MICRO STRUCTURE BULLETIN

Newsletter for Nordic Micro Structure Technology, Vol.4, No.2 May 1996

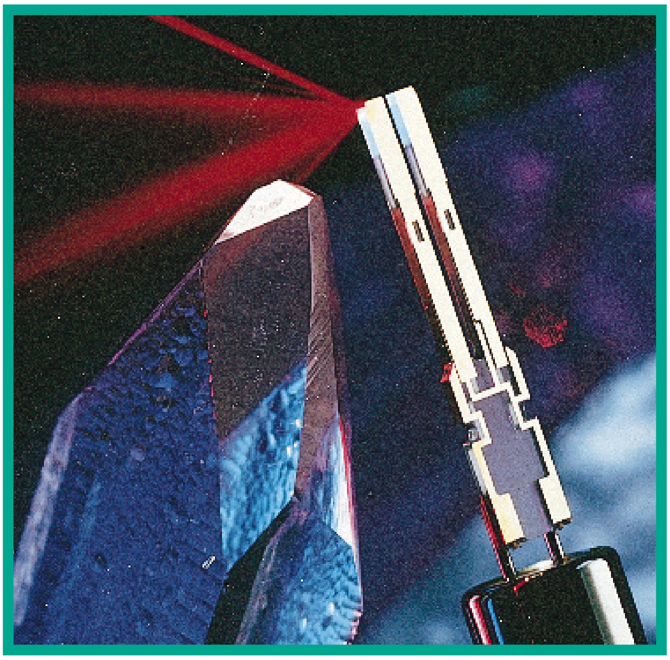
CONTENTS

50 Years with Quartz

The piezoelectric effect has never ceased to fascinate since the brothers Jacques and Pierre Curie discovered it in 1880. The possibility of interconverting mechanical and electrical energy, brings together two different branches of science.

The existence of a piezoelectric material that is its own oxide, has a high Q-value, and is sufficiently anisotropic to have a low temperature dependence is unique. It explains the extensive use of quartz in resonators for frequency control.

This summer, the 50th Annular Frequency Control Symposium (AFCS) will be held in Hawaii. During the past 50 years, development has progressed in the direction of improved performance and more efficient production methods.



Quartz watch crystals are the most successful micromachined component. Each minute, 2000 crystals are produced internationally with a production cost of less than 1 SEK.

Micromachining was introduced in the mid 1970s for low frequency resonators that use bending and longitudinal vibrations. The production of watch crystals is now highly developed. Micromachining is now also on its way of improving the production of resonators based on shear vibrations. Recently, micromachining of quartz was introduced in sensor applications as an alternative to the commonly used silicon. Better performance can often be reached by using quartz, but the production cost may be higher.

The characteristics of quartz have made impressive performance possible. For example, there are microprocessor compensated quartz resonators that have a frequency error of less than one second per year (0.03 ppm) over the temperature range of –40 to +85 degrees Celsius, including one year of aging. Another example are resonating quartz accelerometers with a dynamic range of 10^8.

The quartz activity is constantly increasing in Scandinavia. At the 50th AFCS, Sweden will be represented by scientific contributions from Uppsala University and Quartz Pro AB.

Jan Söderkvist

APPROVAL

The proposal from Uppsala University that was briefly described in *MSB 95:4* has been approved by the Foundation for Strategic Research. The aim is to become an international leader in the cross-disciplinary fields of MST, thin film processing, and functional surfaces. The activities will be supported by roughly 150 MSEK over ten years.

EDITOR'S NOTE

This issue is the first devoted to materials used in MST. Quartz is the natural choice to start with since the most successful micromachined component, the watch crystal, is made of quartz.

MST in polymers and the strong MST-activities at MIC in Denmark will be presented in the next issue. The last issue this year will focus on silicon as a material. If you want to contribute, do not hesitate to contact me.

I would like to thank all the people involved in *MSW '96*, including the participants. Organizing the workshop has been very stimulating. It was a joy listening to all the discussions during the breaks. I hope that you will inform me of the results of these contacts.

Finally, the saying "if you cannot measure it, you cannot control it" conveys an important reason for the interest in sensors. The commercial success of micromachine-based sensors can be explained by them being, for instance, inexpensive and reliable.

Jan Söderkvist

WWW

Nexus has launched the project European Micro-SystemsTechnology On-line (EMSTO), which is an information service to the European community. Their homepage (http://www.vdivde-it.de/it/emsto/) is well worth visiting.

