MICRO STRUCTURE BULLETIN

Newsletter for Nordic Micro Structure Technology, Vol.4, No.3, Aug 1996

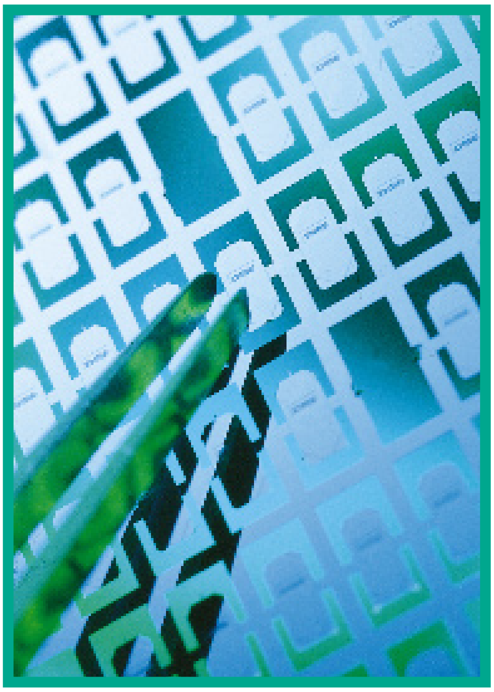
Industrial-Academic Collaboration in Denmark

Although relatively young, Micro Structure Technology (MST) activities are progressing rapidly in Denmark. An important contribution to this is the governmentally supported Mikroelektronik Centret (MIC), founded in 1990, and affiliated with the Technical University of Denmark (DTU).

The formation of MIC was encouraged by Danish industry which early recognized the potential of micromachining and MST. The small size of many companies in Denmark (SME's) enhanced the need for collaborations in retaining their position as relatively large players in their respective niches of the world market. This has already led to the first commercial product designed, developed and produced at MIC in collaboration with one of its partners.

The collaboration often involves industrial researchers stationed at MIC and a strong participation in education. Only occasionally is the relationship that of a client-supplier nature. In this way, MIC acts as a center of excellence that increases the competence level in a way that Danish industry can benefit from. The unique combination of various areas of research, a well-balanced mix of national and international staff, and MIC's medium size is favorable for different research and development areas to strengthen each other.

MIC is interested in extending their collaboration also to partners from the other Nordic countries. MIC and its present partners are also ready to take part in European collaborations on technology development. For instance, they strongly support the realization of a Nordic microsystems manufacturing cluster in the frame of the EU-program, *Europractice*. In conclusion, much can be expect from Denmark in the near future.



Removing commercial atomic force microscope (AFM) probes from a wafer (photo: Karsten Damstedt).

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Micro Structure Science
and Technology
Uppsala University

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EDITOR'S NOTE

I would like to welcome Denmark to MSB. Although new to MST, their high-quality activities are growing rapidly. MSB will continue to summarize activities from all Nordic countries.

The next issue will feature silicon as a micromechanical material. The BRO-project and replication in polymers will be described in the issue thereafter. As always, contributions, suggestions and comments are encouraged and welcome.

Despite the saying, "there is no bigger challenge than to communicate efficiently", I believe that the time spent putting MSB together is well worth the effort. I would, therefore, like to express my thanks to all your comments and contributions to the 96 pages produced during MSB's first three years.

Jan Söderkvist

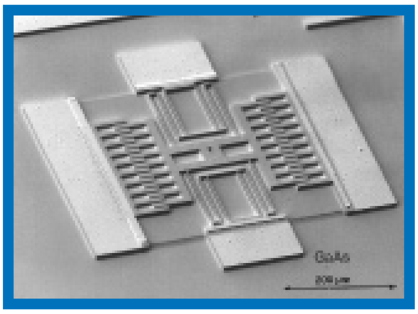
AWARDS

The wonders of micromachining reached a new audience in May during a simulations conference in the U.S.A. with more than 550 participants. Two contributions from Scandinavia involving MST were awarded (Piezoelectric Simulations Validated on Beams by J. Söderkvist, and Thermal Excitation of Mechanical Vibrations by J. Söderkvist and A.-L. Tiensuu). The first was chosen as best paper of the conference and both were chosen as best paper of their respective sessions.

III-V Compounds at Uppsala University

Although the major research effort in micromechanics emphasizes silicon technology, other materials may provide the best system solutions for certain applications. For example, the micromechanical device with the largest impact on society, the quartz tuning fork used as frequency reference in watches, is produced in one billion pieces a year worldwide (cf. *MSB 96:2)*.

