MICRO STRUCTURE BULLETIN

Newsletter for Nordic Micro Structure Technology, Vol.5, No.1, Feb 1997

CONTENTS

MST in Plastics

Silicon micromachining enables the fabrication of microsystems using methods and materials from the semiconductor technology. The development is driven by demands for higher system integration and miniaturization, higher functionality and reliability, and cost reduction.

A characteristic of traditional silicon micromachining technologies is that production processes and materials contribute a large part of the total cost. In fact, the cost per device is strongly dependent on the size of the device.

Polymeric microreplication is a promising alternative for cost-reduction for certain applications. The microreplication technology is based on a three-step process, namely:

– microstructuring of a master,
– micro-electroforming of the mold insert, and
– replication with different micromolding methods.

Conventional polymeric injection and transfer molding techniques are expensive due to tight tolerance requirements on the molding cavities. The enabling tool may well be MST. However, "pure" silicon is not the best material for the mold insert itself. It is necessary to create plating replicas of the silicon master, a technology that is now sufficiently mature.

The possibility of MST-based polymeric replication to offer both cost-effectiveness and high quality in mass production is a good complement to X-ray based LIGA (Lithographie, Galvanoformung, Abformung). The first has the advantage of being faster and easier when fabricating the master, while the second is better at high aspect-ratio structures. MST-based polymeric replication is sufficiently accurate for most applications, and less expensive.

LIGA-formed structures have internationally been demonstrated in several applications, including microsensors (acceleration, pressure, torque), electronics, micro-optics (connectors, mirrors, lenses), microfluidics (nozzles, valves, pumps) and micro-actuators (motors, turbines, gear wheels, springs). In *MSB 96:3*, it was shown how polymeric microreplication can be used to realize small optical components based on diffractive optics (kinoform).

The three process steps in the fabrication of replicated polymeric alignment structures (upper: etched silicon master, left: nickel-plated mold insert of the silicon master, lower: polymeric replica of the mold insert). Courtesy of IMC.

EDITOR'S NOTE

The strong trend towards market-pull means that the best material for each application will be requested. It is, therefore, a pleasure to present one of the more interesting novel MST-materials, plastics, and its machining toolbox.

The expected yearly growth for MST-based systems is 50%, reaching nearly $10 billion in the year 2000. Pressure sensors may account for as much as one-third, with inertial sensors and components for data storage and communications accounting for more than another third of the total. Although any forecast can be controversial, it is clear that the MST market will continue to face an extraordinary growth, with the automotive field as the industrial driver.

Summarizing 1996 revealed a 28% increase in the number of *MSB*-subscribers. Considering the growth-rate for MST, it is our aim to match this number in 1997 in each Nordic country, especially among small companies which presently know very little regarding MST-based possibilities. Please help us by returning the coupon on the last page, and by making the existence of *MSB* widely known.

Unfortunately, it has come to our attention that an unknown number of the latest edition of *MSB* was lost in the mail. If you did not receive *MSB 96:4* (theme: silicon), please contact me (see last page for address) and I will send you a new copy.

Jan Söderkvist

Pharmacia and Polymeric Replication for Bioscience

In modern bioscience there is a need to study small biological systems. While traditional biology often was concerned with whole organisms, modern biology commonly involves the study of single cells, subcellular organelles and, even, single molecules.

To study these very small systems the tools must be miniaturized, including flow paths, detection systems and input/output means for sample and data. MST has been explored for the last 12 years at Biacore AB (formerly Pharmacia Biosensor) and Pharmacia Biotech as an enabling technology for bioscience.

Need for New Materials

Initially, all MST devices produced by Pharmacia Biotech were made in traditional micromechanical materials, such as single crystalline silicon, glass and quartz glass. For several reasons we soon realized that these materials were not ideal for many of the devices that we were trying to make:

1. *Cost:* One driving force for the use of micro fabrication techniques in bioscience is to obtain low cost and disposable devices. Most prototypes we studied required large areas despite their detailed features. As an example, a simple capillary electrophoresis prototype can occupy several cm^2.

2. *Transmission of light 250–700 nm:* Optical detection principles are standard in bio analysis (e.g. absorbtion, fluorescence and luminescence detection). Silicon structures do not transmit light in this wavelength window.

