jan-ake@teknikum.uu.se

Foto: Teddy Thörnlund.

Gas Flow in Micromachined Channels

At Linköping University studies of gas flow through long, narrow micromachined channels are ongoing to investigate the interactions between gas molecules and surfaces. Channels with catalytically active walls are of special interest.

The project investigates very shallow (≈ 100 nm) channels with an extremely large length-to-depth ratio (L/d ≈ 100,000). At a wide pressure range, the gas flow in such a channel will be molecular, meaning that gas-wall collisions will dominate over gas-gas collisions. Due to the large L/d-ratio, a gas molecule which traverses the channel will encounter a very large number of wall collisions (proportional to $[L/d]^2$). Thus, the micromachined channels can be used to induce gas-surface interactions and to possibly amplify related phenomena.

Experimental Details

Materials employed have included silicon-quartz glass channels (Si-Q) and silicon dioxide-quartz glass channels (SiO_2-Q). The SiO_2-Q structure was oxidized to achieve inert channel walls. With either material the channel floors were occasionally coated with a 10 Å thick platinum film (see figure).

The channels were inserted as the leak path between a gas cell and a vacuum mass spectrometer chamber. Both chambers were equipped with pressure gauges and the mass spectrometer was used to analyze the molecules that have traversed the channel. With the aid of this equipment, we can measure how a pressure change in the gas cell propagates in the system and what species are either produced or consumed during the transport process.

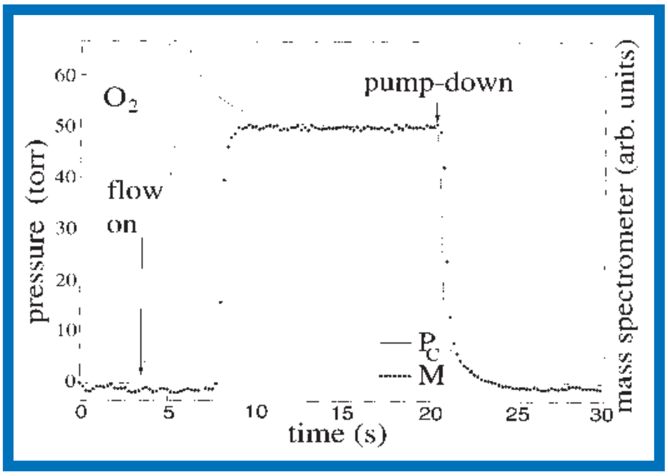
Molecular Flow at High Pressures

In 1909, Martin Knudsen framed the first molecular flow theory. The possibility to fabricate flow vessels with small cross-section dimensions was limited at the time and molecular flow was understood to be rarefied. In micromachined channels, molecular flow may occur also at atmospheric pressure.

During gas flow through the vessel an adsorption layer may build up on the flow vessel walls, especially under higher pressures. This adsorption layer would likely influence the gas-wall interaction, and it is not obvious that traditional molecular flow theory would account for this. The nature of scattering might change, and in a gas mixture, chemical reactions might occur on the channel walls. In our channels with an extremely large L/d ratio, we expect such effects to be particularly emphasized.

Reality

We have exposed the high pressure end of the channels to gas pulses (10–1,000 Torr). In characterizing the subsequent flow through the channels, we have made several findings that are not accounted for in traditional molecular flow theory.

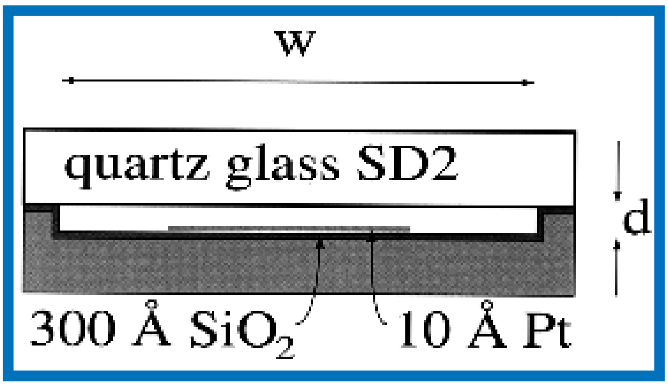


Gas flow through a 600 nm deep channel. Note the difference in slope between the pressure signal at the channel entrance and the spectrometer signal downstream.

In the Si-Q channels we have found that the transit time lag is too small (≈10 times). It was shown to decrease with increasing pressure. In a mixture of helium and argon, the mixing ratio was shown to influence the respective transit time lags. It is reasonable to assume that the flowing species influence one another on the channel wall. The assumption that scattering is more specular on adsorbates and more diffusive on the "bare" channel walls has shown to model several of the findings.