This illustrates that the products with the largest volume may be found outside of the sensor area. Also, it may be advantageous to use materials with special characteristics, for example, quartz for temperature stable resonators and III-V compounds for optoelectronic applications.



Surface micromachined structure in GaAs made in collaboration with Chalmers.

Recently, optical MEMS have become an area of great interest, with driving applications such as inexpensive devices for the forthcoming Fiber-to-the-Home telecommunications and gas sensors for environmental control.

GaAs

In micro-optoelectronic applications, e.g. lasers, photo diodes and photo transistors, III-V direct band-gap compounds are predominant. This should also be the case when micromechanics are integrated with optoelectronic structures. Much encouraging work has recently been made in GaAs-based (GaAs) micro-opto-electro-mechanical systems (MOEMS).

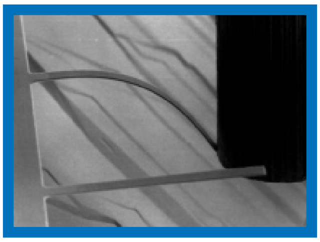
Uppsala University has a long tradition in III-V-based micromechanics, starting in 1984 with a collaboration with ASEA Corporate Research on GaAs based micromechanics (see *MSB 94:3*). This research has been concentrated on capability proofing, fracture strength testing for micromechanical structures, bulk and surface micromachining, anodic and direct bonding, and using piezoelectric properties in resonant structures.

InP

Today, this research effort has moved into the area of indium phosphide-based (InP) micromechanics. In collaboration with the Royal Institute of Technology in Stockholm and the Ecole Centrale de Lyon in France, it is proposed that InP based surface machined micromechanics could provide cost effective MOEMS, and be used for longer wavelengths than is possible with GaAs.

The micromachining technologies are already available for the processing of InP-based optoelectronics and silicon based micromechanics. For example, surface micromachined structures like the paddle shaped structure shown below have already been constructed.

However, InP based structures have not been used in micromechanical applications. As previously was the case for GaAs, there is a general skepticism concerning InP's mechanical strength. Indeed, in wafer sizes the material is more fragile than GaAs, and much more fragile than silicon. A study is currently in progress to determine whether micromachined InP structures possess sufficient strength for micromechanical applications. Based on the fracture toughness, the strength of InP microstructures is expected to be about 80% of that observed in GaAs, given the same defect distribution. This corresponds to a maximum strength of four times that of construction steel.



Bending of an InGaAs beam epitaxially grown on InP. The 200 μm long beam is bent more than 100 μm.

Parallel studies in the near future related to InP-based micromechanics include heterostructure bonding with InP, and InP-based fluidic self-assembling micro structures.

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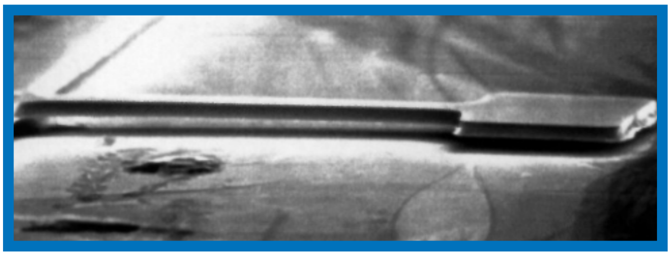

Surface micromachined InGaAs paddle on InP, made at the Laboratoire Electronique, Ecole Centrale de Lyon

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Mikroelektronik Centret (MIC) is a new Danish research institute investigating semiconductor materials and devices. MIC was founded in 1990 as an autonomous national institute affiliated with the Technical University of Denmark (DTU). The charter for MIC defines a 3-fold mission: scientific research at an internationally competitive level, technology transfer to Danish industry, and education of engineers and PhDs within the framework of DTU.

Status

During MIC's 5 year start-up period a board was formed and management and staff were recruited. Processing facilities were planned and built, and these were inaugurated in December 1993. In its fifth year of existence, MIC was extensively evaluated and was granted basic funding for the following 4 years.

MIC received a start-up grant of 130 MDkr from the Ministry of Education, supplemented with 50 MDkr from the Ministry of Industry. The latter was associated with the Materials Centre for Microelectronics (MCM), a public-private collaboration project of MIC with Danish industry. The budget was roughly divided evenly between construction, equipment, and recurrent expenses. Currently, MIC receives 25 MDkr per year from the Ministry of Education, and externally financed projects account for an addition about 15 MDkr per year.

