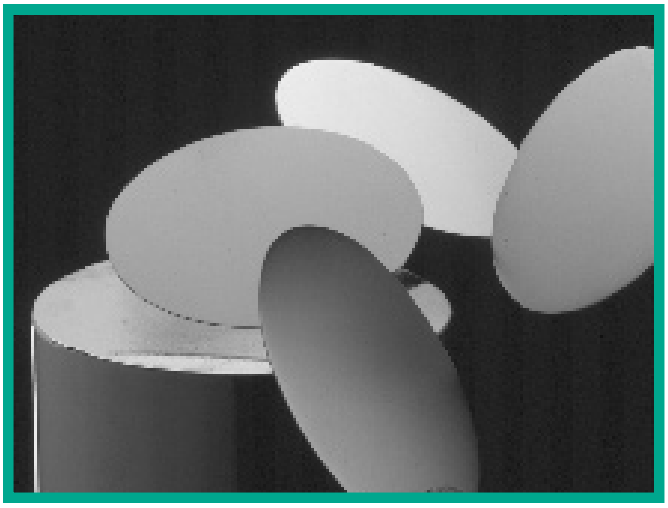
MICRO STRUCTURE BULLETIN

Newsletter for Nordic Micro Structure Technology, Vol.4, No.4, Nov 1996

Silicon Circle Closing?



Courtesy of Topsil Semiconductor Materials A/S, Denmark.

Micromachining evolved from microelectronics. Since silicon was the dominant material for small electronic components, it was natural that it also became an important material in micromachining. The pioneering work of micromachining could take advantage of existing knowledge and production equipment.

Much micromachining research has focused on developing process steps and in exploring their possibilities. The microelectronics process tools have expanded into a special tool box for micromachining. New anisotropic etching, bonding and deposition techniques enable the creation of truly three-dimensional structures both with surface and bulk micromachining.

Complex systems were considered surprisingly early. A single wafer gas chromatograph was produced at Stanford University as early as in late 1970s. The advantage of batch production was soon realized. Several companies aimed at mass-producing small pressure sensors were founded in the mid 1980s.

Silicon has dominated the evolution. Other materials are used only in niche applications. For example, thousands of quartz resonators intended for time-keeping are produced each minute. Although the trend is to explore alternative materials, it will be difficult to replace silicon in many applications. Silicon's advantages include extensive know-how, availability of production equipment, semiconducting properties, and the extreme purity of crystalline silicon.

It is natural that micromachining follows the trends of microelectronics due to the synergistic possibilities. This is recognized by the EU, which tries to stimulate the creation of foundry services for micromachining. These will act as suppliers of micromachined silicon chips just like microelectronics companies can supply custom designed integrated circuits (ASICs). Multi-project wafer services are offered by some foundries in order to reduce development costs.

Electronic systems frequently require sensors, and sensors require signal-processing electronics. The future is to include both sensors and electronics on the same silicon chip. Some foundries aim at offering sensors with integrated electronics. The question is when this possibility will be sufficiently mature for it to be widely used.

In addition, three-dimensional stacking is of interest for microelectronics, and some microsensors are almost truly two-dimensional. One outcome may be that micromechanics and microelectronics will merge, just as was the case when micromachining was first invented.

Jan Söderkvist

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Two awards to MST at Tekniska Mässan:

T. Laurell from Lund was recently awarded the prestigious Skapa Utvecklingsstipendium at Tekniska Mässan, Stockholm. Contributions to the awarded work on continuous glucose monitoring using porous silicon have been made by J. Drott (LTH), K. Lindstöm and L. Rosengren (UU). More on this later (see also *MSB 95:2*). G. Andersson (CTH) received one of four honorary awards for his accelerometer presented in *MSB 95:1*.

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EDITOR'S NOTE

Silicon is an essential material when miniaturizing electronics and mechanics. In fact, this issue of *MSB* would have been difficult to produce if the growth in silicon-related knowledge had been less rapid. With a slower growth rate, insufficient material would have existed to be presented here, which is fortunate since computers might then not have existed. Silicon's importance deserves its use also as a theme in future issues of *MSB*.

Lufthansa's in-flight magazine states that their aircraft fleet requires only 0.53 liters of fuel per 10 kilometers per passenger. I wonder if micro-sensors contribute to this low value, and if micro-sensors are capable of reducing the fuel consumption even further. To be more general, do any of you readers know how much MST contributes in reducing pollution? Depending on your replies, I might devote a coming issue of *MSB* to pollution control.

Plans are now beginning regarding next year's event in the *MSW-MSK* workshop-course series. *MSK '97* will tentatively be held from March 18–19. Considering the success of previous events, I do not hesitate to recommend you to reserve these dates on your calendar. Additional information will be available soon.

Finally, I would like to welcome the European network *Nexus* as a supporting organization to *MSB*.