A SiO_2 structure (17 mm long, 600 nm deep), with a 10 Å Pt string evaporated along the channel floor (see figure), was exposed to a gas pulse of either oxygen, hydrogen or argon. The pressure in the gas cell increased slowly from 0 to 50 Torr steady state pressure, that is, a relatively slowly rising pressure front entered the high pressure channel end and diffused to the high vacuum channel end. In the cases of hydrogen or oxygen exposures, the pressure front was dramatically reshaped during transport so that a very sharp gas pulse entered the mass spectrometer chamber. No reshaping of the front was seen when using argon, or when using a Pt-free structure. We believe that this phenomenon is due to adsorption on Pt.

When the SiO_2-Q(Pt) structure was exposed to hydrogen, measurable amounts of hydrogen remained in the channel for at least 17 hours. Therefore, a micromachined structure, especially one with an active surface layer, could carry its history from earlier exposure on its walls for a long time.



A cross-sectional view of a typical channel structure with w=1 mm and d=600 nm.

Summary

The described findings might, of course, depend strongly on the specific channel wall chemistry, but they may still be of interest for users of gas flow micromachined structures. Furthermore, the channels have shown to be an interesting tool in investigating molecular-surface interactions. In the immediate future the spontaneous release of hydrogen from an initially hydrogen saturated channel will be studied further.

Petronella Norberg (contact person)
L.-G. Ekedahl
I. Lundström
Linköping University
Fax: +46-(0)13-28 89 69
E-mail: pen@ifm.liu.se

Micromachining at Lund University

In 1990, contact was made with the micromachining group in Uppsala to investigate the possibility of transferring biosensor technology for glucose monitoring from the traditional biochemical domain to silicon micromachined structures. The question concerned whether silicon microchannel flow-through cells could work as enzyme reactors instead of more conventionally used controlled porous glass beads (CPG).

In the case of success, benefits could be envisaged in the areas of manufacturing, size, handling, and operational costs for a wide range of biosensors. Since enzymes commonly are immobilized on silica based substrates, the use of silicon was a natural choice in the efforts of developing micromachined enzyme reactors.

Silicon Microreactors

Initial work together with Dr. Lars Rosengren, Uppsala University, demonstrated parallel channel flow-through cells with high aspect ratios in <110>-silicon (Fig. 1). The deep channel design strived to accomplish a surface enlarging structure allowing for high enzyme loading, see *MSB 95:4*.

The silicon reactors were activated with the enzyme glucose oxidase according to the scheme in Fig. 2. Subsequent measurement in the existing glucose monitoring microsystem earlier developed within our group showed the feasibility of such microreactors. However, predicted by biochemists, the total enzyme activity in these micro reactors was far too low for a viable glucose sensor application.

Porous Silicon

At this stage we optionally considered porous silicon as a surface enlarging matrix. The work on porous silicon became the leading theme in the PhD work defined for Tekn. Lic. Johan Drott, Dept. Electrical Measurements. The spongious micro/nanoporous and high surface area morphology of porous silicon was expected to improve the reactor performance considerably.

The initial experiments on porous silicon were carried out on planar <111> n-type substrates. Higher current densities through the silicon substrate as it is anodized in HF/ethanol yields surfaces with rougher pore morphologies. Therefore, different factors of surface enlargement can be achieved. The first porous samples displayed a 30 fold increase in enzyme activity. When the porous etch process was improved and employed to the original channel reactor structure, an 100 fold rise in enzyme activity was recorded when compared to the corresponding non-porous substrates, Fig. 3.

Current work focuses on further optimizing pore morphology and studying of the long-term stability of the immobilized enzymes. A 2% loss of enzyme activity after 5 months of refrigerated storage has been shown. The versatility of the microreactors has been demonstrated in a collaborative work with Prof. Robert Kellner´s group (Dr. Bernard Lendl at the Tech. Univ., Vienna) where microreactors immobilized with fructosidase were employed to a Fourier transform infrared spectroscopy microsystem developed for sucrose determination in soft drinks.