MIC is lead by a management which is advised by an international scientific council, while the management is accountable to MIC's board of directors. Currently, more than 90 people are active at MIC, including administrative, technical and scientific staff. MIC hosts large numbers of industrial researchers, process specialists, postdocs and PhD students.

Collaboration with Industry

Industry plays a significant role at MIC. Within the MCM collaboration, which lasts from the beginning of 1992 until the end of 1996, 5 Danish companies (Danfoss a/s, Grundfos a/s, Brüel & Kjær a/s, NKT a/s and Topsil a/s) collaborate with MIC to establish a basic competence in silicon technology. This 58 man-years collaboration is now reaching its final stage with several demonstrators as means for taking the last steps towards the desired level of competence.

Photo: Jens Lindhe

More recently, new large industrial collaborations for the development of more specific technology platforms were initiated. Some of MIC's PhD and postdoctoral projects are an integral part of these collaborations, while many of the industrial researchers are stationed at MIC. In addition, MIC operates several smaller industrial PhD projects, in which the candidates are recruited by the industrial partner and are stationed at the institute for the duration of the project.

Besides financial support from government programs, all partners, including MIC, contribute from their own resources towards these collaborations. Only in rare occasions has the relationship between MIC and industry been of a client-supplier nature, one example of which is the small scale production of commercial AFM probes which resulted from a research collaboration.

The presence of industry is also tangible in education. Industrial researchers stationed at MIC are involved in some of the undergraduate and graduate research projects, while researchers from industrial R&D departments provide guest lectures and act as external evaluators during examinations at the graduate and PhD level. In addition, industry has a majority in MIC's board, including the chairman position.

Laboratory Facilities

MIC's laboratories include a class 100 clean room with a floor space of 560 m^2 for processing of 4” silicon wafers, with state-of-the-art equipment for basic competence and specific equipment for innovative processing. This infrastructure is continuously being upgraded.

Towards the design of the clean room and the choice of equipment and procedures, safety, cleanliness and large batch processing all played a major role. Still, the conditions are optimum for developing device specific process sequences with large flexibility. Researchers do their own processing.

Below the clean room, MIC has equipped a laboratory for Nanotechnology, including a set-up for laser micromachining. Furthermore, MIC has several laboratories for device characterization, as well as for surface analysis, including the so-called DanSIMS, a national facility for Secondary Ion Mass Spectrometry.

Outlook

During its start up phase, MIC, with the aid of its industrial partners, has built up basic competence in silicon technology. The close collaboration with Danish industry that is made possible in the industrial landscape of Denmark (many SME's, all relatively large players in their respective niches of the world market), is beginning to show results.

Currently, several demonstrators are approaching their completion. The first commercial success resulting from an industrial PhD project is encouraging. MIC and its partners are now ready to take part in European collaborations on technology development in the area of microsystems technology.

For the production of larger volumes, which is not consistent with MIC's commitment to research, the attitude of MIC's industrial partners is also collaborative. Together with MIC, they are currently investigating the possibilities of an alliance with prospective and existing sensor foundries. MIC supports the realization of a Nordic Microsystems Manufacturing cluster in the frame of Europractice.

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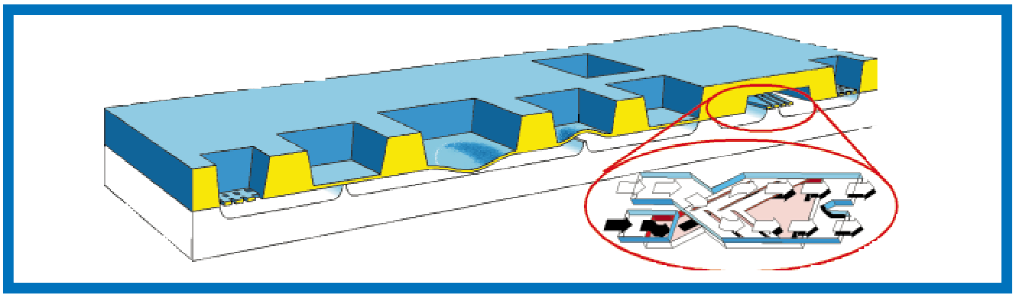
Research Areas @ MIC

The research at MIC covers a broad spectrum ranging from fundamental to applied research. MIC's three research areas are each subdivided into three research groups: *Nanotechnology* into theory, semiconductor physics and nanomachining, *Photonics* into passive waveguides, active waveguides and diffractive optics, and *Microsystem Technologies* into microelectronics, micromechanics and microfluidics. Only the third area is presented here.