Micromachining Basics Part 8: Quartz

Quartz is used extensively in time-keeping applications. For instance, most watches, and all computers and cellular phones contain one or more quartz resonators. Recently, quartz has become of interest also to the sensor community.

The word "quartz" usually refers to crystalline SiO_2. Occasionally, quartz glass (amorphous SiO_2) is also denoted as "quartz". This page deals only with crystalline quartz.

Characteristics

Quartz has several interesting properties. Some of them are independent of crystallographic structure and are equally valid for both quartz and quartz glass (see next page). Other properties are due to the crystallographic structure.

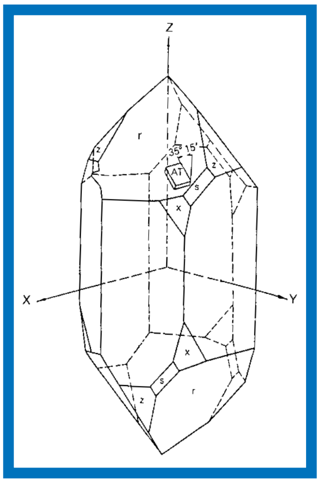
Quartz is sufficiently anisotropic to have cuts for which the resonance frequencies are unaffected by mechanical stress, e.g. the SC-cut. There are also cuts for which the linear and quadratic temperature coefficients of the frequency vanish, e.g. the AT-cut.

The piezoelectric effect can be used to both excite and detect mechanical vibrations (cf. *MSB 94:2* and *96:1*). For resonators, µW power levels suffices to sustain these vibrations.

Quartz has a low aging rate since it is chemically inert and is its own oxide. It is also an almost perfectly elastic material with small internal energy losses. MHz-resonators with a Q-value as high as 2 million exist.

Crystallography

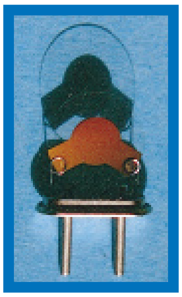
At room temperature, quartz has a trigonal crystal structure. This α-quartz has either a left or a right orientation structure. Above the Curie temperature of 573°C, the structure is transformed into hexagonal β-quartz, which has markedly less piezoelectric activity. Quartz exhibits several natural crystallographic planes with a three-fold symmetry in the XY-plane.



Processing

It is difficult to chemically machine quartz due to its inertness. Strong hydrogen fluoride (HF) based etchants are normally used. With these, the etch rate along the Z-axis is much faster than in the XY-plane. This enables structures with very high aspect ratios.

The several hours long etching affects the masking material. A thin layer of chromium is therefore deposited on the quartz surface to make the gold mask adhere better. An advantage with the gold mask is that it can be patterned and etched a second time to form electrodes.



Dry etch methods are normally not used since they are too slow if well-defined structures are needed.

Few successful attempts have been reported on bonding quartz to other materials. The mismatch in thermal expansion coefficients and the Curie temperature are complications.

Recently, it has been reported that quartz can be "doped". Conductors can be created in quartz by implanting titanium ions. This facilitates the formation of electrically connected hermetic cavities.

Vibration modes

Flexural vibrations are mainly used for kHz frequencies, while shear vibrations are used for MHz frequencies. The intermediate frequency range uses longitudinal and torsional modes. Overtones are commonly used for reaching higher resonance frequencies.

Thickness shear vibrations of circular or rectangular disks are easily excited piezoelectrically. Their resonance frequencies are determined by the thickness of the resonator. The frequency aging can be below 0.03 ppm for quartz. This corresponds to a thickness accuracy of less than 0.1 atomic layers.

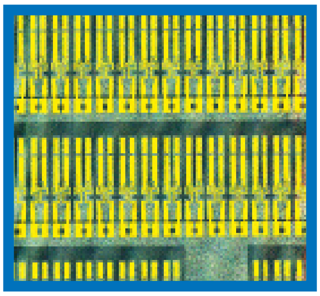
Competence

One reason why quartz is not widely used in sensors is that the knowledge of how to micromachine quartz is not widely spread. Also, existing production equipment is focused on silicon. Nevertheless, micromachining in quartz and silicon is similar.

Some industries have mastered the quartz technology. Unfortunately, it is not in their interest to make this technology widely spread. The situation is much different for silicon where the number of scientific publications is large.

Uppsala University is working on creating a "toolbox" of micromachining steps for quartz. This activity is based on their extensive knowledge of micromachining silicon, and is aimed at sensors and passive components. The work is carried out in close collaboration with Quartz Pro AB.

