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Strokovno društvo za mikroelektroniko
elektronske sestavne dele in materiale

Strokovna revija za mikroelektroniko, elektronske sestavne dele in materiale
Journal of Microelectronics, Electronic Components and Materials

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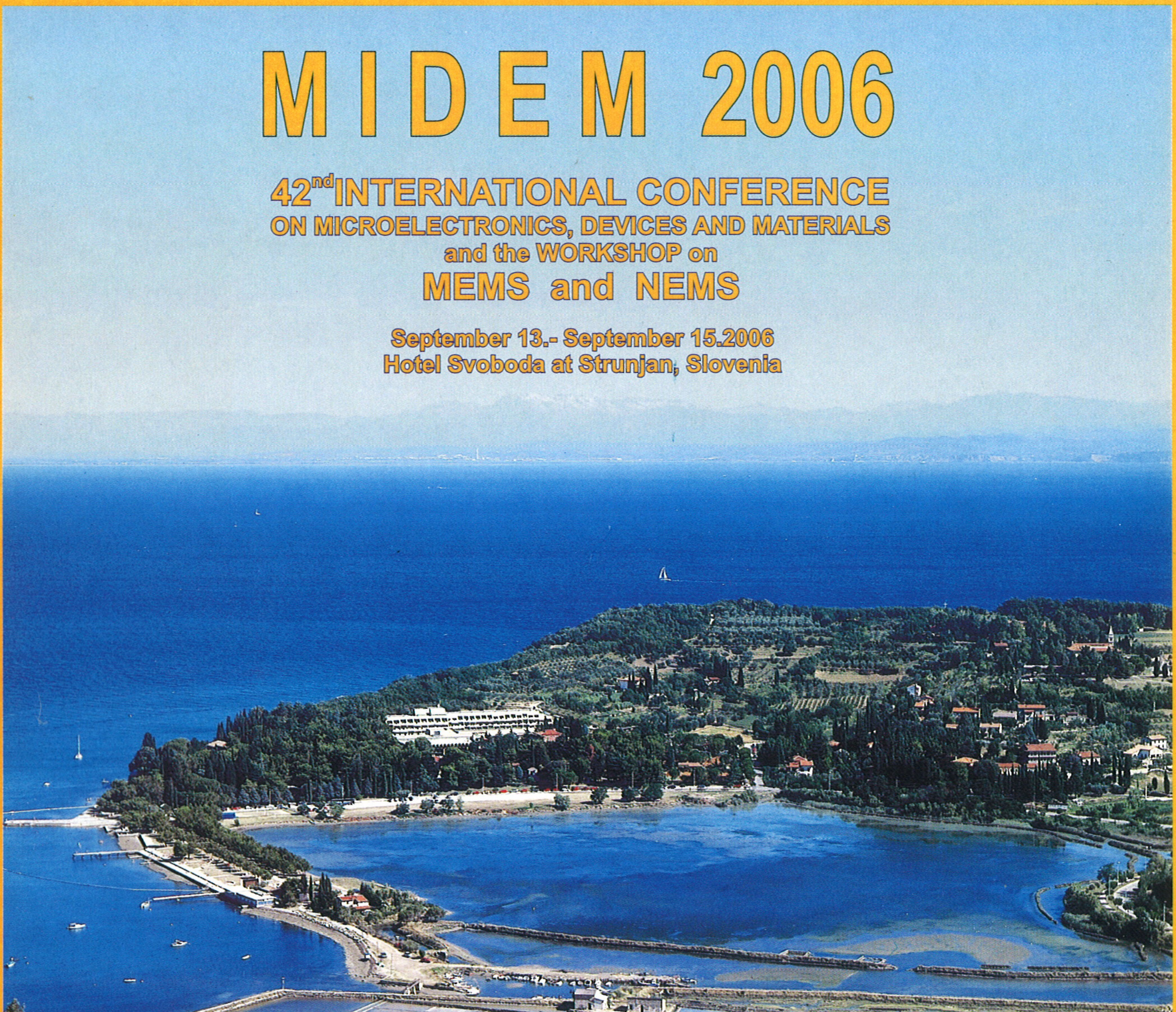

MIDEM 2006

42nd INTERNATIONAL CONFERENCE
ON MICROELECTRONICS, DEVICES AND MATERIALS
and the WORKSHOP on
MEMS and NEMS

September 13.- September 15.2006
Hotel Svoboda at Strunjan, Slovenia

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Obnovitev članstva v strokovnem društvu MIDEM in iz tega izhajajoče ugodnosti in obveznosti

Spoštovani,

V svojem več desetletij dolgem obstoju in delovanju smo si prizadevali narediti društvo privlačno in koristno vsem članom.Z delovanjem društva ste se srečali tudi vi in se odločili, da se v društvo včlanite. Življenske poti, zaposlitev in strokovno zanimanje pa se z leti spreminjajo, najrazličnejši dogodki, izzivi in odločitve so vas morda usmerili v povsem druga področja in vaš interes za delovanje ali članstvo v društvu se je z leti močno spremenil, morda izginil. Morda pa vas aktivnosti društva kljub temu še vedno zanimajo, če ne drugače, kot spomin na prijetne čase, ki smo jih skupaj preživeli. Spremenili so se tudi naslovi in način komuniciranja.

Ker je seznam članstva postal dolg, očitno pa je, da mnogi nekdanji člani nimajo več interesa za sodelovanje v društvu, se je Izvršilni odbor društva odločil, da stanje članstva uredi in **vas zato prosi, da izpolnite in nam pošljete obrazec priložen na koncu revije.**

Naj vas ponovno spomnimo na ugodnosti, ki izhajajo iz vašega članstva. Kot član strokovnega društva prejemate revijo »Informacije MIDEM«, povabljeni ste na strokovne konference, kjer lahko predstavite svoje raziskovalne in razvojne dosežke ali srečate stare znance in nove, povabljene predavatelje s področja, ki vas zanima. O svojih dosežkih in problemih lahko poročate v strokovni reviji, ki ima ugleden IMPACT faktor.S svojimi predlogi lahko usmerjate delovanje društva.

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Upamo, da vas delovanje društva še vedno zanima in da boste članstvo obnovili. Žal pa bomo morali dosedanje člane, ki članstva ne boste obnovili do konca leta 2006, brisati iz seznama članstva.