Cross-section of a microliquid handling system consisting of, from left to right, an inlet filter, an inlet check valve (closed), a pump membrane, an outlet check valve (open), two active valves, a micromixer (see insert), and an outlet filter. The mixing, which is based on interdiffusion of laminated flows, is predicted to give mixing times of a few milliseconds also for flows with small Reynolds numbers when the folding is repeated three times.

Microelectronics

The microelectronics research program focuses on technology development for CMOS on silicon-on-insulator (CMOS-SOI). This process yields robust semiconductor devices with good dielectric isolation properties. It is highly suitable for flexible hybrid and monolithic integration with micromechanical transducers.

In addition, thick resist technology and electroplating are being developed in collaboration with DTU's Process Technology Institute as an add-on technology for mechanical and magnetic functions.

Micromechanics

The micromechanics program focuses on design and realization of transducers, and on innovative concepts for transducer packaging.

As an example, in an industrial PhD project in collaboration with Brüel & Kjær a/s, technology for strain gauges based on Bragg gratings in planar waveguides is under development for accelerometer applications. Another industrial PhD project aims at developing a silicon microphone for hearing aids in collaboration with Microtronic a/s. This is a very demanding application with respect to signal-to-noise ratio, supply voltage, power consumption, robustness and size. A third example is a collaboration with DME – Danish Micro Engineering a/s aimed at technology development for versatile tip shapes, and for integrated read-out for robust AFM probes with high sensitivity.

One activity on packaging concerns technology development for low-stress encapsulation of SAW devices, in collaboration with Ferroperm Components a/s. Packaging of industrial sensors exposed to aggressive media is under development in a collaboration with Grundfos a/s and Danfoss a/s. This 20 man-year project involves surface passivation layers, die attachment with hermetic seals, and robust electrical connections. In a 28 man-year project, Micro System Center, technologies for high performance and space-constrained microsystems are developed in collaboration with Microtronic a/s and DELTA.

The development of innovative processes includes rapid growth rate deposition of glass for anodic thin film bonding, and PECVD-grown thick layers of silicon (oxi-) nitride, germanium doped glass and boro-phosphosilicate glass. Several wafer-bonders for anodic, fusion and eutectic bonding have been developed, as well as sputter deposition equipment for thick layers of silicon, passivation layers, zinc oxide and other materials. Also, processes for laser micromachining of silicon, as well as for photolithography on highly stepped surfaces, have been developed.

Microfluidics

The microfluidics program is in close collaboration with Danfoss a/s. The flow behaviour in microchannels is studied, and appropriate components for microliquid handling are developed. Examples include flow sensors, check valves, active valves, diffuser/nozzle valves, filters, mixers, and hydraulic switches, all realized with silicon-to-glass wafer bonding.

Recently, these activities expanded strongly with the opening of PhD projects and postdoc positions. Technologies are under development for the integration of integrated optics, microchemistry and microliquid handling functions for use in MST-based chemical and biological analysis systems. A second major expansion through collaborations with external partners is expected within the next twelve months.

Siebe Bouwstra, MIC

DISSERTATIONS

MSB wishes to congratulate Torben Storgaard-Larsen for successfully having defended his doctoral theses at MIC in Denmark.

His thesis, entitled *Opto-Mechanical Accelerometers Based on Strain Sensing by a Bragg Grating in a Planar Waveguide*, treats a novel sensor principle based on wavelength encoding. The center wavelength of the light reflected by the Bragg grating is dependent on the grating period, and can be modulated by strain. The wavelength encoding nature of such sensors make them immune to phase and intensity noise. Also, they exhibit typical advantages of optical sensors, such as insensitivity to electro-magnetic interference.

To demonstrate that this type of optomechanical read-out can result in high performance microsensors, a uni- and a tri-axial accelerometer have been developed using anisotropic etching of (110) silicon. Both have the potential of μg-resolution and a wide dynamic range when combined with an interferometric wavelength decoding system. Such systems are capable of a strain resolution better than $6 \cdot 10^{-10}/\sqrt{\text{Hz}}$.

New waveguide glasses for fabrication of low stress waveguide bridges containing strain sensing Bragg gratings were developed. This includes, for instance, photosensitive silica based glasses that enable direct UV writing of Bragg gratings in integrated planar optical waveguide structures.