Jan Söderkvist



Micromachining by Ion-Track Etching

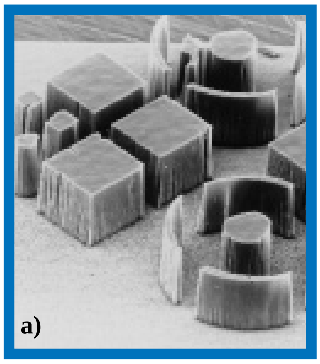
It has been difficult to micromechanically form structures in quartz with high aspect ratios in other orientations than in the crystallographic Z-direction. Uppsala University, in collaboration with GSI (Gesellschaft für Schwerionenforschung) in Darmstadt, has overcome this restriction by developing a new technique referred to as MITE, Micromachining by Ion-Track Etching.

By bombarding a wafer uniformly with ions of a well defined energy and directionality, an anisotropy can be induced arbitrarily. With lithographically defined masks, new designs and improved resonators and resonant sensors in quartz are possible. The process affects the resonant and piezoelectric behaviors very little.

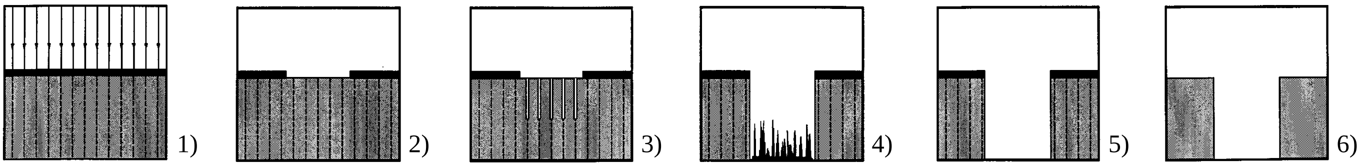
Deep, arbitrarily oriented structures with high directionality in quartz have been created. The track etching itself has elsewhere been shown to apply to a wide range of materials, such as polymers, glasses and single crystalline dielectrics. There is no hindrance as to the usefulness of MITE for these other materials.

The immediate ongoing effort is to make tuning fork resonators and very deep structures (400 µm or more), and to use this technology in mica. Our groups are confident in the MITE process and are looking forward to a completely new set of materials and tools to be incorporated in the already versatile micro structure technology.

Klas Hjort and Greger Thornell
Uppsala University
Fax: +46-(0)18-18 35 72
E-mail: klas.hjort@teknikum.uu.se



MITE of AT-cut (a) and Z-cut (b) quartz wafers showing geometries of a size not feasible with other etching techniques.



MITE in schematics: 1) irradiation of energetic heavy ions in a synchrotron accelerator, 2) lithographic patterning, 3) pore formation during wet etching in KOH, 4) remaining pillars when the etch reaches the bottom, 5) cleaning or further etching, and 6) mask removal and annealing.

Quartz Glass as a Wafer Material

The majority of all Micro Electro Mechanical Systems are fabricated on silicon substrates. For several years, the MEMS-group at the Industrial Microelectronics Center (IMC) in Kista has been working with quartz glass substrates as an alternative, usually for biotechnical applications.

UV-Transparent
Since the interaction of biomolecules with UV-light is one of the most frequently employed analytical methods in the field of biochemistry, UV-transparent materials, such as quartz, are often demanded by biotechnical applications. The transparency of the material can also be important for fluid or particle handling systems where visual observation of the system's interior is of interest.

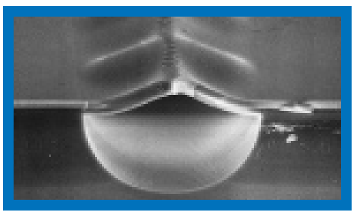
Insulator
The insulating properties of quartz may be required in high voltage applications where the breakdown voltage of a standard insulating oxide is exceeded. Electrophoresis and electroosmotic pumping are two examples of such requirements.

Thermal Conductivity
The high thermal conductivity of silicon is a problem for thermally based sensors. Thus, thermal sensors are often fabricated on top of thin membrane structures in order to function well. An alternative is to use quartz substrates which have a factor 100 lower thermal conductivity than silicon.

Borosilicate Glass
Borosilicate glass is a cheaper alternative to quartz in some applications. However, its relatively poor optical properties and softening temperature excludes many thermal processes.

Processing
Device processing on quartz wafers can essentially be done using the same processing methods and equipment as for silicon wafers. A technical problem is that the transparent wafers sometimes are invisible to the optical sensors of the process equipment's wafer handling systems.