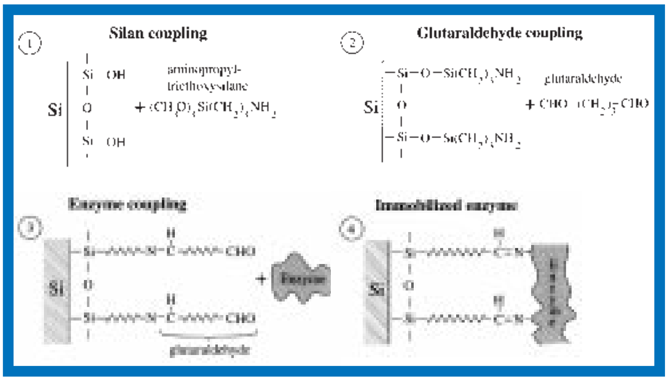


Figure 2. Procedure for coupling enzymes to silicon

The microreactors are now fabricated at the Department of Electrical Measurements in Lund. Tools for basic lithography, anisotropic etching and pn-etch stopping are available there. Fundamental facilities, such as oxidation and doping, are kindly supplied via the Solid State Physics Department in Lund by Doc. L. Montelius. Thus, new ideas in the field of micromachining can be investigated.

Liquid Picoliter Sampler

Among these new ideas is a micro flow-through liquid sampling device which can dispense picoliter volumes of a chemical onto a substrate, such as in the fabrication of biospecific surfaces. Optionally, picoliter samples can be ejected into a nano-scaled chemical reactor or directly into an analysis system.

This device is based on two anisotropically etched structures that are sandwiched together, forming the flow-through cell. The silicon boundary on one side of the channel is a 10 µm thick pn-etch stop defined membrane which is actuated by a piezo-

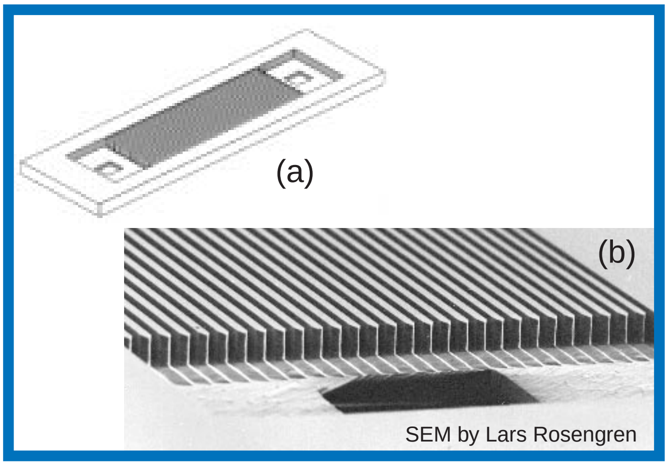


Figure 1. (a) Microreactor design, (b) fabricated reactor with 50 µm wide and 165 µm deep channels.

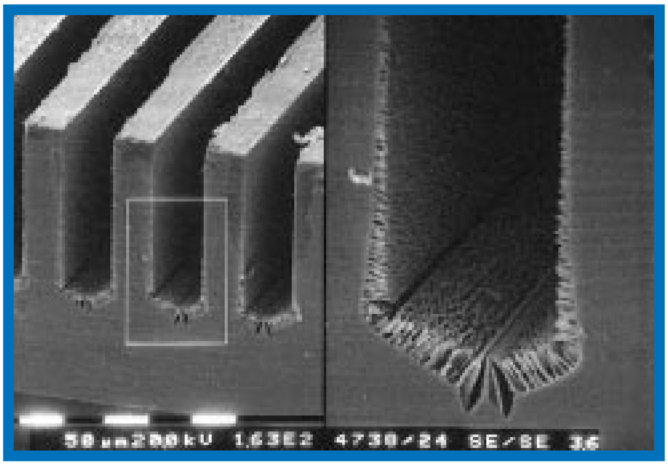


Figure 3. Cross-section of channels in a porous microreactor with 50 µm wide and 250 µm deep channels.

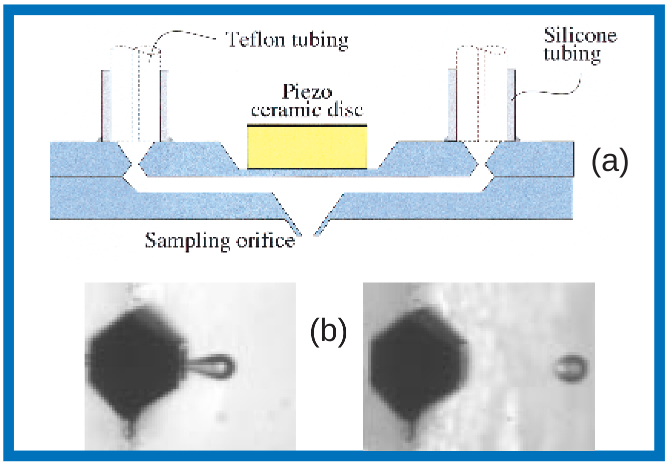


Figure 4. (a) Schematic view of the flow-through sampler and (b) drop generation from the sample orifice, drop volume 100 pl.