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MEMS/NEMS TECHNOLOGIES AT CENTRO RICERCHE FIAT

Marco Pizzi, Valerian Konyachkine[1], Vito Lambertini, Nello Li Pira, Marzia Paderi,
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INVITED PAPER
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13.09.2006 - 15.09.2006, Strunjan, Slovenia

Key words: microtechnologies, nanotechnologies, MEMS, NEMS, etching

Abstract: The research on micro and nanotechnologies at Centro Ricerche Fiat ranges from NEMS/MEMS, to microoptics, substrates nanostructuring, smart materials, to many different technologies for sensors, actuators, displays and miniaturised energy production and storage devices.

Here we will describe two examples, SISA technology (Stress Induced Self Assembly) and its application to the fabrication of low cost MEMS IR spectrometers, and piezoelectric materials nanostructuring for adaptive photonic crystals and diffractive gratings.

Tehnologije MEMS/NEMS v razvojnem oddelku koncerna FIAT

Kjučne besede: mikrotehnologije, nanotehnologije, MEMS, NEMS, jedkanje

Izvleček: V prispevku predstavljamo raziskave na mikro in nanotehnologijah v Raziskovalnem centru firme Fiat, ki obsegajo raziskave NEMS/MEMS, mikrooptike, nanostrukturiranja substratov, pametnih materialov in raziskave različnih tehnologij za izdelavo senzorjev, aktuatorjev, prikazovalnikov in shranjevalnikov energije in podatkov.

Nekoliko bolj podrobno predstavljamo tehnologijo SISA (Stress Induced Self Assembly) za izdelavo cenenih MEMS IR spektrometrov ter nanostrukturiranje piezoelektričnih materialov za izdelavo prilagodljivih optičnih kristalov in uklonskih mrežic.

1. Introduction

Micromachining technologies can be divided in two main classes, distinguishing **top down** and **bottom up** approaches.

The first set essentially consists of "planar" technologies, where the electronic components and MEMS are fabricated on (or in) substrates that are in the form of flat wafers. The microelectronics industry has made huge investments to develop wafer-level processes. To take advantage of these available and well experimented techniques, MEMS designers try to use the same technologies of the microelectronics industry, or variants based on the same steps. Common practice is to identify "bulk micromachining" with processes that etch deeply into the substrate, and "surface micromachining" with processes that remove sacrificial layers from beneath thin-film structures, leaving free standing mechanical structures. The structures are generally defined by film deposition, UV lithography and etching, repeated for each layer of the structure. The etching phase, both in bulk than in surface micromachining, can be wet or dry. Alternatives to photolithography, like focussed ion beam (FIB) or nanoindentation by modified atomic force microscopes, have been recently used to define detail at nanometre scale.

"Bottom up" approaches include all the so called "self assembly" techniques, and are typically referred as part of nanotechnology. Being life the most amazing example of self assembly, these techniques potentially represent the meeting point of "hard sciences", like physics and mathematics, and "life sciences", biology and medicine.

In the following figure (fig. 1) the above described classification is synthesized.

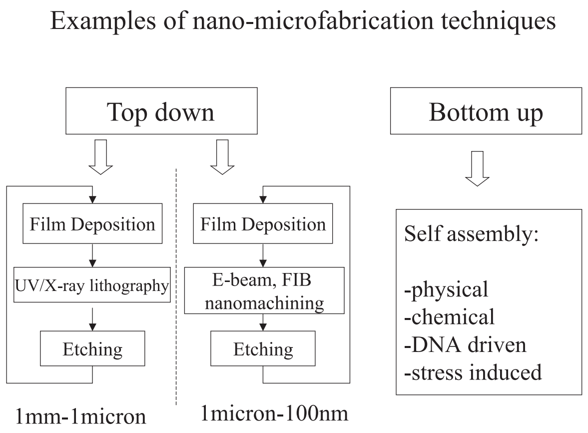

Fig.1. Examples of nano-microfabrication techniques

In this paper we will give few examples of bottom up techniques and their implementation at micro scale in MEMS-NEMS devices.

2. Stress induced 3d self assembly (SISA).

Stress Induced Self Assembly (SISA) technique is a combination of top down and bottom up approaches. In particular the **top down** approach is used to define geometries of objects at the micrometer scale by photolithography and details at the nanoscale level by focussed ion beam technology. The **bottom up** approach is used for the final "stress induced" assembly of the structures. In the following table the logic sequence of the steps defining the proposed technology are summarised (fig.2).

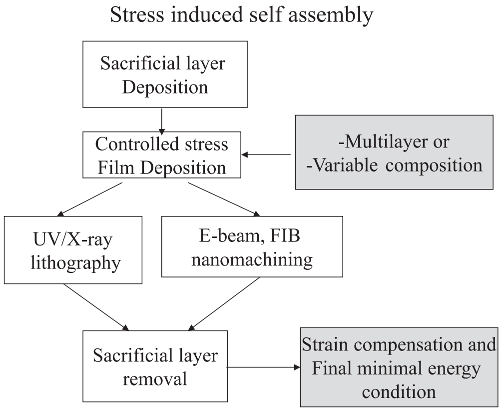

Fig.2. Scheme of SISA technology.

A sacrificial layer is deposited and patterned on a substrate by photolithography and etching. A second structural layer is then deposited, changing the composition of the alloy at different depths to control the stress of the film (fig.3).

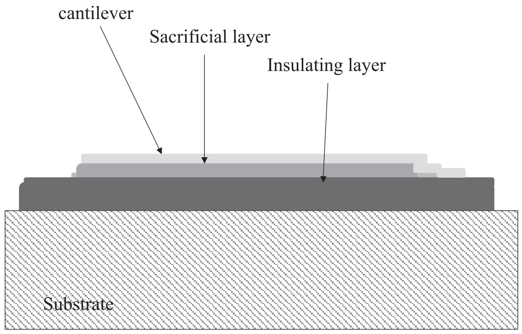

Fig.3. Example of multilayer deposition technique for SISA process.

With a precise control of the deposition conditions, strong internal anisotropic stress can be induced. In particular, if z is the direction perpendicular to the substrate we have:

$$\frac{\partial \sigma_{x,y}}{\partial z} \neq 0 \qquad (1)$$

The structural layer is then patterned by usual photolithography and etching. A selective etching of the sacrificial layer allows the compensation of the stress by deformation of the structural layer. A proper control of both induced stress and patterning generates the desired 3D structures. A similar result can be obtained by bimorph or "multi-morph" structures.