3. *Electrical conductivity:* Silicon is a semiconductor. For capillary electrophoresis, a high voltage (10kV) is applied to separate biomolecules in a liquid-filled capillary. Although the semiconductor properties of silicon can be masked with an insulating layer, it is still not an ideal material in this aspect.

Another observation was that the feature sizes and tolerances routinely expected by the semiconductor society often were far beyond our needs. As a consequence of this, and of the problems indicated above, alternative fabrication methods and materials were explored.

Polymeric Materials

In 1990–91, a number of important technologies regarding the use of polymer materials in micromechanics were developed by Pharmacia Biotech. A very competitive and active network was spontaneously formed for micro fabrication techniques in general and replication technology in particular. Important industrial participants include, Pharmacia Biotech, in addition to Ericsson, Toolex Alpha, Siemens Elema, Telaire and IMC. Academic participants include KTH, LTH, CTH and Uppsala University.

We soon realized that the well defined structures made in single crystalline silicon could be easily "copied" into polymeric materials in a number of ways yielding very high quality replicas. This process is similar to the fabrication methods used for decades in the audio record industry (vinyl and CD) where sub-µm features are routinely replicated into polymeric discs. We now know that it is often difficult to distinguish an original from a replica.

Proc and Cons

Polymeric replicas are solving most of the above listed problems associated with silicon:

Cost: A CD record is produced for less than $1. This is 2 orders of magnitude lower than an assumed cost of $100 for a processed 5" Si wafer.

Transmission of light: Plastic replicas can be produced with excellent optical properties including good UV transmission.

Electrical conductivity: Polymers are good insulators.

As always, there are also some points to be aware of:

Release from the original: Some combinations of originals and plastics will adhere strongly to each other making separation of replica from mold difficult. This may often be avoided by treating the original with a releasing agent prior to replication.

Shrink: Most plastics will increase in density when cooled or cured. This contraction results in stress that can cause damage to the original and/or the replica, and will affect the dimensional tolerances.

Feature sizes and aspect ratio: These parameters will dictate processing conditions for the replication. As an example, the cycle time for production of a CD record with a relief depth of 0.5 µm is a few seconds. With deeper structures the cycle time is substantially longer.

Compatibility with other processes: Polymeric replicas are not compatible with most high temperature processes used in traditional micro structure fabrication.

Outlook

Other interesting possibilities include direct lithography of photo active polymers (photo resists) as adhesives and tape technology. In fact, it is my belief that commercial micro devices for bioscience will be produced by a combination of polymer technology and traditional micromechanics.

One of the most challenging problems in the development of this new technique remains in interfacing these micro devices with the macroscopic word of the laboratory chemist.

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Plastic Replication with CD-Technology

Replication techniques for the low-cost mass production of microstructures are expected to be a key technology for future microsystems. An important contribution to the reduction of cycle time comes from adapting the technology used for producing ordinary CDs (compact discs).

Replication Techniques

To advance the field of MEMS applications toward mass fabrication of real 3D structures, low cost and high precision are crucial. The LIGA process, which is the most well known technique, is based on X-ray lithography in thick PMMA resist layers of the master. The structures are mainly of cross-sectional shapes with vertical straight walls with the possibility to attain extremely high aspect ratios. The master fabrication costs are high due to complicated processes and the use of expensive equipment.

Injection molding seems to be the most efficient and accurate replication technique for mass production. The cycle time for deeper real 3D-microstructures has so far been too long to make the technique economically attractive (reported cycle time: 8 minutes or more). The absence of ejector slopes in LIGA-structures contributes to the long cycle time.

IMC and Toolex Alpha have, within the BRO project, developed a novel and extremely rapid mass fabrication process for polymeric 3D-microstructures of almost any kind of geometry. The replication technique is based on silicon bulk micromachining and conventional CD-injection molding.

Master Fabrication

Traditional anisotropic and isotropic wet etching combined with deep reactive ion etching of silicon (DRIE) makes it possible to structure silicon to almost any kind of shape with µm-precision. V-shapes, deep rectangular trenches and circular shapes are easily structured in silicon. If other shapes are necessary, micro-EDM (electro-discharge machining) combined with wet etching appears to be a promising combination. Anisotropic wet etched silicon masters with structure depths down to 500 µm have been used as well as DRIE-processed silicon wafers with an aspect ratio of 4:1 and structure depths of 80 µm.