Laser Micromachining of Silicon

MIC has developed a process for laser micromachining of silicon. It provides for a wide variety of possible shapes, and enables design, realization and characterization of new structures within two days.

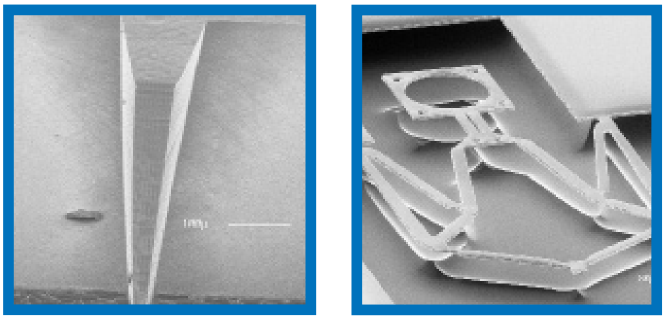
This micromachining is based on focusing a 0.5 watt laser beam onto a very small surface spot, typically 1 µm in diameter. The locally molten silicon reacts with chlorine gas, resulting in silicon chlorides gases. In this way, small volumes, typically sub-micron in dimension, can be removed.

A very high degree of freedom for three-dimensional micromachining is obtained by moving the sample with a computer controlled xy-stage, switching the beam on/off, and translating the objective. The stages used combine a repeatability of 25 nm with a travel range of 100 mm, and a speed of 100 mm/s. Although the size of the removed pixel can be reduced to 50 nm, the practical resolution is 300 nm.

MIC has applied this technique for the realization of diffuser/nozzle valves or flow diodes. Advantages are that length, width and taper angle can be chosen almost arbitrarily, and sharp corners can be avoided.

The technology for optimizing the design and realization of compliant microstructures used for converting magnitude and direction of forces and displacements has also been developed. Laser micromachining is used to pattern a silicon thin film mask, which is transferred to the underlying silicon oxinitride layer by Reactive Ion Etching.

Siebe Bouwstra, MIC



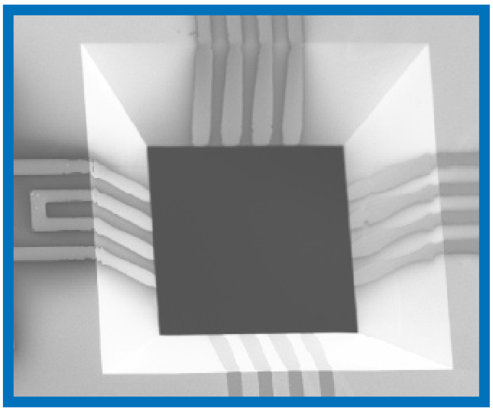
Laser micromachined diffuser/nozzle valve (left) and compliant microstructure (right)

Photolithography on Non-Planar Surfaces

MIC's work with electrodeposited photoresists is inspired by the difficulty of using conventional photolithography on highly stepped surfaces. These photoresists have recently become available on the market, developed for use on printed circuit boards.

Electrodeposited photoresists are formed by applying a voltage between the substrate to be covered and a stainless steel counter electrode. This process, which takes place in a solution containing micelles (granulates) of photosensitive polymer, enables the formation of a uniform several µm thick resist layer within a few seconds. In contrast to conventional photoresists, electrodeposited resists are virtually dry, which enables them to cover convex corners of arbitrary radius of curvature.

MIC has demonstrated the applicability of these resists for deep cavities formed by wet anisotropic etching of (100)-oriented silicon. Multiple feedthroughs with a high wiring density in through-holes of 500 µm thick silicon wafers have also been formed. Experimental results show the feasibility of 20 µm wide lines with 20 µm wide separations, leading to a density of 250 feedthroughs per cm. Potential applications include electrical contacts to the backside of membranes, and the realization of sensor structures on the side-walls of flow channels.



Feedthroughs realized using electrodeposited photoresists on both sides of the wafer.

Siebe Bouwstra, MIC

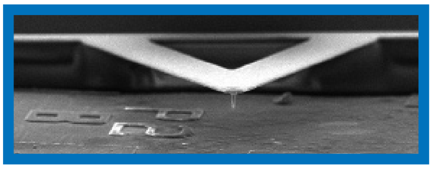
AFM Probes

MIC collaborates with DME – Danish Micro Engineering a/s on innovative probes for Atomic Force Microscopes (AFMs). Passive probes are now routinely produced for DME's product range, and are also used in MIC's Nanotechnology program for surface manipulation. Currently, active probes with an integrated read-out are being developed.