Peter Norlin, IMC
Fax:+46-(0)8-750 54 30
E-mail: peter.norlin@imc.kth.se



A surface micromachining process for microcapillaries in quartz glass has been developed at IMC. The resulting all-quartz, close-to-the-surface capillaries are ideal for sample handling in chemical analysis systems.

Gyroscopes for Automotive Safety

Recently, there was an article in a Swedish newspaper regarding an automotive accident with personal injuries. The journalist was surprised that the airbags were not activated when the car rolled over sideways. This is a weakness of today's airbag systems caused by the crash sensors responding only to velocity changes in the forward direction of the vehicle.

Adding angular rate sensors (gyroscopes) enables activation in additional types of accidents, and helps to reduce the number of erroneous activations. Unfortunately, there are currently no commercially available angular rate sensors that fulfill the price-performance requirements of the automotive industry.

The Quartz Sensor

A suitable sensor based on a micromachined tuning fork has been developed and patented by Colibri Pro Development AB. The quartz sensor element is similar to ordinary batch-processed watch crystals.

Measured performance at room-temperature is well suited for many new applications: resolution 0.1°/s (360°/hour), non-linearity <0.5% and virtually no cross-axis or vibrational sensitivity. In addition, the sensor has survived shock levels of more than 38,000 g.

The stability of the zero rate offset (ZRO) is better than 0.5°/s/hour at constant temperature. Changing the temperature causes the ZRO to change. Self-heating of the electronics induces a 0.7°/s ZRO-drift during the first 15 minutes after power-on.

Industrial Status

The sensor was initially developed for Bofors' military applications. A strong international interest soon showed that its potential was much larger for commercial applications. Currently, Colibri collaborates with a major European automotive company in adopting the sensor for mass-production.

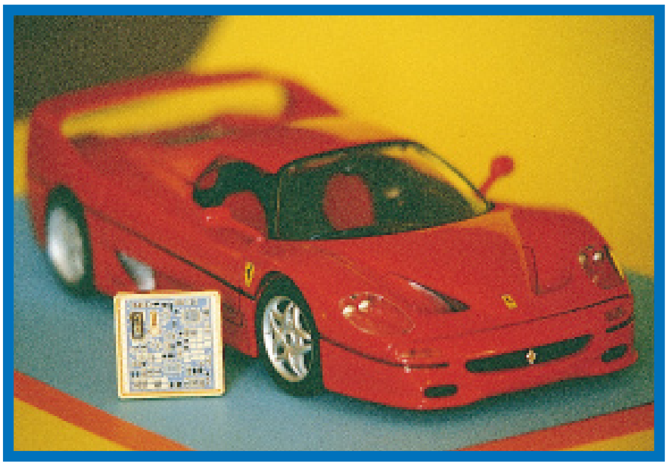
The initial applications will be in safety systems. Airbag and anti-skid systems can use rate sensor information without excessive modification of other systems. Active suspension for improved comfort requires more modifications. An interesting observation is that active suspension was becoming so important for success in Formula 1 racing that its use was restricted there a few years ago.

Additional potential application areas include inertial navigation units that complement GPS-based navigation systems, consumer products such as gyro-based anti-jitter compensation systems for video cameras, and computer mice that detect head movements for improved ease of communication for the disabled (see *MultiPos* in *MSB 95:4*).

Vibrating Rate Sensors

The angular rate sensor is based on Newton's laws in which vibrations favor their original vibration plane. Thus, a rotation of the structure may cause the vibration plane to tilt relative the structure, as shown in the figure. The resulting vibrational component out of the plane of the structure has an amplitude that is proportional to the speed of rotation.

Conventional gyroscopes, based on a spinning rotor, are not a practical alternative for



motor vehicles because of their high costs and short lifetimes.

Strict requirements for the zero point stability and Q-values highlights the two crystalline micromachinable materials quartz and silicon. The major drawback with silicon is that it is not piezoelectric. Quartz is therefore used in the present application.

Challenges

Vibrating angular rate sensors are complex to design. In fact, performance is almost entirely determined by how well error sources are suppressed, and not by the resolution.

One of the most challenging performance parameters for all vibratory rate sensors is the stability of the ZRO. This is due to an unfavorable ratio between the two vibrational amplitudes. A typical reference amplitude for micromachined structures of 5 µm results in a sense amplitude in the order of 0.1 atomic radius at 0.5°/s.

The two vibrations couple mechanically. Therefore, balancing the sensor element by adding or subtracting material is essential. A well designed mounting and vacuum are also recommended.