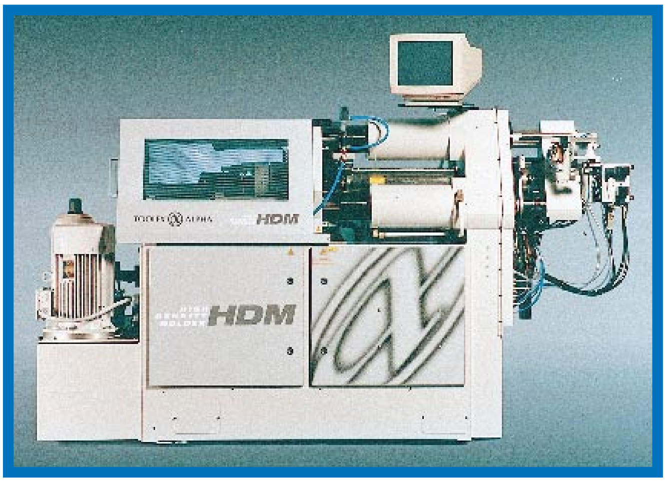
The above described micromachining can also be combined with normal machine shop manufacturing techniques. High precision islands can, thereby, be created in an arbitrary designed landscape.

Mold Insert Fabrication

In the micro-electroforming step electroplating of nickel is used to form a negative copy, i.e. a mold insert of the master structure. The electroforming is done in an optical disc plating system (Toolex Alpha P250) after evaporation of a thin conductive seed layer on the original. This system handles original sizes up to 180 mm diameter with a process time of about 1 hour for a 300 µm thick nickel layer.

Of great importance is to keep precise control of the plating parameters, such as temperature, current, stirring and chemical composition, so as to produce a homogeneous nickel insert free from internal stress.

The mold process injects plastic at an extremely high pressure demanding the insert to have perfect contact to the flat supporting tool. Also, the demand of rapid cooling requires perfect contact to the temperature controlled tool.



Injection molding machine for CD-production, well suited also for replication of polymeric microstructures.

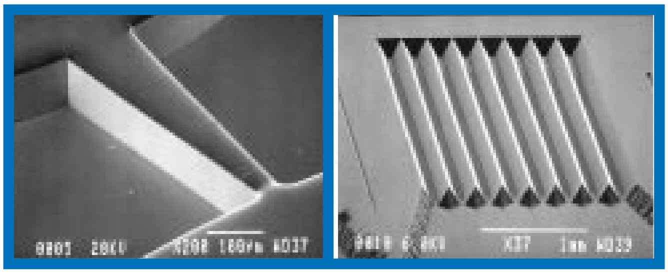
Micromolding

The nickel mold insert could be used for all types of polymeric replications, such as casting, embossing and injection molding. Casting is ruled out due to the mass fabrication demand. Embossing is only applicable for virtually 2-dimensional replicas. Injection molding machines made for mass production of compact discs, such as Toolex Alpha MD100 or HDM, are advanced tools with performances well suited for the replication of micro-patterns with purposes other than for data storage.

Standard cycle times for CDs are 4 seconds with plastic injection temperatures for polycarbonate (PC) as high as 350 °C. The advanced cooling/heating system and hydraulic injection unit together with a thin, 300 µm thick, nickel mold insert make it possible to reduce the cycle time also for 3D-structures. Thousands of replicas have been produced as 80 mm diameter CDs in PC and with cycle times under 10 seconds.

Applications

The silicon based replication technology has been successfully demonstrated for micro-components in microoptics and microfluidics. Examples of this are an optical receiver module with a polymeric motherboard, a mechanical splice for optical ribbon single mode fibers, channel structures for electrophoresis and a valveless diffuser micropump.



Left shows an electroplated nickel mold insert of a diffuser element, and right a polymeric replica of an optical motherboard.