Jan Söderkvist

Silicon Substrates

Silicon manufacturing technology has undergone a rapid and extensive development, ever since the importance of this semiconductor material came into focus by the discovery of the transistor in the late 40'ties. In this short note, a status of current techniques used in the production of silicon substrates will be described.

Polysilicon

The starting material in the manufacturing of silicon wafers are ingots of poly-crystalline silicon. These ingots are grown by a slow and energy intensive process of chemical decomposition of silane or triclorsilane on a heated filament. All-ready at this initial stage, the requirements for chemical purity are very high, and the allowed level of contaminants must be measured in the ppb level (Carbon ≤ 50 ppb, Phosphorous and Boron ≤ 0.1 ppb).

Crystal Growth

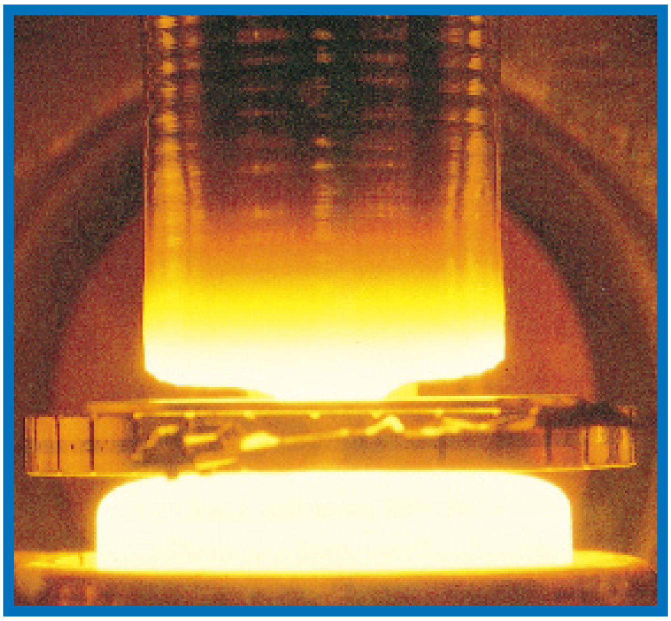
The conversion of polysilicon into mono-crystalline dislocation free ingots, involves melting and recrystallization on a thin seed crystal of known crystallographic orientation. This can be accomplished by use of either the Czochralski (CZ) method or by use of the Float-Zone (FZ) method.

By the CZ growth method, the polysilicon is melted in a graphite heated silica crucible, where the seed crystal is dipped into the melt and then slowly withdrawn. As dissolution of SiO from the crucible is unavoidable, CZ silicon always contain a higher level of Oxygen (≤ 10^{18} cm^{-3}) than silicon produced by the FZ method (≤ $10^{16} cm^{-3}$).

In the FZ-method (see figure), the polysilicon rod is melted by inducing a current at the silicon surface, with the use of an induction coil. Only a small part of the total silicon is melted at a given time, and this melt is passed through the coil onto the seed crystal.

Purification

As the segregation coefficients of most impurities and dopants are very small, these elements tends to remain in the melt during growth. During the FZ-process, the volume of molten silicon is kept constant, and therefore also the fraction of a given impurity that is included into the crystal can be kept constant.



Principle of the crystallization of polysilicon via the Float-Zone (FZ) method.

In contrast, the volume of molten silicon steadily decreases during the CZ-process, and the concentrations of dopants will therefore increase during the crystal growth process.

A large amount of process conditions must by precisely controlled in order to assure a flat axial and radial resistivity profile. The purity of process gases (inert and doping gases), as well as the pull velocity, rotation rates, and the detailed scheme of heating (induction coil shape) and cooling (heat reflectors), are factors that influences the dopant distribution through the melt flow pattern and the solid-liquid interface shape.

Post Processing

After crystal growth, ingots are cut, lapped, etched, and chemical-mechanical polished in order to produce wafers that can be cleaned and shipped to the end-users. In all these mechanical manufacturing steps, improvements have been extensive during the last decades, and highly specialized equipment and processes are now in use in order to meet the requirements of the IC-manufactures.

The advancement in the analytical methods (and other spin-off technologies) used in characterizing the electrical, chemical, optical and mechanical properties of the substrate, can be related to the often quite extreme specifications that has to be met in the production of microelectronic components.

Of the total production of mono-crystalline silicon (≈11,000 tons/year), about 90 % are produced by the CZ method, whereas only 10 % are prepared by use of the FZ-method, which is the only growth method in use at Topsil Semiconductor Materials A/S.

Jan Vedde, Topsil Semiconductor Materials A/S, Denmark
Fax: +45-4231 4269
vedde@mic.dtu.dk

Silicon in Crystal Form, Yes of Course, but What Else ...