Depending on the sign of the derivative of the stress along the z axis, different curvatures can be obtained (fig.4).

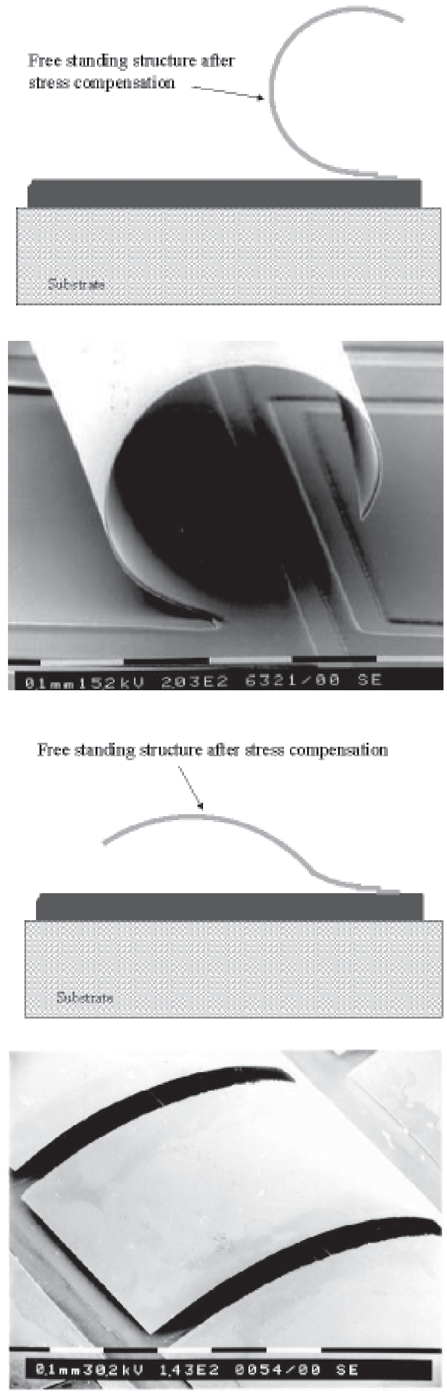

Fig.4. Examles of free standing structures after sacrificial layer removal and stress induced compensation.

Several components like microshutters /1/, microreservoirs /2/, microcoils have been fabricated by this self assembly technique (Fig.5 and 6).

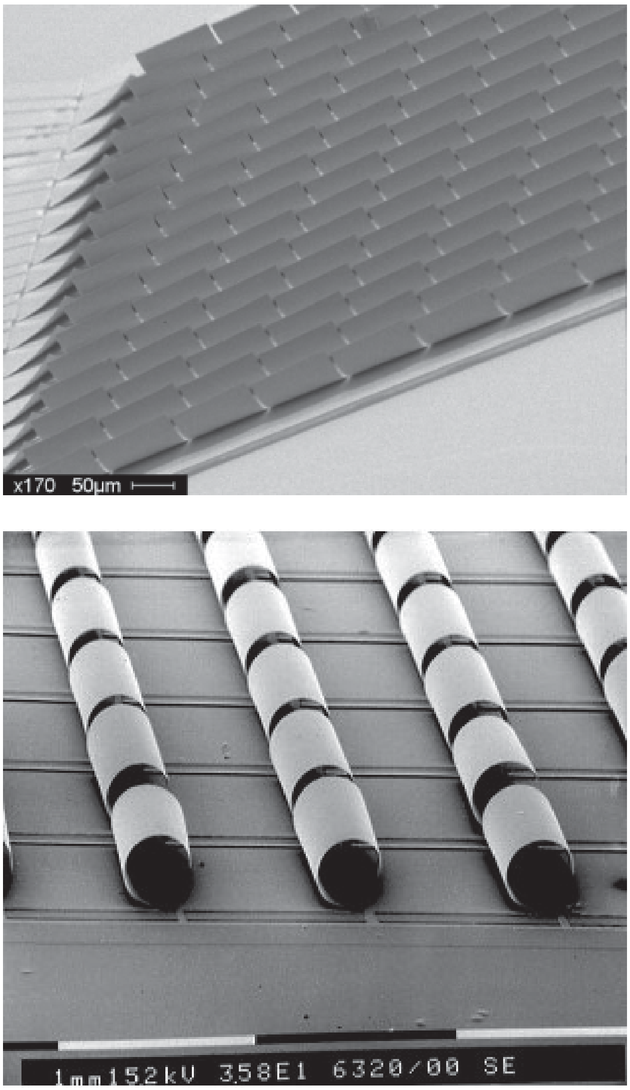

Fig.5 Examples of stress induced microfabrication, microshutters.

This technique is currently gaining more popularity and interesting works have been published implementing this method to fabricate complex structures. An original evolution of these concepts is the so called "origami technique", introduced by the research group in ATR in 2003 /3/. In this technique rigid parts are assembled using the flexible stressed structures as active hinges.