A technology for versatile tip shapes for AFMs has been developed based on reactive ion etching (RIE). All RIE steps, including undercutting a silicon oxide mask, coating with a polymer layer, etching, and removing the polymer, are performed without breaking vacuum. The structure is then oxidized, and the oxide is etched. This results in robust and slender rocket-tips™, typically 2 µm in diameter and 10 µm in height, and with radii of curvature of less than 20 nm.

The rocket-tips™ have been integrated with silicon cantilevers that are defined using a boron stopped KOH etch. The optimum cantilever dimensions, typically 1 µm thick, 50 µm wide and 180 µm long, are dictated by the required minimum value of the resonance frequency and the maximum value of the stiffness.

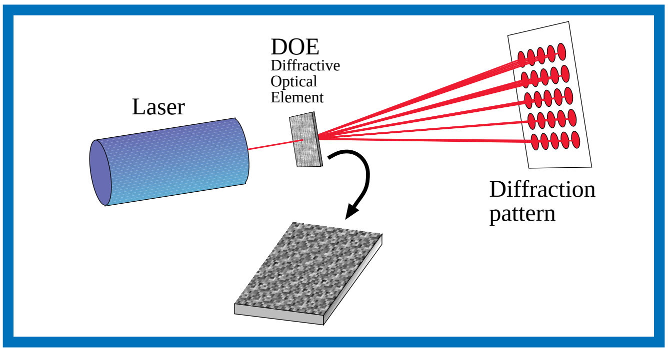
Siebe Bouwstra, MIC



Diffractive Optics ...

With diffractive optics, the propagation of light can be changed in an efficient and flexible way. A diffractive optical component is inserted in the beam in the same manner as a conventional lens, but it can be tailored to implement almost any optical function. For example, a single diffractive optical element may operate as a beam splitter (any number of output beams in any configuration), a corrector for the aberration in an optical system or a shaper of the beam cross section. It may also operate all of these functions. A system using diffractive optics can be more robust with fewer components than if built with conventional optics. Also, diffractive optical components are well suited for mass production with replication techniques.

Diffraction is the phenomenon of interference of light. By disturbing the electric field of a light beam, e.g. by phase modulation, one can change the positions in space where constructive interference occurs. A very simple example is a conventional lens which “disturbs” the beam so that constructive interference occurs in the focal point of the lens.



The laser beam is split into an array of 5 x 5 beams all having the same intensity (fan out component).

With modern micro fabrication techniques, significantly more complex lenses, called diffractive optical elements (DOEs), can be constructed which may be designed to have any number of constructive interference points in almost any position in space.

The primary function of the DOE is to change the propagation of light. A beam is incident upon the DOE, which consists of a thin plate of a dielectric material that is transparent at the wavelength used. A surface relief is present on one side of the plate, and is designed to phase modulate the incident electric field. The distribution in a plane at some distance behind the component can thereby be made to closely resemble a desired distribution.

A common application is a beam splitter (see the figure), in which the intensity (power) distribution at some distance behind the DOE is a number of small, intense spots at a specified lateral distance from one another.

Typically, the feature size of the relief is of the order of the wavelength or slightly larger, i.e. in the micrometer range. However, some interesting new applications, such as DOEs working as antireflection “coatings”, require sub-micron features. The material in which the DOE relief is written must be transparent at the wavelength used. Often, glass or fused quartz is used for visible light and semiconductor materials for the near-infrared part of the electromagnetic spectrum. The efficiency of the DOE can be as high as 80–90%. This is because only the phase of the incident beam is modulated.

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... at CSEM

CSEM, the Swiss Center for Electronics and Microtechnology, is located in the heart of Switzerland’s watch-making region. With a mission to provide research, development and specialized production services to industry, it relies on front-edge know-how and expertise in microelectronics, micromachining, microsystem fabrication, and bio-inspired techniques.