The success of silicon in the MST business is to a considerable extent descendent from the versatility of the silicon crystal. Wafers of good purity and crystalline quality were ready for micromachining from the very beginning. Today, a good quality single crystal silicon (SCSi) wafer can have a silicon content of 99.9999% and a dislocation density of less than one per cm^2. And the absence of crystal defects is *the* most important reason for the great strength of silicon on a micro scale, since breakage of brittle materials is induced at these spots. Another benefit is a useful, easy to manufacture, and chemically resistant oxide, SiO_2.

Since the development of anisotropic wet etching, silicon wafers of many different cuts have been used in micromachining. These include (100), (110), (111), (221), see *MSB 94:1*, in additions to cuts not parallel to any natural crystallographic plane.

In spite of the versatility of the Si crystal, there are other forms of silicon that could be useful in MST, including poly, porous silicon, or epi.

Polycrystalline silicon, or poly for short, is a material that is easily grown by LPCVD (Low Pressure Chemical Vapor Deposition) at 625°C. The usefulness of poly in MST was largely boosted with the inventions of surface micromachining and the sacrificial technique in the mid 1980s. Here, the SCSi wafer is used as a carrier substrate, and SiO_2 as an intermediate layer later to be removed. The useful features, for instance movable structures, are made of poly, deposited on top of the oxide.

Historically, poly silicon has been difficult to deposit in a layer thick enough for many devices. Laterally driven comb drive motors, for example, need a large lateral surface in order to generate sufficient electrostatic forces to drive the motor. However, built-in stress from the LPCVD process makes these layers peel off or bend. With a different deposition method using an Epi reactor (see below) instead of LPCVD, more than 10 µm thick poly silicon layers have been deposited, with a very low residual stress of less than 5 MPa.

If the same LPCVD process is used at a slightly lower temperature (580°C), **amorphous silicon**, or α-Si, is created. However, this material is not frequently used in MST.

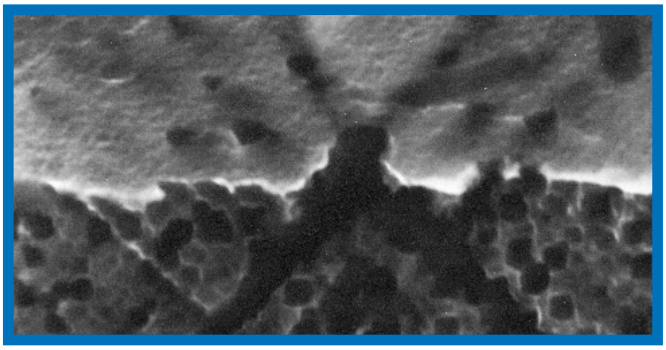
If monocrystalline silicon is desired, an annealing process can be used. The poly layer that is in direct physical contact with the SCSi substrate will then recrystallize into the same crystal as the substrate. Hence, a monocrystalline material is formed again.

Porous silicon is a form of monocrystalline silicon that is finding its way into MST. By anodizing the silicon and etching it in an HF/alcohol mix, pores can be etched in the material. Depending on the etching parameters, such as current density or dopant type, these pores can either be wide or fine, be straight or have a finely branched arrangement.

Porous silicon can be used, for instance, in photo- or electroluminescence. But other interesting ways of using it benefit from the extremely large surface available. Porous silicon is oxidized very quickly, which makes it useful as a sacrificial layer. For capacitors or chemical sensors, it is of value to have as large an available surface as possible on a confined chip area.

Epitaxially grown silicon, or epi for short, are layers that are grown onto a single crystal, atom by atom, *maintaining the crystal orientation*. Hence, you can have extremely abrupt changes of material parameters, for example doping, within the single crystal. This is, as you might guess, a very expensive material compared to all the others. But in MST, material consumption is not very large, so if necessary, even expensive materials can be justified.

Lars Rosengren
Uppsala University
Fax:+46-(0)18-55 50 95
E-mail:lars.rosengren@teknikum.uu.se



A cross-sectional cut through a porous silicon wafer showing sub-µm pores.

PRETTY PAPERS AT EUROSENSORS X

The 10th Eurosensors conference was held on Sept. 8–11 in Leuven, Belgium. The concept of the conference is to offer an up-to-date impression of the scientific activities in the field of sensors and actuators, in Europe as well as from all over the world. This year more than 350 papers were presented, and the number of participants approached 500 with as much as 20% from former eastern Europe.

The micromachining community was well represented with papers on both etching (several papers presented micromachining using porous silicon as a sacrificial layer) as well as low-temperature bonding. There were also several papers that presented fully CMOS integration with micromechanics.