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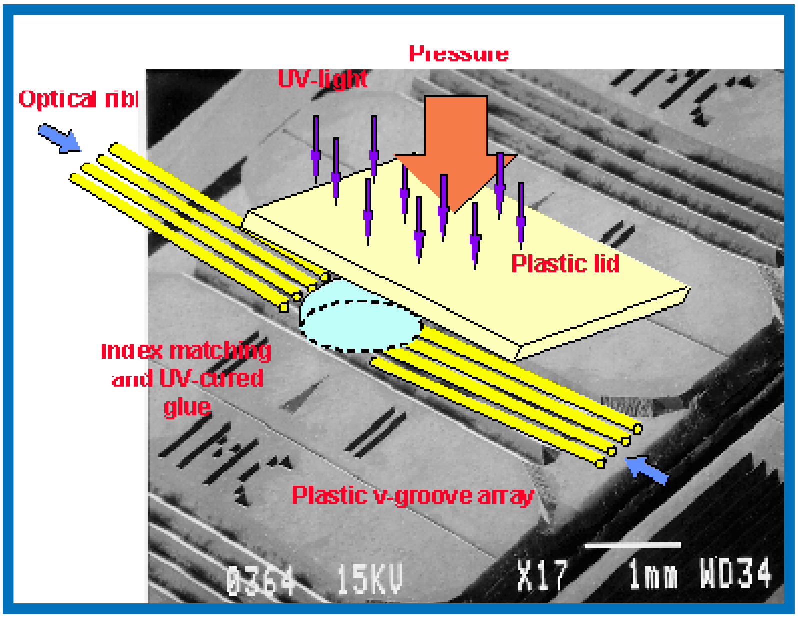
The BRO Consortium

The BRO-consortium (see box below) was selected for funding in 1993 by the Swedish National Board for Industrial and Technical Development (NUTEK) under its newly initiated collaborative research program in the Microelectronics area.

A main objective of NUTEK's efforts is to increase the level of interaction between the academic and industrial worlds by forming consortia with participants from both spheres. This will enable the transfer of knowledge from university research to industrial technology and product development. From an industrial point of view, these consortia are important since they provide an excellent opportunity to influence and streamline the national research activities of particular interest to industrial companies. From the academic point of view, they provide greater awareness of the areas and problems most relevant to industry.

The main purpose of the BRO project was to develop new micropackaging technology for opto-electronic components in order to enhance the competitive edge of the Swedish electronics industry. Five separate sub-projects were organized. They involved both university and industrial participants with at least one active industrial partner in each project. Different types of technology demonstrators, each illustrating novel technologies, were defined for each sub-project.

The BRO consortium was positively evaluated by an international committee and is generally regarded as very successful.



A fiber-optic ribbon splice based on plastic V-grooves, a typical target component of BRO.

The Ericsson Perspective

The main obstacle towards the widespread use of optical solutions in telecommunications lies in the unacceptably high costs for packaging and alignment for optoelectronic modules and components. For a laser diode (LD) module, this can be as high as 70% of the total module cost. This problem might be solved by new types of packaging and alignment techniques. This includes Ericsson's interest in the "high-volume, low-cost scenario" for optical components and sub-systems.

Important achievements include:

- development and evaluation of polymeric replication technology for the packaging and aligning of structures in opto-electronic modules, passive optical components, medical analysis and sensor applications,
- demonstration of polymeric optical waveguides with single mode performances;
- demonstration of a polymeric optical splitter, a splicer and a detector module using polymeric replication technology;
- demonstration of an "all-polymeric" optical link using polymeric LEDs and waveguides;
- development of a measurement setup for optical waveguide characterization with the ability to measure key parameters, such as the refractive index and waveguide attenuation;
- demonstration of an optical array receiver using microstructures in silicon (V-grooves and mirrors);
- demonstration of silicon microstructure technology and a new process for self-aligned flip-chip mounting for a detector array;
- demonstration of snap-in structures for alignment and assembly of optical fibers.

The Future BRO Project

The BRO project is applying for funding for an additional period of three years. One vision is to apply the developed techniques on two different application areas, a low cost optoelectronic access module for an IT application and a miniaturized microspectrophotometer for an analytical gas sensor system.

There will be a focus on three generic technical areas:

- coupling
- waveguides
- microsystem integration

The management of the project has an important mission to continuously evaluate the developed techniques and choose a combination of the most optimal technical performance at the lowest possible cost for the future demonstrators.