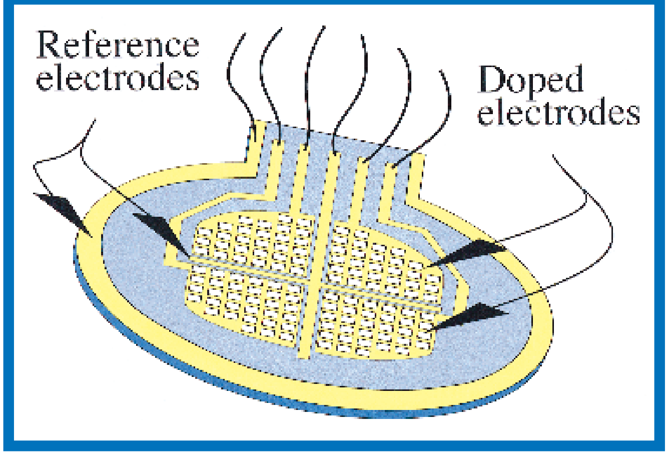


Figure 5. Drawing of the silicon micromachined sieve electrodes.

ceramic disc. This disc generates a pressure pulse that ejects a 100 picoliter droplet through the orifice opposite the channel, Fig. 4.

Dr. Johan Nilsson, Dept. Electrical Measurements, is conducting the work on drop physics as new generations of microsamplers are developed. He is also involved in exploring the applications of the device. The sampler is currently being used as an injector in capillary electrophoresis combined with laser induced fluorescence imaging and is subject to an international patent application. This work is carried out in collaboration with Dr. Staffan Nilsson, Technical Analytical Chemistry, LU and Dr. Jonas Johansson, Atomic Physics, LU.

Neural Interface

A more long-term research project comprises the development of silicon micro sieve electrodes for implantation in a peripheral neural trunk. Optionally, these will enable real time registration of neural traffic, Fig. 5. The signals from the micromachined sieve electrode will ultimately be interpreted by artificial neural networks for application in a mind controlled prosthesis, see *MSB 95:4*.

This project is an interdisciplinary collaboration with the Departments of Solid State Physics, Physiology and Neuroscience, Experimental Research, Handsurgery, Animal Physiology and Cognitive Science, and has until now been supported by NUTEK's Micronics program.

MSc Lars Wallman is doing his interdisciplinary PhD thesis on the sieve electrodes and is, therefore, involved in both the micromachining and the neurophysiological parts of the project, as well as taking courses both at the technical faculty and the medical faculty. The sieve electrodes are micromachined and characterized electronically at the Dept. of Electrical Measurements, and the electrode implantation and biomedical studies are conducted by the medical section of the group.

LIGA in Lund

In parallel to the silicon micromachining at the Dept. of Electrical Measurements, a facility for X-ray lithography and LIGA (Lithographie Galvano Abformung) microfabrication is being set-up at the synchrotron radiation source at MAX-lab in Lund. The Dept. of Physics, Synchrotron Radiation Research in collaboration with Solid State Physics, Lund Institute of Technology are in charge of the project. Currently the beam-line is ready and the exposure station for nanolithography and LIGA structures are now being set-up. The first exposures are estimated to take place in early October of this year.

Thomas Laurell,
Lund Institute of Technology
Fax: +46-(0)46-222 4527
E-mail: thomas.laurell@elmat.lth.se

Application Areas

The international development of microstructures in the field of micro total analysis systems, µTAS, is currently showing rapid progress. This progress is partially driven by the new demands on tools and instruments for performing rapid nanoliter chemistry by the pharmaceutical industry. One example is large scale combinatorial chemistry in nano/picoliter volumes. This requires extremely small system volumes to accomplish a reasonable throughput. High throughput screening (HTS) and rapid micro scale chemical analysis are, thus, the target areas of study for the porous silicon micro reactors and picoliter flow-through fluid dispensers developed within our group.