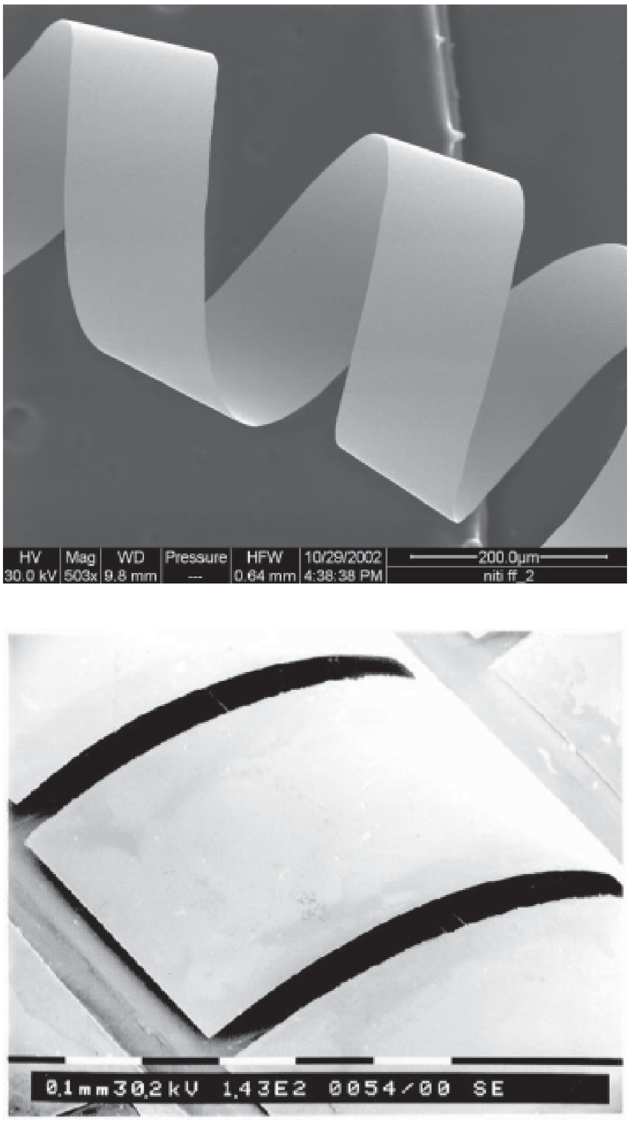

Fig.6. Examples of stress induced microfabrication, microcoils and flexible elements for electrostatic actuators

Photolithography and etching are generally used to obtain the patterns in the stressed films but during the study and development of a new device the implementation of FIB (focussed ion beam) technology in a sort of "rapid nanoprototyping" can be very useful. A structural layer with controlled internal stress is deposited on a sacrificial layer. FIB technology is then used to define the shape of the film (cutting with the ion beam with tens of nanometers level precision) and to deposit additional patterns to compensate the internal stress in defined regions. After release by etching of the sacrificial layer the desired self assembled structure is obtained. An example of this technique is given in the next figure (fig. 7), where a rectangle with two lateral circles have been defined. On the circles an additional "doughnut" platinum layer has been deposited. After the etching of the sacrificial layer the rectangular part will roll up in a cylindrical shape while the rigid circles will form the basis of the cylinder.

Parts of the stressed layer can be covered by a selective Pt layer to obtain, after sacrificial layer removal, a flat part of the free standing film, as reported in fig. 8.

The technology is expected to reduce the development time of nano and microstructures allowing the preparation of few test samples without the need of mask design and fabrication, multiple steps of photoresist deposition, baking, exposure, development and dry or wet etching of the

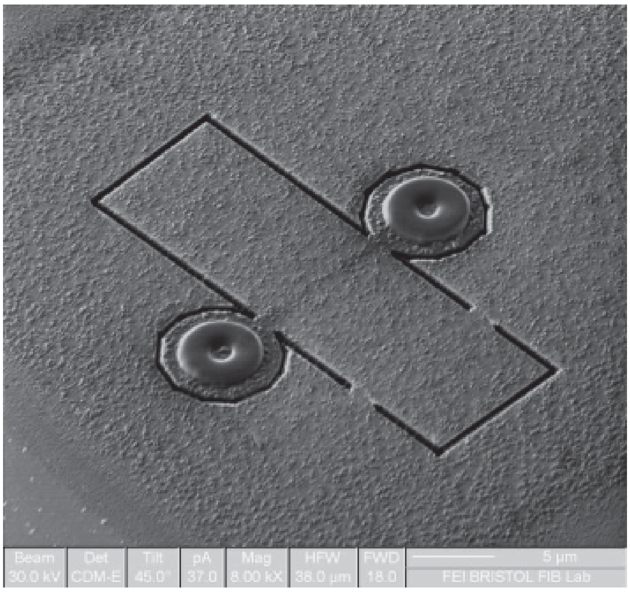

Fig. 7. Example of FIB micromachining

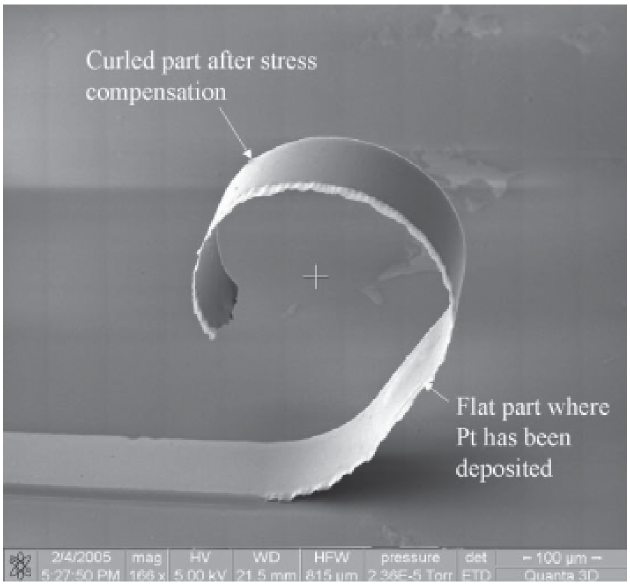

Fig. 8. Stress control by FIB additional layers deposition.

microstructures, deposition of additional layers, and again lithography steps. For successful configurations only the masks for batch processing are generated.

The main application explored by the authors implementing stress induced self assembling techniques is related to electrostatically driven microstructures, used both for optical modulation than for miniaturised actuators. Many technological issues have been addressed to combine suitable materials and processes for electrostatic actuation, self assembly, etching compatibility, optical and mechanical features. In the following an example of application of SISA technology to IR and optical modulators will be given.

2.1 Exhaust gases emission control

Microsystem technologies can have a strong impact on the evolution of the engine control strategies. The availability of low cost, miniaturised sensor arrays for the detection of the main physical and chemical parameters will enable a higher degree of control of the combustion conditions and of the engine operation in general.

Due to the concern of health, environment and climate the limits for emissions of nitrogen oxides (NOx), hydrocarbon (HC), carbon monoxide (CO), particulate matter (PM), and the greenhouse gas carbon dioxide (CO2) from vehicles equipped with combustion engines are continuously lowered. In the year 2008 the European limits for NOx and PM for diesel engines will be 0.08 g/km and 0.005 g/km, respectively (Euro V). The US limits will be similar (TIER 2-BIN 5).

The continuous evolution towards low ecologic impact cars can be enabled by a more precise and continuous control of the emissions.

Infra red spectroscopy is normally used to characterise the engine behaviour but the available gas spectrometers are currently not suitable for on board application, being bulky and expensive. A novel concept of spectrometer based on SISA fabrication is here presented.