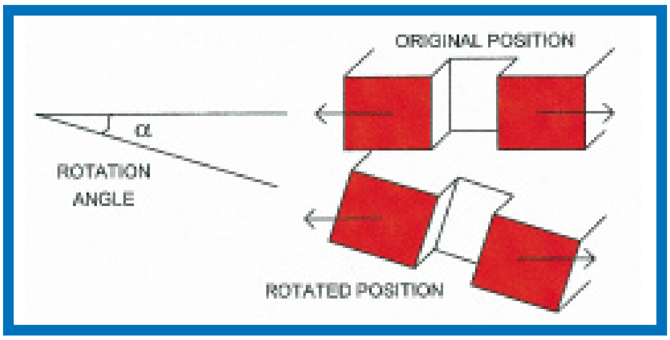
The piezoelectric sensor generate pA-currents. Thus, even the smallest stray capacitance can result in an erroneous ZRO signal. A patented technique for compensating for this error is a key to the performance.

The sensor element must be combined with electronics in which some error sources are suppressed. The electronics must be designed according to MHZ-requirements although the mechanical vibration frequency is in the kHz-range.

Comments

Accidents due to failure of components in automotive safety systems must be avoided at all cost. Bad publicity may be the least damaging effect of failures. The reliability requirements are often stricter than for military products.

Finally, house-flies use vibrating organs for obtaining stability in pitch. The angular rate sensor attempts to recreate this 200 million years old (re-search) invention — with the help of micromachining.



This cross-section view of a tuning fork illustrates how a vibrational component out of the plane of the tuning fork is generated due to a rotation

Jan Söderkvist
Colibri Pro Development AB
Fax: +46-(0)8-510 116 15
E-mail: colibri@prodev.se

Atomically Clean Crystals in Pro-Line

Pro-Line consists of four vacuum chambers. The in-line connection between the chambers enables the crystal resonators to be transported between them without exposing the crystals to the contaminating atmosphere. Once the crystals are loaded into Pro-Line, the process is completely automatic. One batch can accommodate up to 1000 crystals.

A number of processing steps are carried out in order to clean the crystal resonator surfaces to an atomically clean level. These steps consist of vacuum baking enhancing outgassing, cracking of adsorbed hydrocarbons and bombardment of the surfaces with neutral argon atoms from two atom guns.

The crystal surfaces are now clean at an atomic level and ready to be coated with a metallic thin film onto both surfaces by means of a specially developed magnetron sputtering technique. The thickness ranges between 500 and 1,500 Å and is controlled to an accuracy on the order of a few atomic layers! This process step takes place in a vacuum chamber that can be evacuated to a pressure lower than 10^{-9} mbar, which is 12 orders of magnitude lower than atmospheric pressure, and 15 lower than the pressure in which quartz is grown.

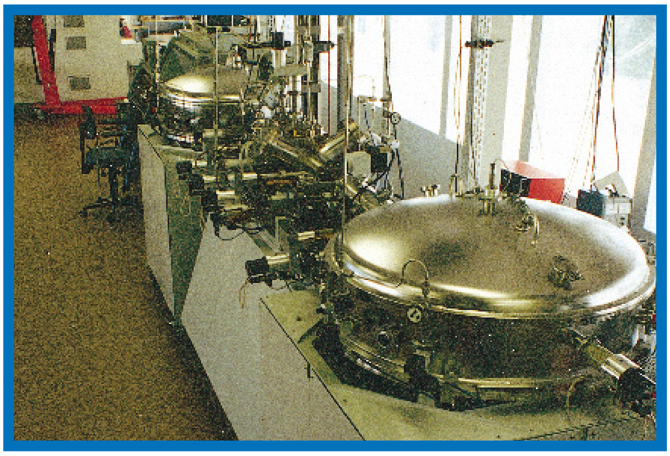
The thin films constitute two electrodes used to excite mechanical shear vibrations in the bulk of the quartz. Its thickness determines the frequency of the crystal resonator. If required, an annealing process can be performed which aids in the reduction of mechanical stresses, thereby improving the long term stability of the crystal resonators.

Finally, the crystals are protected from the environment by a hermetic seal in a protective nitrogen gas. Resistance welding gives a very reliable seal. The nitrogen gas used is produced at QP with PSA-technique (Pressure Swing Absorption). The gas quality is very high with residual oxygen and water contents of less than 10 ppm.

The main advantage of this extremely clean production technology is that all crystals produced exhibit consistently very low aging, i.e. high frequency stability with time. In order to meet the aging specifications, the film thickness must be stable within parts of an atomic layer, which is made possible by the very clean environment in Pro-Line.