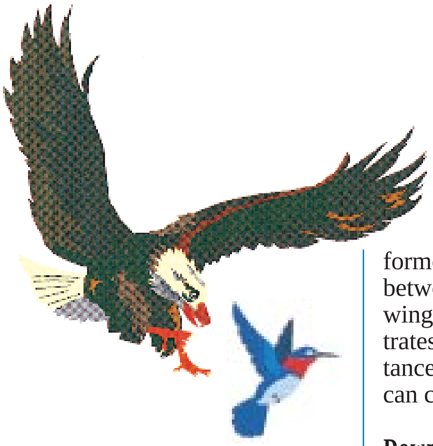
Thomas Laurell

MEMS-97

This year international conference on Microelectromechanical Systems was held in Nagoya, Japan on January 26–30. It was the tenth anniversary of this annual conference. The conference was attended by 385 participants and 91 papers were presented. Among the many interesting papers which were presented was one by the IBM Research Division in Zürich. This group described a new ultra-thick (1200 µm), high-aspect-ratio photosensitive epoxy-based resist, SU-8, which makes its possible to fabricate plastic and electroplated structures. Another true MEMS work was presented by Prof. C T.-C. Nguyen at the University of Michigan who demonstrated an IC-compatible, third-order, band-pass micromechanical filter based on polysilicon surface micromachining technology.

The next MEMS conference will be held in Heidelberg, Germany on January 25–29, 1998. Abstracts are due on September 15, 1997. More information is available on the web: http://www.imit.uni-stuttgart.de/mems98. The MEMS community is invited to submit abstracts and to attend the conference in Heidelberg!

Göran Stemme, General Co-chair
Royal Institute of Technology (KTH)
Fax: +46-(0)8-10 08 58



Micromachining Basics Part 9:

Is Size Important?

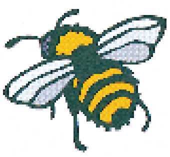
Have you looked at the birds in the sky and wondered how they can fly so gracefully? Why are small birds experts at aerobatics while large birds almost look clumsy? Why are large birds able to hover without moving their wings while small birds have to vigorously use their wings in order not to move. Is all this just a coincidence, or are there deeper reasons for these differences?

Flying Observations

For eons, birds of prey have, via trial and error, developed excellent skills for locating pray. Often, this involves hovering, which is remaining afloat without moving relative the ground. In mastering this technique, natural selection has shaped these large birds into their current forms.

Rarely does a bird of prey actually manage to catch a smaller, flying bird. Small birds stay alive partly due to their well-developed ability to rapidly change their direction of flying. Is the difference in size just a coincidence, or does size play an important part in flying?

The bumble-bee is said to be unaware of that it should not be able to fly, at least not based on simple aerodynamic theories that suffices for explaining why birds and aircrafts can fly. Fortunate for the bumble-bee, advanced aerodynamic simulations have revealed that an air-pocket with sufficiently low pressure is formed above the bumble-bee between the wings when its wings are fluttering. This illustrates that the relative importance of physical phenomena can change at different size.



Downscaled Physics

Experience shows that macroscopic physical laws are valid also in the micro-world when the dimensions are large compared with atomic dimensions. A fundamental rule for downscaling is that volume-depend effects ($\propto length^3$) often are of minor importance compared with surface-dependent effects ($\propto length^2$).

Although material parameters may differ between macro and micro-scales, it is usually a negligible difference. More important are the characteristics of materials used for micromachining. For instance, some crystalline materials have an almost perfect material quality which reduces the problem of material fatigue to an academic question. It is only occasionally considered a drawback that these materials lack plastic behavior.

The number of surface damages can be dramatically reduced by using micromachining. Most such processes affect the material on an atomic level, and the material can be processed without being touched by tools. Micromachined structures can, therefore, be stronger than high-quality construction steel if the dimensions are small compared with the distance between surface damages.

Downscaling Inertia

Gravitational and inertial forces are volume-dependent, and are, therefore, less important after downscaling. In fact, gravity can almost always be neglected in the μ-world. The reduced importance of inertia is one reason why small birds are better at rapidly changing direction of flying, i.e. at aerobatics, than are large birds.

Small birds can also flutter their wings more rapidly than large birds can. This is a natural consequence of scaling inertia and resonant frequencies. The resonant frequencies increase ($\propto length^{-1}$) with decreased dimensions since spring constants are proportional to *length*, and mass to $length^3$, assuming that stiffness and density are unaffected by scaling.

In addition, small birds survive collisions better than large birds. The increased ability to survive a mechanical shock is due to inertia decreasing faster than spring constants. A rule of thumb is that the shock level a device can survive is proportional to the lowest resonance frequency ($\propto length^{-1}$). In addition, smaller objects have a tendency to fall slower since air-friction ($\propto length^2$) counteracts gravity ($\propto length^3$).