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BRO FACTS

The **objectives** for Building Practice Research for Opto- and Microelectronics (BRO) are to develop technologies for low-cost access and internal optical communication links. This includes:

- polymeric waveguides and replication technology
- methods for passive alignment between opto-components and waveguides
- solutions for the shaping and joining of semiconductor materials

The **active participants** are:

- Department of Electronics at Uppsala University
- Institute of Optical Research (IOF)
- Department of Energy Technology at the Royal Institute of Technology (KTH), Stockholm
- Industrial Microelectronics Center (IMC), Stockholm and Linköping
- Ericsson Components
- Pharmacia Biotechnology
- Toolex Alpha

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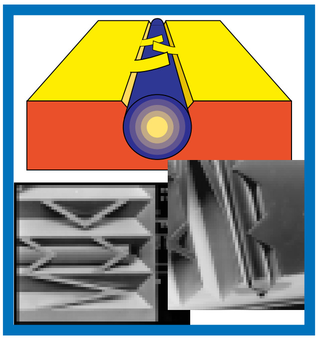
Micromechanics for Passive Alignment

Precise micromachining of semiconductors can offer suitable solutions in the field of micro assembling. For instance, optics for telecommunication with single-mode performance requires an alignment accuracy on the order of a micrometer. Today, this is solved by time consuming and costly techniques based on active alignment.

Research projects within BRO at UU (Uppsala University) and at IMC (Industrial Microelectronics Center) are aimed at developing technologies and processes for the passive alignment of microstructures, using MST. The work has mainly been focused on how to use MST for passive alignment when building hybrid micro optical systems, with focus on optical telecommunication systems.



Bulk silicon beams over V-grooves for holding optical fibers in position.

The Micromechanics Group at UU has mainly studied etching of 45° mirrors, silicon holding structures, and techniques for precise mask alignment. The focus of the project at IMC has been passive alignment techniques, and in collaboration with UU and Ericsson, a technology demonstrator has been designed and manufactured.

45° Mirrors

Using wet silicon etching, we have produced planes with a 45° angle to the surface of a (100) oriented silicon wafer. This is not an angle normally obtained in wet etching of silicon (which is 54.7° between the (111) and (100) planes). We have shown two different ways of producing 45° angles: using slow etching (110) planes and using 9.7° off-axis cut (100) silicon wafers for which the slow-etching (111)-planes have a 45° angle to the surface.

Silicon Holding Structures

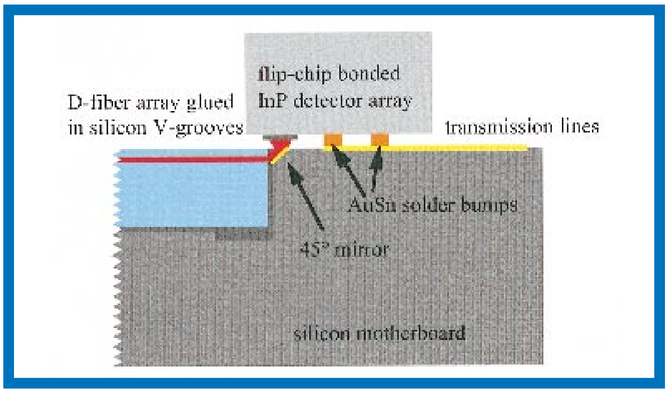
We have come up with novel silicon structures for holding optical fibers in etched V-grooves (see the SEM photo). The structures are produced in the same etching step as the V-groove itself, using an electro-chemical, electrode-less etch stop technique. They consist of free standing cantilever beams and bridges made of bulk silicon. No deposited poly-silicon or nitride is used.

The holding capability has been demonstrated for fibers in V-grooves. It assists in the mounting of the fibers substantially, as well as forces the fibers down into position in the grooves. This idea was rewarded with the first prize in the "East-Region Final" of the Swedish Innovation Cup 1995.

The holding structures are now under further development to hold micro building blocks, such as monolithic, electrical and electro-optical chips. The idea is to use the silicon motherboard as a multi chip substrate and to put, for instance, active electronic chips close to micromachined sensor structures and optically active chips close to V-grooves.

Precise Mask Alignment

The precision in alignment between optical elements for telecommunication applications has to be in the µm or sub-µm range. This means that the normal way to align masks for anisotropic wet etching in silicon, i.e. along the wafer flat, is no longer sufficient.



Schematic cross section of the D-fiber silicon microbench with a flip-chip mounted detector array.