2.2 Microshutter based spectrometer.

The structure of the MEMS device implemented in the spectrometer is shown in fig.9. It is based on an optically transparent substrate, e.g., glass or sapphire. The substrate is coated with two optically transparent layers, first an electrically conductive layer and then an insulating layer.

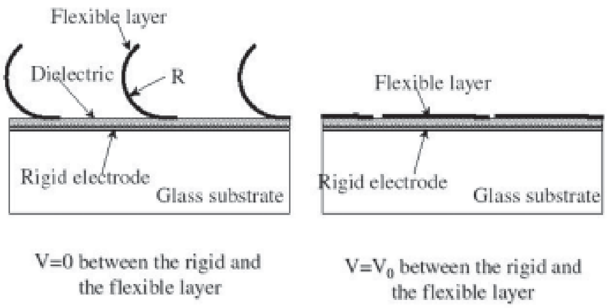

Fig. 9. Structure and working principle of electrostatic microshutters.

Pixels have a “digital” response that is freely programmable by the user, e.g., in a Hadamard sequence. A choice of substrate materials is available, including glass and sapphire, which in turn allows utilisation over a wide wavelength range including the visible, near infrared, and mid infrared ranges. The device can be used in both transmittive and reflective optical architectures. Hermetic packaging is not required, instead, dust-proofing is sufficient. A light beam is directed on the gas sample under study; the transmitted light beam is divided in its components: a narrow part of the dispersed beam is selected by mean of a linear array of micromechanical shutters. The intensity of the transmitted beam is than detected by a single sensor (fig.10).

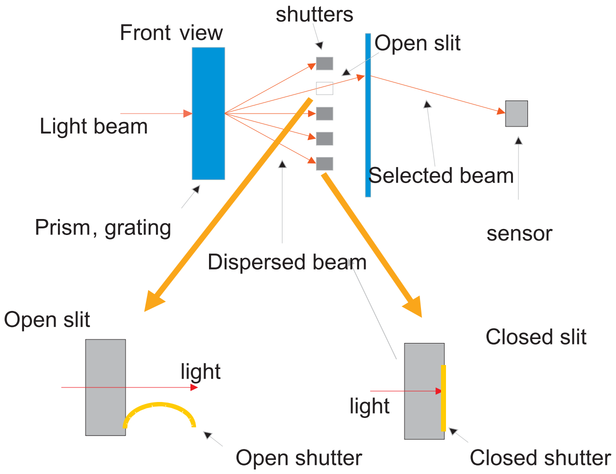

Fig.10. Concept of the Microshutter based single sensor spectrometer.

A single detector instead of a detectors array will improve the performances and will simplify the production process. Fig. 11 presents the packaged 25-element MOEMS shutter array and the key parts inside the spectrometer prototype.

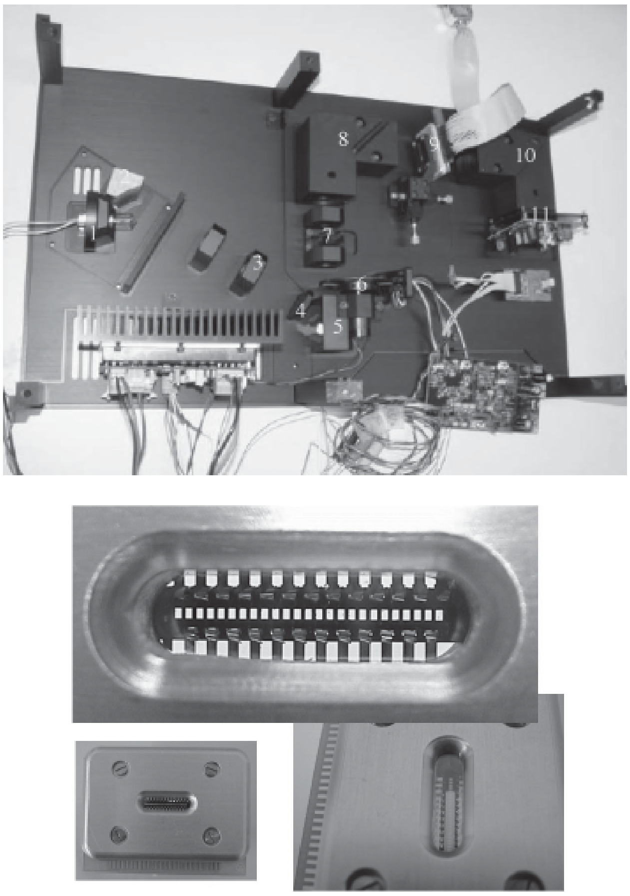

Fig.11. The spectrometer prototype system.

It is composed by a light source (1), a mirror (2), a band pass filter (3), an iris (4), a second mirror (5), a chopper (6), generating both the needed pulsed light beam and a clock at 525 Hz for system synchronisation, the housing for the material to be analysed (7), in particular a cuvette, the first grating (8), the microshutter device (9), the second grating (10) and the single element PbS sensor (11).

The main benefit expected from this technique is the low price level of the shutter array together with the single element detector, which will enable cost-effective spectrometers to be made. The implementation of fibre and/or integrated optics architectures will enable the miniaturisation of the system. To test the performances of the spectrometer we measured spectra of different liquids. We report here the case of urea that is of interest for some biomedical applications.