The success of introducing Pro-Line crystals into the market speaks for itself. QP has produced over 1 million crystals which have been purchased by all the major telecommunication customers in Scandinavia.

Guy Portnoff, QP
Fax: +46-(0)8-761 20 67
E-mail: guy.portnoff@qpro.se



MSW '96

The second Micro Structure Workshop, organized by Colibri Pro Development in collaboration with Uppsala University, was held in Uppsala on March 26–27. This year the program was based on the response to the 'call for papers'. Although most presentations were given by universities and research institutes, their industrial relevance was clearly noticeable.

The purpose of *MSW* is to aid in stimulating the development of Micro Structure Technology (MST) within the Nordic countries. Bringing together in an informal way those interested in MST forms an important part of *MSW*. For instance, ample time for discussions between the participants was included in the program. The program also included a poster session to further stimulate contacts between the participants.

The responses from the 81 participants (30 from industry) to the questionnaire were very positive and showed that several new contacts were formed, both on an information basis and on a project basis. This will most likely result in activities to be presented in future issues of *MSB*.

The program included 23 oral presentations, including presentations given by three invited speakers.

Professor Nico F. de Rooij from IMT in Neuchâtel, Switzerland, gave the keynote presentation. He presented an overview concerning recent advances in micromachining technology, and gave several examples dealing with the design, fabrication and application of microsystems.

Martin Nese, SINTEF, and Per Øhlckers, SensoNor, reported on a collaborative development of technology for silicon micromachined sensors for automotive applications. The development of SensoNor's new accelerometer SA-30 was highlighted. This sensor is based on a thermally excited resonating silicon beam. SensoNor indicated that future cars could include eleven of their sensors.

Unfortunately, the third invited speaker, Matthias Müllenborn from MIC in Denmark, had to leave during *MSW*. Congratulations for your newborn son.

Several presentations were given by centers whose key role is to facilitate and broaden the implementation of these emerging technologies within industry (see also *MSB 96:1*).

A notable trend is that silicon is beginning to be challenged by other materials, such as quartz. The best material for each application should be chosen.

Did you miss *MSW '96*? There is a 135 page long proceeding in English (except four pages that are in Swedish). Next *MSW* will be held in 1998.

Jan Söderkvist
Coordinator MSW

Microstructure-Biosensors, will they do the job?

The ability of living systems to extract information from its surrounding is an essential process. This ability is achieved by the use of a variety of physiochemical sensing systems that have developed under the pressure of natural selection.

Modern man-made technology has created a demand for information collecting systems that can be integrated easily with other technologies, such as microprocessor based electronics. For many applications, chemical sensors are required that are suitable both for miniaturization and mass production

In particular, biosensors have attracted much attention. These biomolecule based measuring devices show excellent sensitivity and specificity. However, there are significant problems that have to be solved before they are practical. Almost all of them are related to the instability of the biorecognition element.

Stable Micro-Biosensors

A new emerging technology, SIRE (Sensors based on Injectable Recognition Elements), has proven to solve these problems. This technology was introduced one year ago by CHEMEL, a research company at IDEON in Lund.

Traditionally, biosensor developing scientists have focused on biomolecules being expensive and thus must be reused (i.e. immobilized). This has often resulted in situations where unstable recognition elements have been bound to stable transducers. In SIRE technology another approach has been chosen.

By using micro structures, the amount of biomolecule used per measurement is minimized. An extra bonus is that differential measurements using the same transducer are made possible.

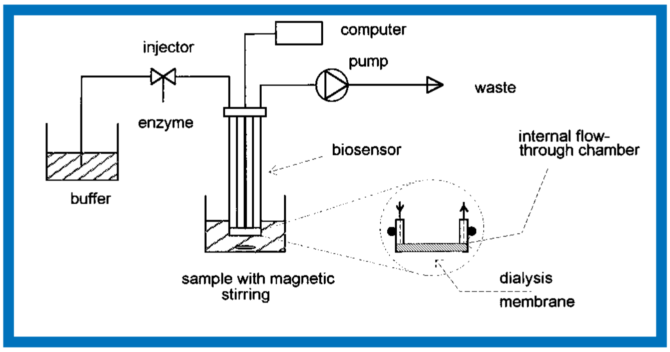
Applications

The principle of SIRE technology based biosensors is shown in the figure. The recognition element is injected into a buffer flow passing in front of the transducer. At present, only 10 µl of solution containing the recognition element is needed, but this can be further minimized to further reduce the analysis costs.

With silicon technology, the whole system can be integrated on a silicon chip, including the sensor, injector, valve and pumps. Only a droplet of test sample will be needed with an extremely low amount of the recognition element.