A design tool for the fast and precise determination of the crystallographic orientations has been developed. A pattern is etched for a short time, and after a quick optical inspection the pattern can be used for aligning subsequent masks. The precision of the method was found to be better than ±0.05°. The mask is available in GDSII format for public use, please contact: Mattias.Vangbo@Teknikum.uu.se

Self-Aligning Solder Bumps

A flip chip technique for passive alignment of optoelectronic chips has been developed. The technique relies on self-aligning solder bumps.

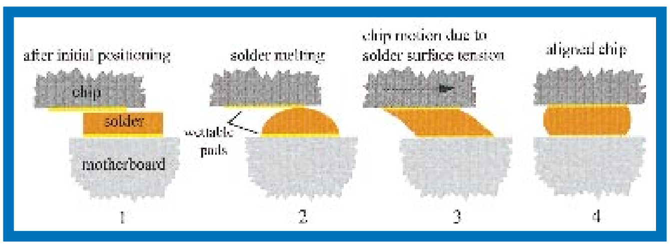
Gold-tin solder of the eutectic composition is deposited by electroplating on silicon carriers with lithographically defined wetable pads. During soldering the surface tension of the melted solder causes precise alignment (within ± 2 µm) of the chip with respect to the carrier.

Technology Demonstrator

We have designed and manufactured a technology demonstrator for the coupling of single-mode fibers to a surface illuminated detector array. The demonstrator consists of a silicon micro bench with four parallel V-grooves having 45° end-face mirrors for 90° deflection of the light from D-fibers positioned in the grooves. Detector arrays are mounted and aligned using the self-aligning solder bump technique.

The use of D-fibers and 45° mirrors (instead of conventional 55° mirrors) is partially due to the possibility to couple light to high-speed detectors with small detector areas. It also enables the demonstration of a microbench which potentially can be used for fiber coupling from surface emitting lasers (VCSEL).

The PIN diode detector arrays which were used in the demonstrator were designed exclusively for flip chip mounting and passive alignment. The bandwidth of the detectors exceeds 15 GHz and the responsitivity is greater than 0.55 A/W.



The self-aligning solder bump technique.

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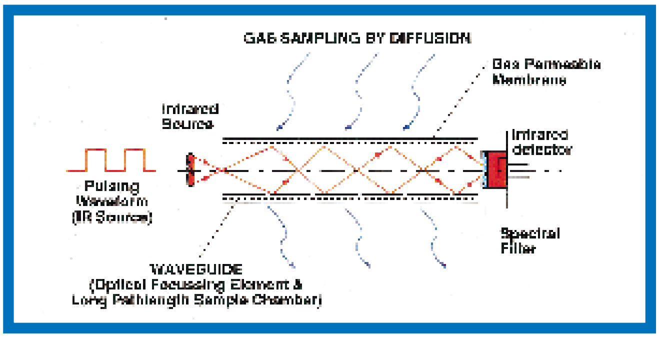
IR Gas Sensing Gets Low Cost With Plastic Molding

Telaire Europe AB, located in the village of Delsbo, is a young Swedish company specializing in gas sensing using optical methods. The company's current main product is a Thermo-Ventostat, which is a combined temperature and carbon dioxide gas sensor with powerful regulating capabilities intended for indoor climate control.

"Our challenge is to reduce our manufacturing costs down to the level where our sensors can be offered to the consumer market at a cost comparable to that of a standard thermostat", informs Telaire's R&D manager, Dr. Hans Martin. Infrared gas sensing technology, which has been frequently used in hospital equipment and other applications for many decades now, has been very expensive in the past. However, this is no longer the case. The retail price tag has dropped by a factor of two almost every third year, a trend that Telaire has contributed to significantly since their first product release in 1991.

"The only way we now can proceed to further reduce the manufacturing costs is to substitute the previously expensive IR optics with precision molded plastics", says Dr. Martin. Telaire is currently funded by NUTEK to explore these possibilities. Its latest generation of gas sensors is the company's first attempt along these lines. A unique multipass absorption cell made out of two curved parts has been designed (patent pending). It allows for a long optical absorption path length in a small and mass replicable plastic device. The injection molded parts are gold plated making them highly reflective in the infrared spectral region.

The major obstacle Telaire has been facing in the implementation of these new ideas relates to the making of the toolings. The required combination of extreme surface flatness (needed for the required reflectivity) and mathematically exact and well defined three-dimensional shapes (needed for the collimating and focusing properties), was not readily solved. Standard mechanical techniques handle only one or the other of these requirements.