Downscaling Gas Theory

Large birds need large wings ($\propto length^2$) in order to be able to lift their own weight ($\propto length^3$). For smaller birds the scaling rule indicates that their wings can be smaller in size relative to the dimensions of their body compared to larger birds.

Other effects may become limiting factors when downscaling. Air friction is more important when the wing area is reduced since air drag acts on both wings and body. If the wings are too small the birds are not able to overcome strong winds, and they become sensitive to sudden changes in the wind. Note that the wings of insects are relatively large compared to the size of their bodies.

For microstructures, air-friction can be a very dominating factor in dynamic behavior. Squeeze film damping in small air-gaps is used in some non-resonant devices to achieve a suitable frequency response spectrum. In other applications, such as resonators, energy losses must be kept to a minimum,

and vacuum packaging may be necessary.

Gas flow in narrow micromachined channels is not well described by classical gas-theory based on continuum models. Molecular behavior has to be taken into account if the mean-free path (average distance between molecular collisions) is larger that 1% of the channel cross-sectional dimensions. One consequence is that the zero-velocity-assumption at the channel walls no longer is valid (slip boundary condition). The article on page 3 addresses flow in narrow channels.

Downscaling Fluidic

The influence of liquid surface tension is often negligible in the macro-world. Downscaling changes this drastically, and the surface tension can be strong enough to allow small insects to “walk” on a water surface. Here, the surface tension is not a drawback, and the saying “it is not a bug, it is a feature” applies.

In drop formation the surface tension creates an energy barrier that must be overcome. Condensation is an easier way of creating sub-mm water droplets.

In micro-dimensions the surface tension is even more important. It is often difficult to fill small channels with a liquid, especially if no trapped air bubbles are allowed. It is important to use surfaces with good wetting properties (hydrophilic); capillary forces will then help to fill the channels. Since gravity has little influence in small dimensions, liquids can creep far into channels. If this creeping is undesired, the surfaces may be coated with a hydrophobic layer.

The effect of viscosity is also more noticeable in the micro-world, and it is important to use low-viscosity liquids. Small "swimming" objects are very rapidly brought to a halt due to viscosity.

In micro-dimensions flow is normally laminar. This makes it difficult to mix liquids in micro-channels.

Detection and Excitation

Detection is often based on measuring a deformation, via mechanical stress or deflection. Stress-measurements are often volume-dependent and are more sensitive to disturbances on downscaling.

For deflection dependent detection, the resolution is scaled as *length*$^{-2}$. The error sources must also be considered since they often influence resolution. As an example, the thermal noise of a resistor is scaled as *length*$^{-1}$. Unfortunately, the large variety of error sources makes it difficult to set up general scaling rules for error sources.

A more scaling-independent method of detection is to measure relative changes of, for example, frequency or (piezo-)resistance. Unfortunately, the signals used to detect the resonance frequency or the piezoresistor values are also vulnerable to noise.

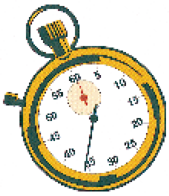
More about detection and excitation principles for micromachined structures have been presented in *MSB 94:2* and *MSB 96:1*.

Miscellaneous Observations

Micromachining produces reproducible structures. Nevertheless, it is difficult to set very tight dimensional tolerances. Atomic diameters (a few Ångström) set a fundamental limit. Furthermore, most production equipment rely on optical mask aligners, which often limits the alignment accuracy to a few µm (cf. the optical wavelength).

Temperature gradients are rapidly equalized in small structures. Nevertheless, smaller structures are normally more sensitive to the negative effects of temperature gradients. For example, the tendency to buckle increases with reduced dimensions.

Mechanical friction imposes a severe limitation on the life-time of micromachined moving objects. For some structures, the increased friction is due to an increased surface roughness to size ratio upon downscaling. For smoother structures, friction in micro-scale is controlled more by attractive surface forces than the volume-dependent inertia forces that controls macroscopic friction.



Reference Scale

A rapid event in the macro-world may be interpreted as a slow-motion event in the micro-world. Who has an intuitive feeling for what a picoliter (10^{-12} liter) is? When is it appropriate to count an electric current in electrons instead of in ampere?

Clearly, the reference scale changes on downscaling. Space and time dimensions will be reduced, surfaces will be more important, and we do not need to worry about our weight. In conclusion, downscaling will do its best to confused us.