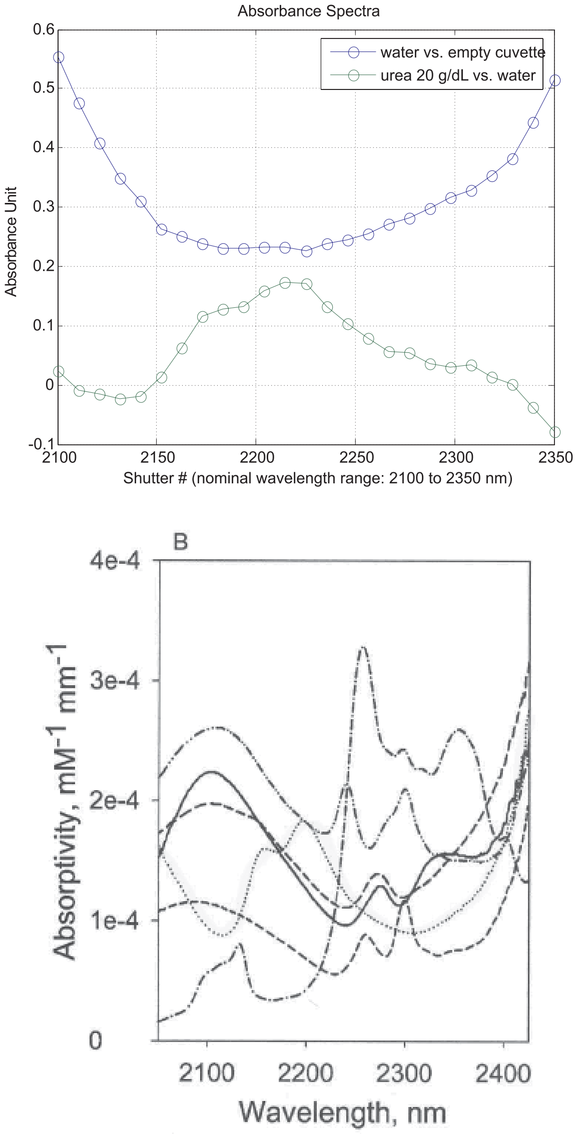

FIG. 2. Molar absorptivity spectra of glucose (solid), alanine (dash-dot-dot), ascorbate (medium dash), lactate (short dash), urea (dotted), and triacetin (dash-dot) at 37.0 ± 0.1 °C over (A) the first overtone and (B) the combination spectral regions of the near-infrared spectrum.

Fig.12A,B Comparison of spectrum from microshutter based spectrometer and /4/

The absorbance spectrum of 0.5 mm water measured with the prototype has the expected shape. Very convincing is also the analysis of the high-concentration urea absorbance spectrum measured using the prototype (green trace in Fig.12 A), which can be compared to the spectrum measured on highly accurate FT-IR type spectrometer shown in Fig.12 B.

The double absorbance peak feature near 2200 nm shown in Fig.12B can clearly be seen also in Fig.12A. The water displacement effect, which was computed out in fig.12B but not in fig.12A, is responsible for the differences in the absorbance slopes near the edges of the plotted wavelength range, but this is expected and inconsequential here.

We calculated the noise performance is close to the limit set by the PbS photodetector. The prototype, given only 1 second of integration time, can resolve urea concentration changes as small as about 4.7 $(mg/dL)_{RMS}$.

3. Piezoelectric nanostructures.

As an example of smart materials nanostructuring and integration in MEMS devices we will shortly describe the concept and proposed fabrication of an adaptive piezoelectric photonic crystal.

Photonic crystal is a periodic dielectric material. The dielectric permeability of photonic crystal is given by

$$\varepsilon\left(\mathbf{x}+n\mathbf{a}_1+m\mathbf{a}_2+l\mathbf{a}_3\right)=\varepsilon\left(\mathbf{x}\right) \qquad (2)$$

where $\mathbf{a}_1$, $\mathbf{a}_2$, $\mathbf{a}_3$ are the lattice vectors defining the directions of periodicity. Photonic crystals can totally reflect the radiation of certain wavelengths. The so called "band gap" depends on the structure and geometry of a photonic crystal. The computing of the band gap is reduced to the solution of Maxwell's equations describing the propagation of electromagnetic waves in a periodic dielectric material. A modulation of the geometry and/or dielectric permeability would enable the fabrication of novel optical modulators and adaptive waveguides. Nanostructured piezoelectric materials can be used for that purpose. We started from the fabrication of ordered templates by self assembly techniques, in particular anodic porous alumina (APA) and artificial opals. The templates are then impregnated by solutions of PZT and reticulated by thermal treatments.

3.1. APA

APA is an example of 2D photonic crystal. To form the structure a high purity aluminium foil is put in contact with the anode of a electrochemical cell; the anodization process is carried out with acid electrolyte. An oxide layer begins to grow on the surface of aluminium, after some minutes pores form on the surface and the mechanical stress of the oxide force the hexagonal distribution of the pores: at this point the walls of the pore grow with constant velocity and the bottom layer thickness of the pore remains constant. Therefore it is possible to obtain thick membranes of alumina with straight channels from one side to the other with one open end; the barrier layer can be removed with a chemical etching to obtain micro channels both sides opened. Many tests have been made to determinate the main parameters of the process that affects sample geometry: time of anodization, current density, type and concentration of electrolyte, temperature of the environment. The inter-pore distance depends nearly on the anodic potential, so structures with different dimension but same geometry can be obtained as shown in figure 13.

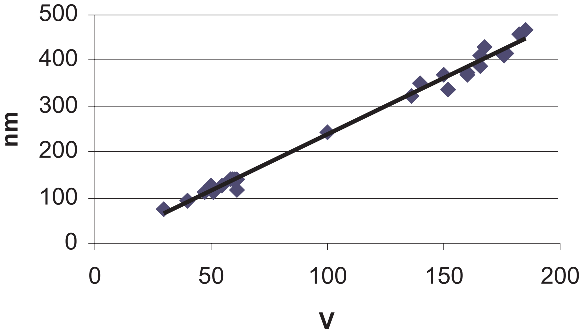

Fig.13. Interpore distance depending on electrolytes and voltage

Pores diameter can be increased with widening process in acid solution that penetrates in the pores and consumes pores walls. Surface and section views are reported in fig.14.

The growth rate of alumina depends on current density as well and varies from 5 to 25 μm/h, that permits to obtain alumina membranes with the desired thickness.

Porous anodic alumina is a nanostructured material that can be produced with a fast and low-cost process although the lattice can present many defects and irregularity.

3.2 Artificial Opals

Opal-like structures are 3D photonic crystals and are produced by CRF by two different methodologies: the first utilising Layer by Layer (LBL) process, the second by sedimentation in a centrifuge.

The LBL assembly is based on the alternating adsorption of oppositely charged species, such as positively and negatively charged polyelectrolyte pairs or polyelectrolytes and nanoparticles. Multilayer ultrathin films can be developed with "molecular architecture" design with precise control of thickness and molecular composition. It can be effectively applied to the coating of both macroscopically flat and nonplanar (e.g. colloidal particles) surfaces. Opals nanospheres syntesized in water/Ethanol solvent are negatively charged: if coupled with appropriate positive polyelectrolyte the spheres can be deposited in a nanostructured film.