The basic principle for Telaire's low-cost infrared gas sensors

For design flexibility, new techniques have to be developed that allows for computer aided designs of complex macroscopic (centimeters) toolings with microscopic (sub-µm) precision. More work is needed in this area before optical instruments in general can go low cost by replicative techniques. However, there is no doubt that in the near future we will find on the market all types of miniature optical instruments based on old classical principles, but with unprecedented performance over cost ratios. This is one very positive effect of the rapid evolution of micromechanics and replication in plastics technologies.

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Evaluation of Optical Waveguides

The Institute of Optical Research (IOF) with its extensive academic experience of optical evaluation for industrial applications, participates in the BRO consortium. Contributions has been made with several techniques and measurement setups. The IOF-BRO activities are concentrated on:

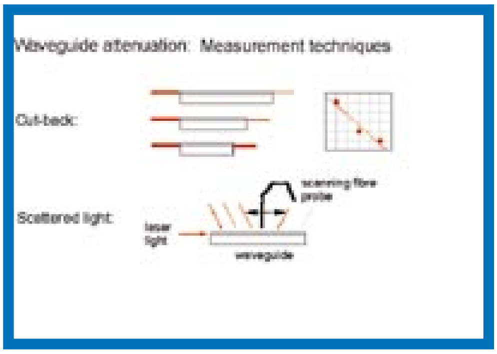
- optical building practice: optimizing technologies for low cost, fulfilling demands of environmental stability and simple packaging
- measurement methods and simulation techniques for the evaluation and characterization of devices realized with polymeric microstructure technology.

Several methods for evaluating attenuation in polymeric optical waveguides have been investigated. One is to measure light scattered perpendicularly out of the waveguide using a motor-driven fiber probe. This method can be applied to channel and planar waveguides. However, an IR-sensitive camera proved to have a limited resolution and was not applied.

For low-loss waveguides more reliable results are obtained by successively shortening the waveguide by cutting and measuring the transmitted power as a function of waveguide length. This method gives absolute values but is destructive and requires channel waveguides.

The absolute measurements are based on discrete wavelengths. The relative measurements use a continuous function of wavelengths (0.6–1.55 µm) and either an optical spectrum analyzer or a monochromator with a lock-in amplifier.

In addition, computer simulations were carried out for the determination of optimal waveguide dimensions and bend losses. The results were applied to the BRO optical splitter demonstrator in particular.



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Replication of Diffractive Optical Elements

Diffractive optical elements (DOEs), in the shape of phase modulating micro-reliefs, are currently being developed by many research groups around the world, among them the optics group at the Department of Microwave Technology, CTH. Over the years, many ingenious relief structures have been designed and well-performing original DOEs manufactured that convincingly demonstrate the potential of diffractive optics.

However, original DOEs are expensive. To find a widespread use outside of research laboratories, the market has to be offered high quality replicated DOEs. Recognizing this fact, the CTH group studies various replication techniques to find suitable processes and materials. Both DOE replicas in polymer, as well as in fused quartz, have been manufactured and tested by the group.

An example of what has been achieved are the DOEs replicated on the face of an injection molded CD, shown in the figure. This particular DOE could be developed thanks to the close, and informal, cooperation between the CTH group and the three BRO project participants IMC, Pharmacia and Toolex Alpha. A problem that had to be solved before the DOE CD could be created was how to adapt the original DOE electron beam manufacture so that it would smoothly fit into the standard injection molding procedures used for CD production. Atomic force microscopy studies of the DOE original and the CD replicas showed virtually no differences and the optical performance of the CD DOEs are satisfying as well.

In another experiment, carried out in cooperation with the Paul Scherrer Institute in Zurich, Switzerland, procedures to manufacture batches of all fused quartz DOEs were developed. In this case, the manufacturing steps are as follows: A nickel shim is electroplated from a direct write original DOE, the latter manufactured in resist by e-beam lithography. The nickel shim is used to hot emboss the DOE relief in a thin thermoplastic layer deposited on a fused quartz substrate. In the final step, the polymer relief is transferred into quartz substrate in a reactive ion etch step. The resulting all fused quartz DOE is durable and resistant to high power laser beams, and is thus useful in laser machining applications.