Jan Söderkvist
Colibri Pro Development AB

WINNERS

MSB congratulates M. Bexell and S. Johansson on winning Innovation Cup with their contribution "strong miniature motors" (see *MSB 95:4*). Innovation Cup is a national invention contest between university employed researchers in Sweden. Micromachining-based devices has been awarded before in this contest, as presented in *MSB 96:1*.

DISSERTATIONS

MSB wishes to congratulate Peter Enoksson and Christer Hedlund on successfully having defended their doctoral theses on March 14 at the Royal Institute of Technology (KTH) and Uppsala University, respectively.

Peter Enoksson

Enoksson's thesis, *Novel Resonant Micromachined Silicon Devices for Fluid Applications – Densitometer, Coriolis Mass Flow Sensor and Diffuser Pump*, studies three structures intended for use in micro-fluidics, as well as related fabrication methods.

Two of the structures are based on a resonating tube system. A change in density of the fluid in the tube changes the resonance frequency. Thus, the resonance frequency becomes a measure of the fluid density. The sensors showed very good sensitivities of 200–300 ppm/(kgm^{-3}). Sample volume is as small as 30 mm^3.

The tube structure was used also as a mass flow sensor based on the Coriolis principle. The Coriolis force is proportional to the mass flow and the excitation amplitude. The sensitivity is maximized at resonance. Measurements show a very linear relation between mass flow and Coriolis signal.

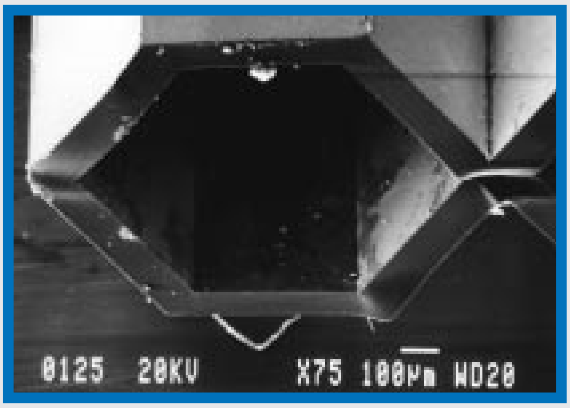
The third structure is a silicon/glass micromachined pump. It is based on a valveless diffuser/nozzle principle, and is excited near the resonance frequency of the pump chamber via piezoelectric discs. Two different fabrication processes are presented in the thesis. The first is based on isotropic wet etching and the second on dry deep reactive ion etching. The pump performance is very good with a maximum pressure of 74 kPa and a maximum flow of 2.3 ml/min.

Christer Hedlund

Hedlund's thesis, *Simulation and Experimental Studies of Plasma Processing*, studies various aspects of etching and deposition. A goal of plasma processing studies is to provide a detailed understanding about the processes leading to etching/deposition and to subsequently provide a comprehensive description of the surface evolution. A novel test structure for measuring the angular dependence of etch rate has been studied.

The thesis also contains a study of highly anisotropic wet chemical etching of quartz. Piezoelectric crystalline materials are normally very anisotropic, which means that a detailed knowledge of the etch process is essential if reliable and optimized structures are to be manufactured in quartz.

In most cases, experiments have been complemented and compared with computer simulations.



SEM-photo of a silicon tube cross-section fabricated using KOH-etching and silicon-to-silicon fusion bonding.