My own favorite this year was one of the invited plenary speeches, *Fiber optical chemical sensors* presented by Paul O'Leary, Graz, Austria. It was not the expected review of fiber optic chemical sensors but a critical review on how they have been presented. O'Leary points at the increasing tendency to publish "pretty papers" which present beautiful results and ignore many of the problems. His points were enlightened with examples from one of his own early published papers. As a conclusion O'Leary says: "The research and development can only gain from openness and honesty. And please reviewers, be more stringent. And to the whole community: Please, don't write pretty papers!!"

Ylva Bäcklund
Uppsala University

The Center for Advanced Micro Engineering at Uppsala University

In a previous edition (*MSB 96:1*) the launching of a new Center for Surface and Micro Structure Technology (SUMMIT) at Uppsala University was described. The activities within SUMMIT are oriented toward the industrial needs for MST-related research, and several small, medium and large-sized Swedish industries are directly involved.

During the fall of 1996, another new MST-related research center was started at Uppsala University: The Strategic Center for Advanced Micro Engineering (AME).

The activities of AME will be complementary to the SUMMIT-based activities as issues of a more fundamental and long-term nature will be addressed. Still, AME ultimately aims at satisfying existing and future R&D needs of Swedish industry and society, and a close collaboration between AME and SUMMIT is planned. In fact, the head of both AME and SUMMIT is the same person, Professor Jan-Åke Schweitz.

Cross-disciplinary Center

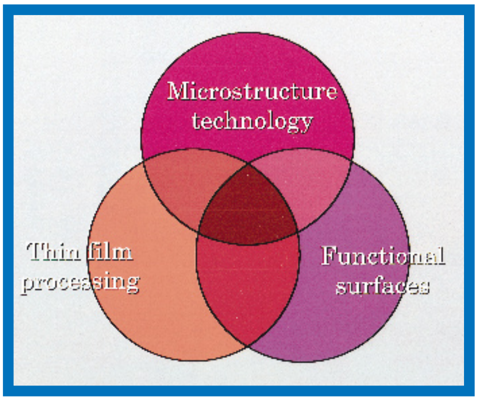
AME will implement a program for cross-disciplinary research and graduate education in the interconnected fields of micro structure technology (MST), thin film processing, and functional surfaces.

Micromechanics is the generic technology behind MST, which comprises the fabrication of micro devices ranging from simple and passive micro structures to advanced and multifunctional micro systems.

Micromechanics and MST rely heavily on recent advancements in thin film processing. MST-based devices always depend on the functionality of surfaces in thin or layered structures. They involve a multitude of materials, processes and microsize applications in physics, chemistry, biology, medicine and, of course, in all branches of engineering. Nanometer structures are considered part of this field.

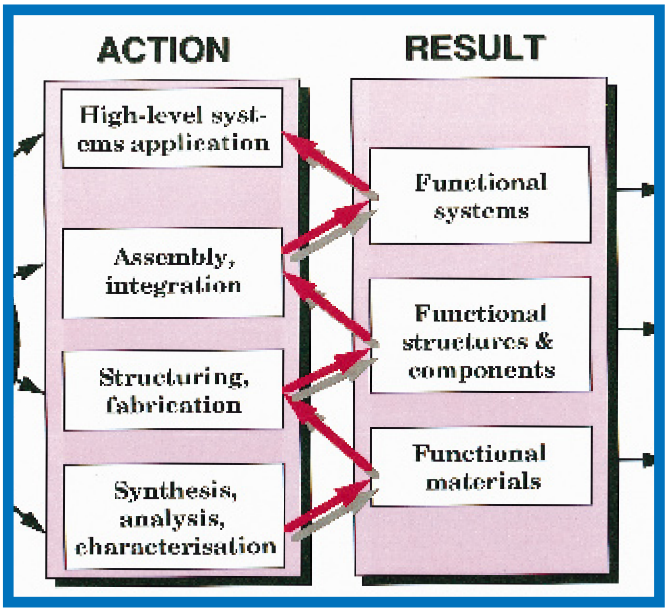
Participants

Participating research groups at Uppsala University are Materials Science, Electronics, Inorganic Chemistry, and Solid State Physics. These groups constitute the scientific nucleus of the Ångström Laboratory, housed in a newly constructed 35,000 m^2 facility for research and education.



The three fields of research comprising the program.

AME will establish a long-term scientific collaboration with leading universities and institutes in the world, including exchange programs for graduate students, post-docs and senior scientists. The Center will expand its collaboration with Swedish industry in research and education, aiming towards an increased employment of PhDs in industry and an increased participation of industry personnel in the activities of the Center (adjunct professors, graduate students from industry etc.).



General flow chart for vertically integrated research.

Objective

The objective of AME is to obtain an internationally leading scientific position, and to contribute in introducing important, emerging technologies to Swedish industry, by providing knowledge, competence and educated personnel at early stages in the development of such technologies.