This development is expected to give rise to analytically powerful chemical sensors that are inexpensive, compact, require only simple handling, demonstrate excellent analyte specificity and exhibit excellent mechanical and chemical stability. Future applications of integrated chemical sensing and response systems will probably be found in many different areas, such as research, medicine, industry, environmental monitoring, agriculture, military and robotics.

Contact person:
Dario Kriz
Fax: +46-(0)46-29 11 07



Quartz is Strong

A trend in the defense industry is to convert into "smart ammunition". Smart ammunition includes different electronic blocks depending on the shell. If the electronic system is digital, a reliable clock signal is needed. For this reason, Bofors decided to create a quartz oscillator that will survive a launching acceleration of 40,000 g.

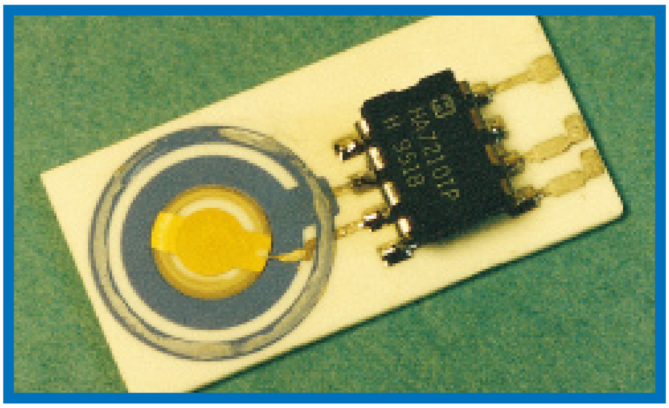
The figure demonstrates the result. A circular AT-cut crystal with a 13 MHz resonance frequency was mounted flat on the substrate and fed from a standard crystal drive IC from Harris. The crystal was protected by a metallic package and the complete hybrid was coated with polyurethane. It was then placed in a test shell and fired in a Bofors 40 mm AA-gun. The device performed excellently after the firing.

The key to the shock survivability is the mounting. High Q-values are obtained despite the mounting being larger than usual and it being located fairly near the vibrationally active area. This is made possible by the thickness shear vibration being well localized to the center of the resonator and the air friction being almost negligible.

The next step will be to investigate its performance during launch. With this mounting concept, a low-cost device was obtained with good performance.

Quartz Pro AB in Sweden is greatly acknowledged for supplying the crystals.

Hans Richert, Bofors AB
Fax: +46-(0)31-772 41 53



Quartz PRO — a High Tech Company

Quartz Pro AB, QP was founded in 1986 around a new idea on how to produce high quality, low aging, precision quartz crystal resonators. The project required knowledge from a broad range of disciplines such as ultra high vacuum technology, physics, chemistry, mechanics, measurement technology, automation and computer programming. Important outside contributions came from LiTH, CTH and KTH.

A high tech production line, Pro-Line, was developed with hard work and production started in the end of 1989. As always with a new technique, there were several problems during the first year. Some required redesigning. The Pro-Line process is protected by an extensive patent.

The growth of the company markedly increased after the move to new premises in Veddesta, Järfälla, in 1994. The company employed 15 people and had a turnover of 15 MSEK in 1995. As the company moves more into the production of crystal oscillators, an even larger expansion is expected. Preparations for expanding into markets outside Scandinavia are on the way. In addition, the switch over to SMD (surface mounted devices) components is progressing.

An advantage with the new premises is that the most sensitive part of the production, including Pro-Line, is now carried out in a clean room. Despite the quite rapid growth, the company has suffered from the relatively limited production capacity during the last two years. However, with recent new investments in high tech and high capacity equipment the company will have the increased resources needed for an export expansion.

An important goal is to increase the capabilities for custom designing via simulations, a task which is not simple due to the precision requirements to avoid error sources. In addition, Quartz Pro strongly supports the development of quartz micromachining at Uppsala University. This competence will be essential in the future since the international trend is to use smaller crystals. Those companies that master the micromachining of quartz and have good production equipment, can rapidly custom design crystals, will be the winners.

Contact person:
Guy Portnoff, QP
Fax: +46-(0)8-761 20 67
E-mail: guy.portnoff@qpro.se

DISSERTATIONS

MSB *wishes to congratulate the following three individuals for successfully having defended their doctoral theses.*

Zhaohua Xiao, CTH
On March 14 he presented his thesis entitled *Applications of Artificial Microcavities in Wafer Bonded Silicon*. The work is based on a sensor structure consisting of two silicon wafers bonded together. One of the wafers includes a thin micromachined membrane. The change in depth of the enclosed cavity due to a bending of the membrane can be monitored interferometrically (see *MSB 95:1*).