The following standard cyclic procedure was employed,

(i) dipping of the substrate into a solution of positive polyelectrolyte

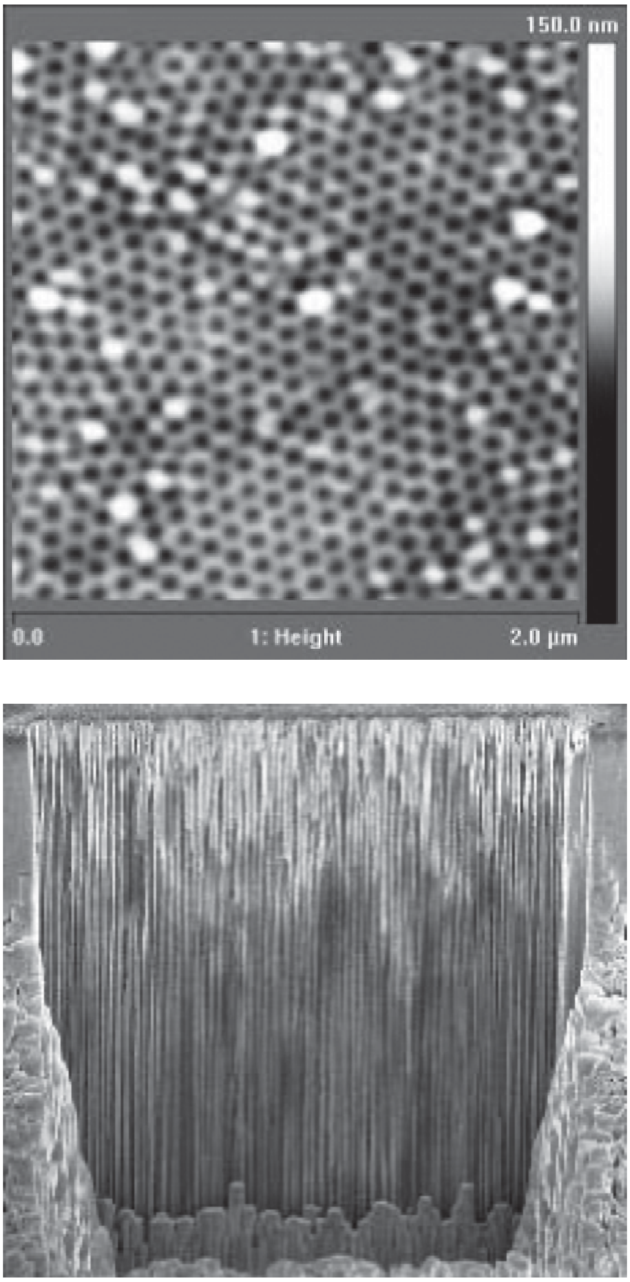

Fig. 14. AFM image of alumina surface and FIB image of the section of alumina surface

(ii) rinsing with water

(iii) dipping into the aqueous dispersion of opals nanospheres and rinsing with water again

The process can be cycled to obtain a multilayer film of the needed thickness. The slides with deposited opals are impregnated with PZT solution (provided by Josef Stefan Institute) by drop, dip, and spin coating. The sol infiltrates the interstitials, leaving a flat layer above the spheres (see fig. 15). After the impregnation a thermal treatment in oven is performed.

Alternatively the opals can be fabricated by sedimentation in a centrifuge. In order to have a very ordered opals film, substrates 0.5 x 0.5 cm are inserted in a flat centrifuge tube. A very short volume of opals solution is placed into the tube and centrifuged. The liquid surnatant is separated and the glass with the film is thermal treated at 400°C. The slides are characterised by AFM and FIB techniques.

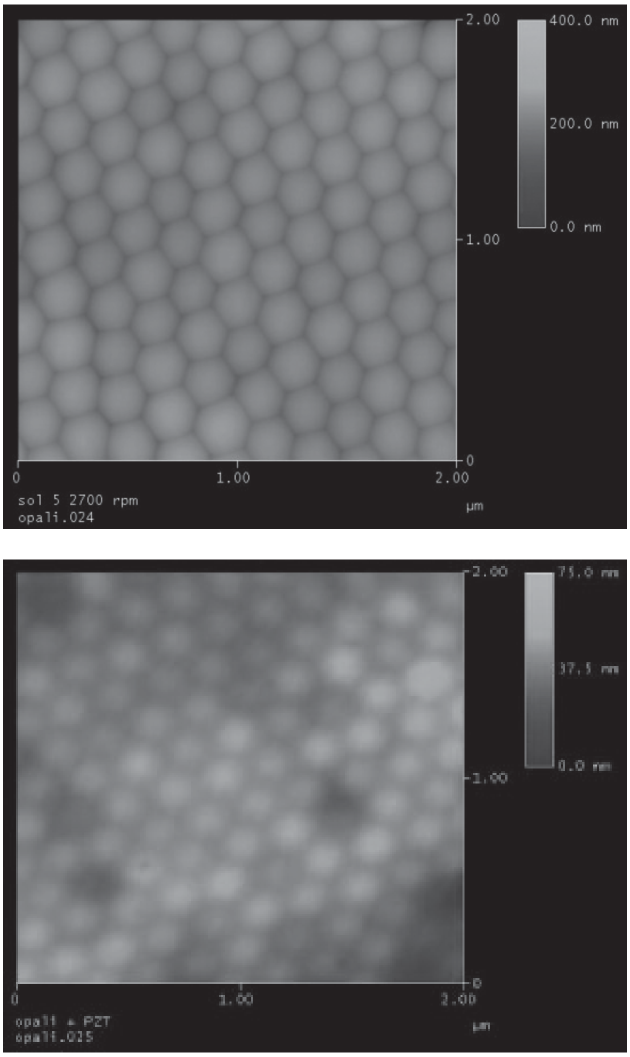

Fig.15. Opals before and after impregnation.

Experiments on the electrooptical characterisation are currently in progress.

3.3 Adaptive diffractive gratings

A different approach based on adaptive diffractive gratings has been investigated too. A binary grating has been fabricated on a flexible, compliant material and integrated with a piezo tube (supplied by Ferroperm). The coupling of the grating with the piezo actuator allows the modulation of the height of the grating profile. Being the efficiency diffraction dependent on that height, the idea is to actuate the compliant grating to change the diffracted light in different orders.