The Center will include a graduate school with a total of 40 graduate students. The graduate school will provide an interdisciplinary graduate education with special emphasis on international and industrial interaction. Relevant undergraduate programs will be modified to stimulate an effective coupling and bi-directional communication with the graduate school.

The research and education in AME will be closely integrated in a lateral, cross-disciplinary, sense. The research activities will also be integrated in a vertical sense, from basics to applications, in order to ensure an efficient transfer of academic knowledge into practical results of relevance to society.

Main Fields and Financing

Initially the research projects will be oriented toward three main fields: medical and biomedical applications, optical and magnetic applications, and space applications including telecommunications. Fundamental research problems to be addressed are found in, for instance, MST-related analysis, characterization and testing, nano-structured materials and systems, signal-converting materials, and new methods and processes for 3D micro shaping and joining.

A financial support of 15 MSEK per year for a duration of ten years has been conditionally granted by the Swedish Foundation for Strategic Research (FSR). Besides from FSR, AME is funded by other sources, such as faculty funds, research councils and NUTEK. These additional activities comprise research and education which are already in line with the goals of AME, or which can be reoriented to fit in.

Jan-Åke Schweitz, Uppsala University
Phone +46-(0)18-18 30 89
Fax: +46-(0)18-18 35 72
E-mail: jan-ake@teknikum.uu.se

Mechanical Characterization with Micromachined Structures

The use of micromachined mechanical details has increased in recent years, e.g. in the field of sensors. The mechanical characteristics of microstructures must be measured with micromachined test structures in order for the values to be accurate. The Materials Science group at Uppsala University has a long experience in measuring the mechanical properties of silicon, dating back to 1985. Recent measurements include tensile tests with the aid of micromanipulator based test equipment, and internal stress evaluation from specially designed structures. During design and evaluation of test structures, Finite Element Analysis (FEA) is a crucial tool.

Tensile Testing

Below, an SEM (scanning electron microscope) picture shows a test structure in surface micromachined poly silicon used for measuring tensile stress. The test unit is mounted on a micromanipulator adapted for use in an SEM where the test procedure can be monitored in high magnification. The test unit is equipped with force sensors and an optical displacement sensor to measure parameters such as fracture strength and Young's modulus.

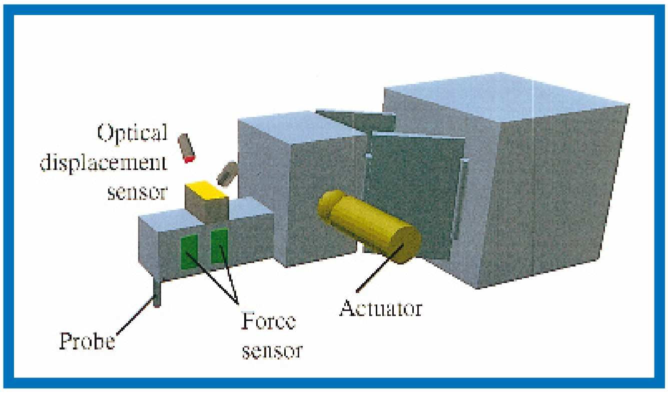
Internal Stress

The internal stress can be compressive, tending to expand a structure that has been released from its substrate, or tensile which shrinks a released structure. The internal stress often varies across the thickness of a film, giving rise to a stress gradient that will bend a structure upwards or downwards toward the substrate.

To measure internal stress, a structure was designed based on earlier studies. It consists of two actuator beams attached to an indicator by slender hinges. An internal stress in the actuator beams will deflect the indicator through an angle proportional to the stress. The structure is placed opposite to its own mirror copy to enhance the readout. A Vernier scale on the indicators makes evaluation with an optical microscope possible. FEA was used both to optimize the design and to evaluate the indications of the structure. The structure evaluates both compressive and tensile stress, and its design is so compact that it can be included in the wafer layout of other devices to be used for on-line process diagnostics. This is done, for instance, by Bosch Automotive Equipment in Germany.

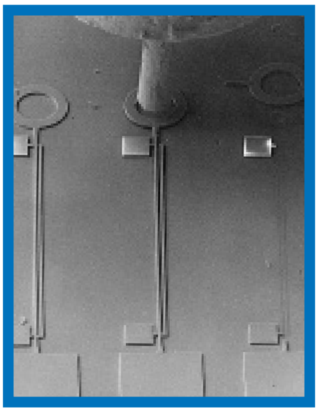
The stress gradient has been determined by measuring the curvature of cantilever beams in a microscope, and by evaluating these results with the aid of FEA.

Ongoing and future studies include the investigation of electroplated metals, such as nickel, and III-V semiconductors, such as InP.