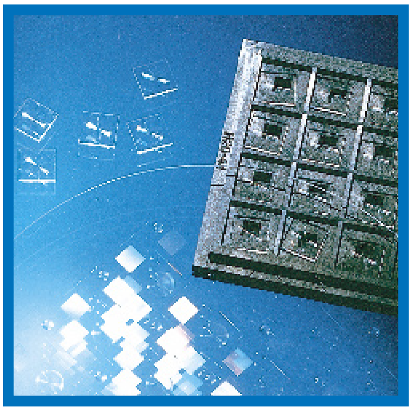
Diffractive optical elements (DOEs) are designed and manufactured for CSEM’s microsystems. Custom integration and prototyping is now offered externally at reduced costs with CSEM’s new Multi-Project Wafer (MPW) service.

The unique properties of DOEs, such as small size, light weight and great design flexibility, allow for the creation of new applications and products. The efficiency and usefulness of conventional refractive and reflective optical systems can thereby be improved.

However, the realization requires large production runs to which most industries or institutes cannot commit unless an inexpensive way of evaluating an idea exists. Unfortunately, the prototype cost is often too high.

To solve this dilemma, CSEM now offers an MPW service based on fused silica. Test samples and prototypes can thereby be realized at a cost of about 25% of that of a custom integration. The set-up of this MPW service is partially funded by the EU-program Europractice.

The MPW service includes mask design and fabrication, as well as processing and dicing. The DOEs may be designed by the customer or by CSEM’s CAD service.



Typically, specifications include 10 dies with a maximum size of 6.9×6.9 mm^2 each, produced from a 525 µm thick substrate. The smallest feature size is 1 µm and the maximum etching depth is 2 µm. 2, 4, and 8-level structuring is possible

Three MPW runs are scheduled each year. In particular, CSEM will accept projects with several wavelengths (different depths) within the same run.

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... at Chalmers University of Technology

At CTH, the research activities cover the whole spectrum of diffractive optics from the design of the diffractive optical element (DOE) relief and the fabrication of the DOE with micro lithography, to the replication of DOEs that enables low-cost mass production. There are also several collaborative projects with industry to test different applications of DOEs, such as high power beam splitters and components in fiber optic communications.

The typical DOE structure is complicated and requires the use of efficient computer algorithms for the design. The design also takes into account the effects of fabricating the micro structures, and compensates for the proximity effect of the lithograph process.

The fabrication of the DOE is done by electron beam lithography. Electrons are shot into a polymer resist spun on a substrate, causing some of the polymer molecular chains to break. The resist is then developed. The dissolving rate of the resist is highest in those parts with the most broken chains.

By adjusting the time that the electron beam is aimed at a point, the dissolving rate, and accordingly the final height of the relief at that point, can be controlled. One can thus obtain an almost continuous relief as the electron beam lithograph controls the exposure doses in 64 levels for each point. The relief in the resist can then be transferred into the underlying substrate with ion-etching.

A DOE fabricated in this way is expensive. In low-cost replication, therefore, it is desirable to use it only as a master for replications. Several techniques have been studied, such as hot embossing and injection molding. In addition, the technique used for making standard CDs has shown to be suitable also for the replication of DOEs.

Several applications of DOEs involve high power optical systems. A DOE has very little absorption and, therefore, needs no cooling even at high laser power levels. An example is a DOE that improves the quality of an Excimer laser UV-beam and shapes the beam cross-section into a square of constant intensity as shown below.

DOEs are also used together with semiconductor lasers in optical communication systems where their small size and the possibility of integrating the laser and the DOE onto the same chip are advantages. These DOEs are normally made in semiconductor materials (e.g. GaAs).

Further information is found on http://www.nt.chalmers.se/opticsgroup/research.html