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MICROMECHANICS EUROPE

The 7th *Micromechanics Europe workshop* (*MME' 96*) was held in Barcelona, Spain, on October 21–22. This series aims at providing an informal workshop spirit so as to promote people getting acquainted, sharing experiences, and establishing contacts and friendships for the future. A well appreciated ingredient in creating this atmosphere was a panoramic city tour followed by a gala dinner on the first evening.

The record high number of participants, more than 145, suggests that the workshop was also very successful scientifically. Examples of invited talks included reviews of sensors for automotive applications (Dr. H. Seidel, D), biomedical applications (U. Meyer, D), CMOS MEMS (H. Baltes, CH), microsystem packaging (G. Kelly, UK), optical microsystems (Y. Bäcklund, Uppsala Univ.) and polymeric MST (H. Elderstig, IMC). A selected number of the more than 74 presented papers will be published in a special issue of *J. Micromech. Microeng.* scheduled for June/July.

Three posters were awarded:

- A method to reduce sticking using side-wall spacers (University of Twente, The Netherlands)
- Passive alignment using flexible tongues (Uppsala University, Sweden)
- A CMOS-compatible fluid density sensor (Chalmers University of Technology, Sweden)

The next *MME* will be held in Southampton in early September. Welcome!

Jan Söderkvist

ÅNGSTRÖM

The micromechanics activities at Uppsala University are moving to the newly constructed Ångström Laboratory. The official inauguration takes place on April 18 in the presence of His Royal Majesty the King of Sweden.

The move constitutes an important step in the launching of AME and the Uppsala part of SUMMIT. The staff moved just prior to Christmas and the equipment will be moved early this year.

The mailing address' P.O. Box and ZIP-code will be the same, but the visiting address is changed to Lägerhyddsvägen 1 at Polacksbacken in Uppsala. The phone numbers will change later this year.

PUBLICATIONS

- A flow-through picoliter sampling cell; J. Nilsson, T. Laurell, L. Wallman and J. Drott (LTH); *Analytical Methods and Instr., special issue: µTAS 96* (Nov. 1996) 88–90.
- Catalytic Increase in Micro Flow-Through Bio-reactors Using Porous Silicon as a Surface Enlarging Matrix; T. Laurell, J. Drott (LTH) and L. Rosengren (UU); *Analytical Methods and Instr., special issue: µTAS 96* (Nov. 1996) 100–103.
- Limitations to the Piezoelectric Effect for Materials with Finite Resistivity; J. Söderkvist (Colibri); *Sensors and Actuators A*, **54** (1996) 690–694.
- The Influence of Wafer Dimensions on the Contact Wave Velocity in Silicon Wafer Bonding; S. Bengtsson (CTH), Karin Ljungberg (UU/MIC), and Jan Vedde (MIC/Topsil); *Appl. Phys. Lett.*, **69**(22) (1996) 3381– 3383.

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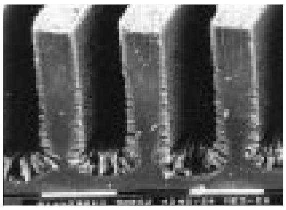
MICRO STRUCTURE BULLETIN NO.1 NOV 1997

NEXT ISSUE

Some topics covered will be:

- Scaling – What happens in μ-scale
- Micromachining at Lund University
- The Ångström Laboratory



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FUTURE EVENTS

8th *Europ. Conf. on Integrated Optics* (ECIO'97), Stockholm, Sweden, April 2–4, 1997. For information contact: G. Arvidsson, Fax: + 46-(0)8-789 6672.

Optical Microsystems for Telecommunication (course),Uppsala, Sweden, April 10-11, 1997. For information contact: FSRM, Fax: +41-32 720 09 09, or Y. Bäcklund, Fax: +46-(0)18-55 50 95.

Micro Mat '97, Berlin, Germany, April 16–18, 1997. For information contact: Prof. Dr. B. Michel, FhG-IZM, Fax: +49-30-46403 211.

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. For information contact: Thomas E. Parker, NIST, Fax: (303) 497-6461.

Transducers '97, Chicago, U.S.A., June 16–19, 1997. 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. *Abstract deadline: June 1*. For information contact: Dr. A.G.R. Evans, Univ. of Southampton, Fax: +44-1703-593 029.

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.

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Layout and production:
Ord & Form, Uppsala

UPPSALA UNIVERSITY

ISSN 1104-7453