The bending of the membrane can be caused by a change in pressure difference or an applied electrostatic voltage. This enables the device to be used as a pressure or voltage sensor.

Using different doping of the two silicon wafers creates a pn-junction in the interface that enables the light from one source to be modulated by that from a second light source via charge-generated electrostatic forces.

Edvard Kälvesten, KTH
On April 12 he presented his thesis entitled *Pressure and Wall Shear Stress Sensors for Turbulence Measurements*. The pressure and flow sensors are specially designed for experiments in turbulent gas flows. They have been applied to measurements of pressure and wall shear stress fluctuations in a turbulent flat plate boundary layer.

The surface micromachined piezoresistive pressure sensor is based on a polysilicon diaphragm with a width of 100 µm and a thickness of 0.4 µm. The bulk micromachined wall shear stress sensor is based on gas cooling of a thermally insulated, flow direction sensitive heated chip with a top area of 300×60 µm and a thickness of 30 µm. The small dimensions are needed to obtain the required spatial resolution of the smallest turbulent eddies.

Amir Baranzahi, LiTH
On April 19 he presented his thesis entitled *High Temperature Solid State Gas Sensors Based on Silicon Carbide, Device Development and Applications*. The new chemical sensor technology uses silicon carbide as the semiconducting material in catalytic metal-oxide-semiconductor structures (see *MSB 95:2*). The MOSiC structures have been studied as gas sensors up to temperatures of about 850°C for detecting, for example, hydrogen and hydrocarbons in oxygen or inert atmospheres.

Gas sensors based on silicon carbide show great promise as combustion monitors and in sensor arrays for the analysis of gas mixtures. The rapid response and high temperature capabilities are of particular interest since they may allow the monitoring of individual cylinders in internal combustion engines.

GROWTH

Synthetic quartz blocks are grown in large autoclaves about 10 meters in height and one meter in diameter. The single crystals are grown for approximately one month by a hydrothermal process at approximately 350°C and 1000 atm pressure (10^8 Pa). Seed plates are hanged vertically in the top of the autoclaves. The roughly 1 mm thick seeds are normally Z-cut, and are selected from particularly pure quartz grown very slowly, and are, therefore, quite free from dislocations and other growth defects. The bottom of the autoclave is filled with dissolved quartz in an alkaline solution, for example, sodium hydroxide. The temperature gradient along the height is carefully controlled and protected from competitors. After the growth, the seed plate is removed and the remaining parts of the quartz block are cut into long square bars.

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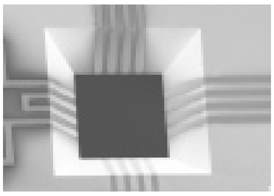
MICRO STRUCTURE BULLETIN NO.2 MAY 1996

NEXT ISSUE

Some topics covered will be:

- MST at Mikroelektronik Centre (MIC), Denmark
- Replication in polymers
- Diffractive optical elements



PUBLICATIONS

Some MST-related results published during the last months:

- Applications of Artificial Microcavities in Wafer Bonded Silicon; Z. Xiao (CTH); Doctoral thesis, *Technical Report No. 285*, ISBN 91-7197-247-1 (1996).
- High Temperature Solid State Gas Sensors Based on Silicon Carbide, Device Development and Applications; Amir Baranzahi (LiTH); Doctoral thesis, *Linköping Studies in Science and Technology, Dissertations No. 422*, ISBN 91-7871-685-3 (1996).
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Actuator 96, Bremen, Germany, June 26–28, 1996. For information contact: AXON Technologie Consult GmbH, Fax: +49-421-17 16 86.

Micro Actuators (course), Copenhagen/Lyngby, Denmark, September 5–6, 1996. For information contact: FSRM, Fax: +41-38 200 990.

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. *Abstract deadline: May 31, 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.

MEMS ´97 (Micro Electro Mechanical Systems), Nagoya, Japan, January 26–30, 1997. Abstract deadline: September 16, 1996. For information contact: MEMS '97, c/o MESAGO Japan Corp., Fax: +81-3-3359 9328.

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Editor-in-Chief:
Assoc. Prof. Jan Söderkvist, Colibri Pro Development AB
Torgnyvägen 48
S-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:
Hand Richert, Bofors AB/Chalmers Teknikpark
Fax: +46-(0)31-772 41 53

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