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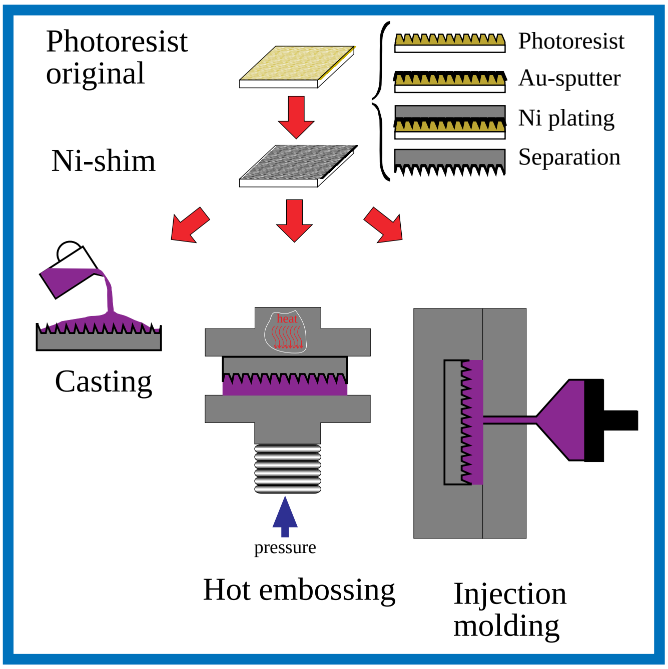
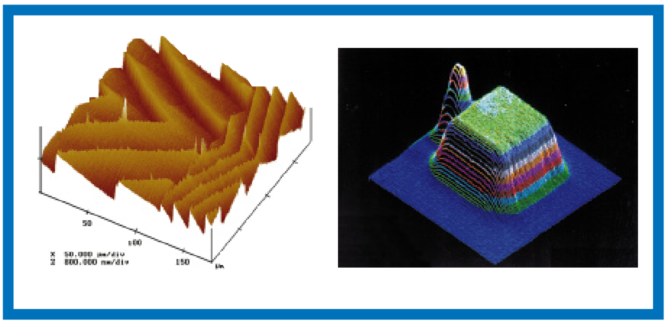


DOE replication techniques (upper). Example of DOEs replicated using standard CD (Compact Disc) fabrication techniques (injection molding).



AFM picture (left) showing the continuous relief (part of an array of off-axis Fresnel lenses) used for the redistribution of the energy in an Excimer laser beam. The resulting intensity profile of the reshaped beam is shown to the right. The small single spike is due to zeroth order diffraction and is easily masked.

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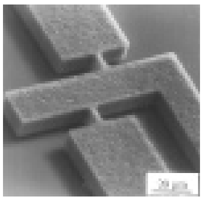
MICRO STRUCTURE BULLETIN NO.3 AUG 1996

NEXT ISSUE

The next MSB will feature a special issue on silicon as a micromechanical material.

Your contributions are welcomed.



PUBLICATIONS

Some MST-related results published during the last months:

- Fast Three-Dimensional Laser Micromachining of Silicon for Microsystems; M. Müllenborn, H. Dirac, J.W. Petersen and S. Bouwstra (MIC); *Sensors and Actuators A*, **52** (1996) 121–125.
- Modification of Silicon Surfaces with H_2SO_4:H_2O_2: HF and HNO_3:HF for Wafer Bonding Applications; K. Ljungberg (UU, presently at MIC), U. Jansson (UU), S. Bengtsson (CTH) and A. Söderbärg (Ericsson); *J. Electrochem. Soc.*, **143**(5) (1996) 1697–1702.
- Opto-Mechanical Accelerometer Based on Strain Sensing by a Bragg Grating in a Planar Waveguide; T. Storgaard-Larsen (Brüel & Kjær/ MIC), S. Bouwstra and O. Leistiko (MIC); *Sensors and Actuators A*, **52** (1996) 25–32.
- Photolithography on Micromachined 3D Surfaces Using Electrodeposited Photoresists; P. Kersten, S. Bouwstra and J.W. Petersen (MIC); *Sensors and Actuators A*, **51** (1995) 51–54.
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Eurosensors X, Leuven, Belgium, September 8–11, 1996. For information contact: Timshel Conference Consultancy & Management, Fax:+32-16-29 05 10.

MME'96 (MicroMechanics Europe), Barcelona, Spain, October 21–22, 1996. For information contact: Prof. J.R. Morante, Fax: +34-3-402 11 48.

µTAS'96 (Micro Total Analysis Systems), Basel, Switzerland, November 20–22, 1996. For information contact: Mrs. E. Müller, Ciba Geigy Inc., Fax: +41-61 696 45 04.

Engineering in Microsystems (course), Uppsala, Sweden, November 29, 1996. For information contact: FSRM, Fax: +41-38 200 990, or J. Söderkvist, Fax: +46-(0)8-510 116 15.

MEMS-97 (Micro Electro Mechanical Systems), Nagoya, Japan, January 26–30, 1997. *Abstract deadline: September 16*. For information contact: MEMS-97, c/o MESAGO Japan Corp., Fax: +81-3-3359 9328.

Sensor 97, Nürnberg, Germany, May 13–15, 1997. *Abstract deadline: September 30*. For information contact: ACS Organisations GmbH, Fax: +49-50-33 10 56.

Transducers '97, Chicago, U.S.A., June 16–19, 1997. For information contact: Ken D. Wise, Fax: (313) 747-1781.

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