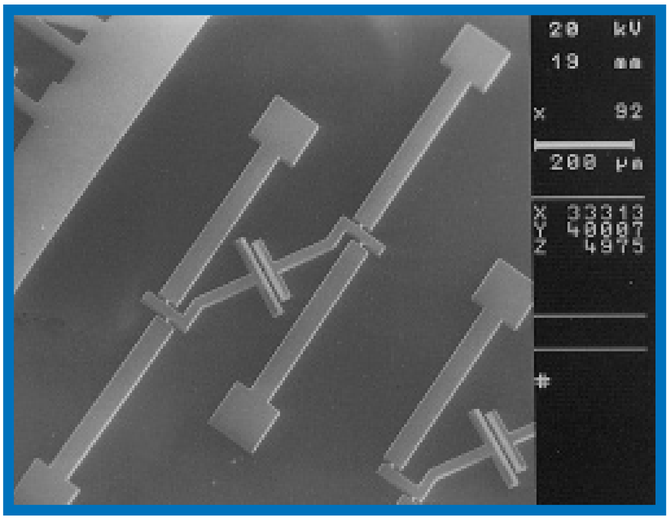


A schematic view of the test unit.

Staffan Greek and Fredric Ericson, Uppsala University
Fax: +46-(0)18-18 35 72
E-mail: Staffan.Greek@teknikum.uu.se



A tensile test structure consisting of a beam with a ring fixed to the substrate by a base plate. At the top, the probe of the test unit is about to grip the ring.



A structure used to evaluate internal stress consisting of two actuator beams and an indicator structure.

DISSERTATION

MSB congratulates Pontus Eriksson on successfully having defended his work for the degree of Licentiate of Engineering on October 4 at the Royal Institute of Technology (KTH). His thesis, *Surface Micromachined Bolometers Intended for Long Infrared Wavelength Detector Arrays*, deals with a 50×50 μm^2 microbolometer. A bolometer is a thermal IR detector that measures a radiation induced temperature difference as a change in electrical resistance. Silicon nitride was used for the membrane, platinum or amorphous silicon for the resistor, and polyimide as a sacrificial layer. A total absorption of 84% and a resolution limit of 84 mK is expected for the wavelength range of 8–14 μm when using a silicon based interferometric absorber.

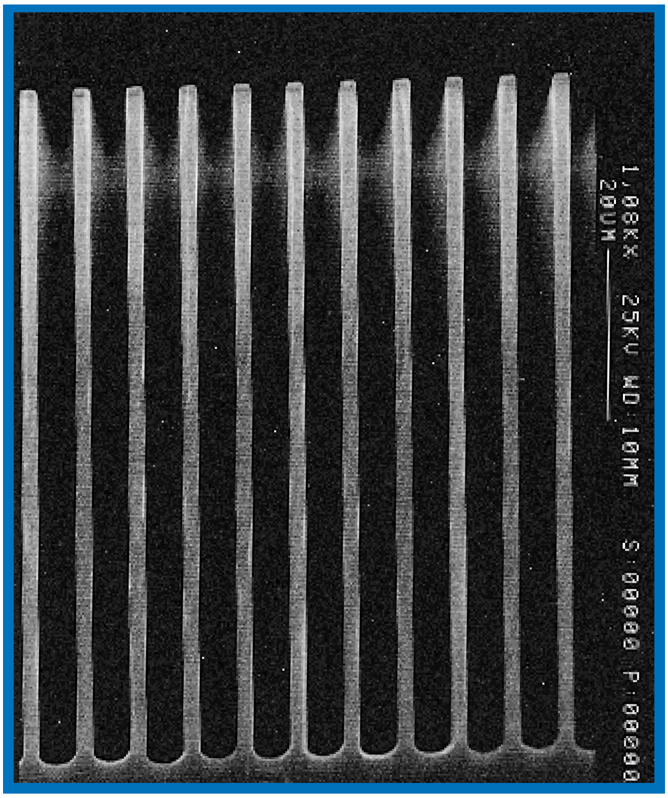
New A.S.E. Process for Deep Anisotropic Etching

An increasing number of applications now require high etch rate deep anisotropic silicon etching. Process requirements can be exceptionally demanding:

1. Etch depths ranging from several tens to hundreds of microns for micro-machining applications.
2. Sidewall angle ranging from anisotropic (89–90˚) to even re-entrant (>90˚). Smooth etched surfaces are usually necessary for optimum device performance.
3. Large aspect ratios, typically > 10:1 and occasionally > 20:1.
4. Accurate etch depth and profile control across the wafer, typically for a 150 mm wafer this should be within ± 3.0%.
5. Minimization of particle and contamination levels.
6. Use of fluorine based process chemistry.
7. Use of standard positive photoresist mask.

These requirements have all been fully addressed by the new Advanced Silicon Etch (ASE) process. ASE has been developed on the Multiplex ICP, which is a high plasma density low pressure processing system. Enhanced wafer cooling is used to maintain accurate wafer temperature control using either mechanical or electrostatic clamping with He backside cooling.