POSTTIDNING B

B

SVERIGE
PORTO BETALT

NEXT ISSUE

Next issue will report on high-lights from the conference Transducers '97

PUBLICATIONS

- Approaches and Mechanisms to Solid State Based Sensing; I. Lundström (LiTH); *Sensors and Actuators B*, **35**(1–3) (1996) 11–19.
- High-Sensitive Surface Micromachined Structures for Internal Stress and Stress Gradient Evaluation; F. Ericson, S. Greek (UU), J. Söderkvist (Colibri) and J.-Å. Schweitz (UU); *J. Micromech. Microeng.*, **7** (1997) 30–36.
- Microassembly of a Piezoelectric Miniature Motor; M. Bexell and S. Johansson (UU); *Proc. SPIE Microrobotics Components and Applications*, Vol 2906 Boston, Massachusetts, 151–161, 1996.
- Modeling, Simulation and Experimental Studies of Plasma Processing; C. Hedlund (UU); Doctoral thesis, *Acta Univ. Ups. 258*, ISBN 91-554-3922-5.
- Novel Resonant Micromachined Silicon Devices for Fluid Applications; P. Enoksson (KTH); Doctoral thesis, *TRITA-ILA-9701*, ISSN 0281-2878.
- Porous Silicon as the Carrier Matrix in Microstructured Enzyme Reactors Yielding High Enzyme Activities; J. Drott, K. Kindström (LTH), L. Rosengren (UU) and T. Laurell (LTH); *J. Micromech and Microeng.*, **7** (1997) 14–23.
- Quartz Micromachining by Lithographic Control of Ion Track Etching; K. Hjort, G. Thornell (UU), R. Spohr (GSI, Germany) and J.-Å. Schweitz (UU); *Appl. Phys Lett.*, **69**(22) (1996) 3435-6.
- Rat Sciatic Nerve Regeneration Through a Micromachined Silicon Chip; Q. Zhao (LU), J. Drott, T. Laurell, L. Wallman, K. Lindström (LTH), L. M. Bjursten, G. Lundborg (LU), L. Montelius (LTH), and N. Danielsen (LU); *Biomaterials*, **18**(1) (1997) 75–80.
- Surface Micromachining by Sacrificial Aluminium Etching; D. Westberg (CTH), O. Paul and H. Baltes (ETH, Switzerland), *J. Micromech. and Microeng.*, **6** (1996) 376–384.
- Why Bother About Gas-Sensitive Field-Effect Devices; I. Lundström (LiTH); *Sensors and Actuators A*, **56**(1–2) (1996) 75–82.
- Ångström Far och Son; O. Beckman (UU); *Acta Univ. Ups. 60*, ISBN 91-554-3959-4.

FUTURE EVENTS

Transducers '97, Chicago, U.S.A., June 16–19, 1997. For info.: Courtesy Associates, Fax: (202) 347-6109, or visit http://www.eecs.umich.edu/transducers.

MME '97 (MicroMechanics Europe), Southampton, Great Britain, Sept. 1–2, 1997. *Abstract deadline: June 1*. For info.: Dr. A.G.R. Evans, Univ. of Southampton, Fax: +44-1703-593 029, or visit http://www.soton.ac.uk/~mk2/mme97/mme97.html.

Microsystems in Biomedical Engineering (course), London, England, Sept. 11-12, 1997. For info.: FSRM, Fax: +41-32 720 09 90, or visit http://www.fsrm.ch.

Laser Microengineering (course), Oxford, England, Sept. 18-19, 1997. For info.: FSRM, Fax: +41-32 720 09 90, or visit http://www.fsrm.ch.

Eurosensors XI, Warsaw, Poland, Sept. 21-24, 1997. For info.: Prof. Zbigniew Brzózka, Fax: +48-22-660 54 27.

MEMS 98 (Micro Electro Mechanical Systems), Heidelberg, Germany, Jan. 25–29, 1998. *Abstract deadline: Sept. 15*. For info.: G. Stemme, Fax +46-(0)8-10 08 58, or visit http://www.imit.uni-stuttgart.de/mems98.

Biosensors 98, Berlin, Germany, June 3-5, 1998. *Abstract deadline: Aug. 31*. For info.: Biosensors 98, Fax: +44-1865-843 958, or visit http://www.elsevier.nl/locate/bios98.

THE AIM OF the *Micro Structure Bulletin* is to promote the use of micromechanics and micro structure technology. It constitutes one part of Uppsala University's effort to share scientific and technological information.

MSB is published quarterly and is distributed free of charge within Scandinavia and to a limited number of international experts.

MSB is supported by: Biacore AB, Bofors AB, Chalmers KiselDesign, Colibri Pro Development AB, Datex-Engström AB, Ericsson, Modular Ink Technology i Stockholm AB, Nexus, Nutek, Pacesetter AB, Pharmacia Biotech AB, SensoNor a.s., Siemens-Elema AB, Uppsala University, Volvo Teknisk Utveckling and VTI Hamlin Oy.

Editor-in-Chief:
Assoc. Prof. Jan Söderkvist, Colibri Pro Development AB
Torgnyvägen 48
SE-187 76 Täby, Sweden
Phone: +46-(0)8-510 116 49
Fax: +46-(0)8-510 116 15
E-mail: colibri@prodev.se

Scientific editor:
Prof. Jan-Åke Schweitz, Uppsala University
Fax: +46-(0)18-18 35 72

Industrial editor:
Hans Richert, Bofors AB/ Chalmers Teknikpark
Fax: +46-(0)31-772 41 53

Linguistics:
Assis. Prof. Richard G. Boles, U. of Southern California, U.S.A.

Layout and production:
Ord & Form, Uppsala

UPPSALA UNIVERSITY

ISSN 1104-7453