Prior to the development of the ASE process, STS investigated a number of processes for MEMS Si etching applications. The key parameter of the sidewall passivation was the fundamental item that differed between the various techniques studied. For example, sidewall passivation for anisotropic etching can be achieved by using cryogenic temperatures in the –100˚C to –130˚C range. This can produce near anisotropic etching up to 70 µm in depth using SF_6/O_2 based chemistry. However, the cryogenic system significantly increases equipment complexity and cost, and introduces anisotropy limitations for high aspect ratios. Another major drawback is that contaminants condensate on the wafer, the coldest surface in the chamber. This severely affects reproducibility. Additional problems, such as cracking of the photoresist at the low temperatures, further limit this approach.



STS ASE SiO_2 mask: 80 µm deep, 4.5 µm space widths, and 2 µm line widths. Aspect ratio equals 18.

The new ASE process is based on a patented novel processing technique which overcomes the limitation of cryogenic etching, and provides very accurate profile control. Rather than freezing the etch products, this technique relies on conventional sidewall passivation to inhibit lateral etching and maintain profile control. This allows the use of fluorine based chemistry to etch the silicon anisotropically at high rates, with good selectivity to the photoresist mask. Typical process results are presented in the following table, while the accompanying SEM illustrates just one capability of the process. Further details on processes and applications are available upon request.

Some typical results of ASE include:

- Etch Rate: > 2.5 µm/min
- Selectivity to Resist: > 75:1
- Selectivity to Oxide: >150:1
- Etch Uniformity: < ± 3.0%
- Etch Depths: > 500 µm
- Aspect Ratios: > 20:1

Ian Wright, Surface Technology Systems Ltd., United Kingdom
Tel: +44 (1495) 249044
Fax: +44 (1495) 249478
URL: http://www.stsystems.com

SPIE

On October 14–15, the second SPIE symposium on *Micromachining and Microfabrication* was held in Austin, Texas, USA, in conjunction with SEMICON/ Southwest '96. Scandinavia was represented by two invited presentations (Colibri, MIC) and one poster (MIC).

The presence of industry was noticeable among both the organizers and the more than 300 participants. The symposium is well summarized by the following collection of guiding principles presented by industrial speakers:

- Do not over-design
- Do not reduce size more than necessary
- Do not be too technologically oriented/blind
- Microstructures obey the laws of physics
- Learn from conventional and micromachined sensors
- Employ good designs
- Thicker, more 3D-like, parts perform better and are less expensive
- Better-looking (esthetic, clean, symmetric) parts perform better
- Know your tools
- Use clean rooms
- Reliability issues motivate the inclusion of test structures on wafers
- Process technology moves toward robustness, except for packaging
- Packaging usually drives cost
- MST is an automotive opportunity, not a necessity
- May require another decade before a variety of MST components are widely used in vehicles

Jan Söderkvist

Capacitive Silicon Accelerometers

VTI Hamlin has, in a short period of time, become a leading supplier of low-g accelerometers to the automotive and non-automotive industry. This achievement is mainly based on the performance and reliability of VTI's sensing element technology.

VTI's sensors are based on capacitive detection, and are micromachined in single crystal bulk silicon. When needed, silicon areas are isolated from each other with glass layers. The beauty of capacitive sensors is that the change in capacitance is a direct measure of the physical phenomenon, for example acceleration or pressure, causing a displacement. The sensitivity of the sensing element is only determined by mechanical dimensions and mechanical properties of single crystalline silicon. Silicon is only being used as an elastic and conductive material. This all gives silicon capacitive technology its excellent stability and reliability.

In VTI's products, only room temperature calibration is needed because of the low thermal dependence of the sensing element. This provides significant cost savings in volume production. Each individual sensing element is hermetically sealed already during the wafer processing before dicing, which improves reliability and also reduces the cost of packaging.

VTI Hamlin recently introduced the new SCA 600 accelerometer chip. The SCA 600 is a true two-chip solution which combines an electrically trimmed ASIC with a silicon capacitive sensing element in a plastic IC package. The ASIC circuit includes a self test function which deflects the sensing element's proof mass to provide true full system diagnostics. Also, the ASIC has memory parity check to verify the memory integrity. The combination of small package size, low cost and high performance makes the chip ideal for most low-g (up to 3g) and high-g (up to 500g) applications. The size of packaging is 9×5×11 mm^3. Leg pitch is standard 10 mils, and SMD or through hole type parts are available. The accelerometer weighs less than 1 gram.

The possibilities for VTI sensors are unlimited, and they play a vital role in a number of industrial applications. The sensors can be used in various motion, vibration and shock measurements as well as in the measurement of inclination. VTI's acceleration sensors are used in automotive applications throughout the vehicle, including passive restrain systems, electrically controlled suspension systems, anti-lock braking systems, vehicle stability management systems, inclination systems etc.

Henrik Hultin and
Jouni Hänninen, VTI Hamlin
Fax. +358-9-894 9789
E-mail: henrik.hultin@vti.fi
http://www.vti.fi

PATENTS

The US Patent Office provides access to their database on their web-site http://www.uspto.gov. To facilitate finding relevant patents, an easy-to-use search engine is provided. Patent abstracts and bibliographic data can be downloaded free of charge.

PUBLICATIONS

Some MST-related results published during the last months:

- Chemical Wet Etching of InP; Å. Richard (UU); *UPTEC 96 126E* (diploma work) (Aug. 1996).
- Design and Fabrication of a Gripping Tool for Micromanipulation; G. Thornell, M. Bexell, S. Johansson and J.-Å. Schweitz (UU); *Sensors and Actuators A*, **53** (1996) 428–433.
- Electrochemical Micromachining of Chromium and Nickel; L. Hillevärn and R. Lindman (UU); *UPTEC 96 118E* (diploma work) (Aug. 1996).
- Enhanced Enzyme Activity in Silicon Integrated Enzyme Reactors Utilizing Porous Silicon as the Coupling Matrix; T. Laurell, J. Drott (LTH), L. Rosengren (UU) and K. Lindström (LTH); *Sensors and Actuators B*, **31**(3) (1996) 161–166.
- New Method for Testing Hermeticity of Silicon Sensor Structures; M. Nese, R.W. Bernstein, I.-R. Johansen and R. Spooren (SINTEF); *Sensors and Actuators A*, **53** (1996) 349–352.
- Sensor Foundries and Production of Sensors at SensoNor a.s; H. Jakobsen (SensoNor); *J. Micromech. Microeng.*, **6**(1) (1996) 193–196.
- Surface Micromachined Bolometers Intended for Long Infrared Wavelength Detector Arrays; P. Eriksson (KTH); Licentiate thesis, TRITA-ILA 9602, ISSN 0281-2878 (1996).
- Vibration Modes of a Resonant Silicon Tube Density Sensor; P. Enoksson, G. Stemme (KTH) and E. Stemme (CTH); *J. Microelectromechanical Systems*, **5**(1) (1996) 39–44.

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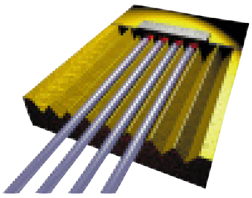
NEXT ISSUE

Some topics covered will be:

- the BRO-project
- Replication in polymers



Micro Mechanics Program at Uppsala University

PhD students are invited to participate in graduate studies, and research within the field of Micro Structure Technology (MST), with applications in sensor and actuator technology, micro optics, medical technology and space technology. Candidates will work in close cooperation with two newly established centers for research and training: AME (see page 3) and SUMMIT (see *MSB 96:1*). Training will take place in the recently built and ultramodern Ångström Laboratory.

Recruitment of new candidates will take place in stages toward the end of 1996 and at the beginning of 1997.

A suitable background would be MSc in Engineering (civilingenjör) or corresponding, with adequate specialization in the fields of physics, chemistry, materials or electronics.

Inquiries to Professor Jan-Åke Schweitz, Uppsala University, Box 534, SE-751 21 Uppsala, Sweden. Phone: +46-(0)18-18 30 89, fax: +46-(0)18-18 35 72, E-mail: jan-ake@teknikum.uu.se.

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FUTURE EVENTS

MEMS-97 (Micro Electro Mechanical Systems), Nagoya, Japan, Jan. 26–30, 1997. For information contact: MESAGO Japan Corp., Fax: +81-3-3359 9328.

MSK '97 (Mikro Struktur Kurs) in Uppsala, Sweden, preliminary March 18–19, 1997. For information contact: J. Söderkvist, Fax: +46-8 510 116 15.

Optical Microsystems for Telecommunication (course), Uppsala, Sweden, April 10–11, 1997. For information contact: FSRM, Fax: +41-327 200 990, or Y. Bäcklund, Fax: +46-(0)18-55 50 95.

Sensor 97, Nürnberg, Germany, May 13–15, 1997. For information contact: ACS Organisations GmbH, Fax: +49-5033 1056.

51st IEEE Int. Frequency Control Symposium, Orlando, USA, May 28–30, 1997. *Abstract deadline: Jan. 6, 1997.* For information contact: Thomas E. Parker, NIST, Fax: (303) 497-6461.

Transducers '97, Chicago, U.S.A., June 16–19, 1997. *Abstract deadline: Dec. 10.* For information, contact 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.

Eurosensors XI, Warsaw, Poland, Sept. 21–24, 1997. *Abstract deadline: Feb. 28.* For information contact: Prof. Zbigniew Brzózka, Fax: +48-22-660 54 27.

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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.

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