The experimental setup to verify the feasibility of the device is composed by a laser source, the adaptive diffractive grating and an optical sensor measuring the intensity of a part of the diffracted light (fig.16)

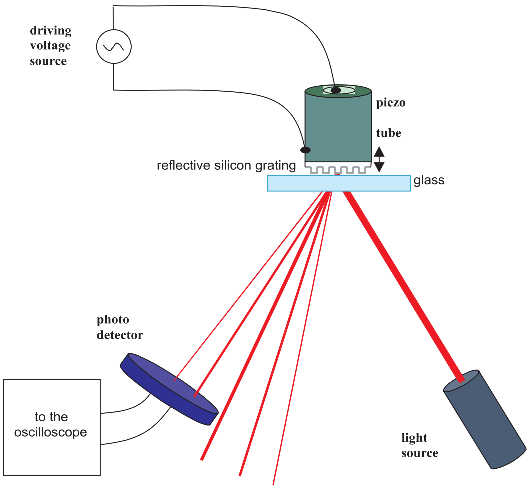

Fig.16A

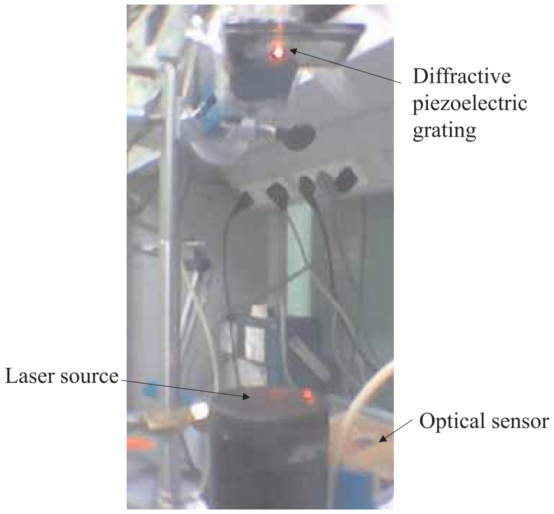

Fig. 16B

When the element is not actuated there is no AC signal on the sensor (fig.17A) while when the element is actuated the modulation is displayed.(fig.17B)

As expected the light modulation follows the frequency of the piezoelectric actuator.

4. Conclusion

Several automotive applications of MEMS have been proposed in the last years. Sensing seems to be the most promising field for the implementation of MEMS-NEMS technologies in new components with novel or improved functions. In particular a new application of Microshutter Technology to exhaust gases control has been presented.

A novel MEMS optical modulator based on adaptive nanostructured metamaterials has been addressed. It is an example on how the implementation of nanoscale techniques in MEMS devices can be a promising way to effectively exploit the great potentialities offered by nanotechnology.

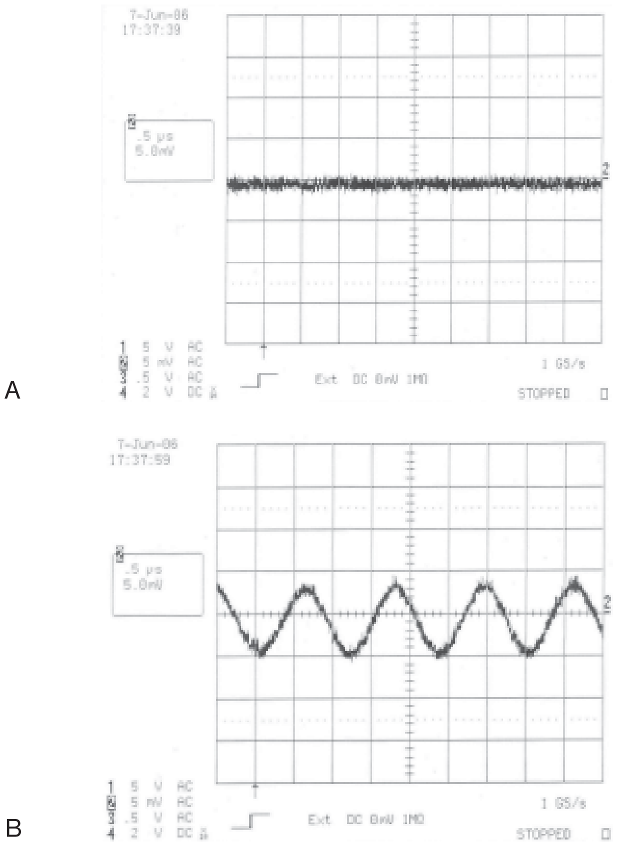

Fig.17A Piezoelectric not actuated – no signal on the photodetector and B Piezoelectric actuated @ 860 kHz (60 Vpp) – modulated light on photodetector

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MEMS PRODUCTS AND MEMS TECHNOLOGIES FOR AUTOMOTIVE APPLICATIONS AT INFINEON

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Key words: sensors, avtomotive sensors, MEMS, GMR sensors

Abstract: Sensor products and the corresponding fabricating technologies represent a challenging field within semiconductor development. The article will give you an overview of Infineon sensors and shows the development of the required technologies.

The product portfolio can be described with two major sensing principles, magnetic sensing with Hall sensors and GMR Sensors and "moving mass sensing" with Gyrometers, accelerometers and pressure sensors.

On one side the technology is based on bulk micromaching integrating the piezoresistive resisors. On the other side, BiCMOS technologies with integrated Hall elements, GMR elements and integrated micromechanical devices are used. A focus within the development of these technologies and products is to assure robustness, high yield and automotive quality within automotive specifications.

An outline of the principal development flow of such a technology development will be given. A prerequisite to provide quality is to use a well known and qualified process base and the IP pool of an established fab.

In case of SMM Devices this process base is a 0,5µm BiCMOS process. Within qualification DOE's provide a deep device and technology understanding.

The summary shows the corresponding fields of application and products

Infineonovi MEMS izdelki in tehnologije za uporabo v avtomobilski industriji

Kjučne besede: senzorji, avtomobilski senzorji, MEMS, senzorji GMR

Izvleček: Senzorji in njim pripadajoče tehnologije predstavljajo zanimivo področje znotraj razvoja polprevodnikov. V prispevku podajamo pregled nad Infineonovimi senzorji in pregled nad razvojem ustreznih tehnologij.

Delovanje senzorjev temelji na dve osnovnih principih: magnetno zaznavanje (Hall in GMR senzorji), oz. zaznavanje z gibajočo se maso (žiroskopi, merilniki pospeška in merilniki pritiska).

Na eni strani je tehnologija osnovana na mikrojedkanju substrata za izdelavo piezo uporov. Na drugi strani pa BiCMOS tehnologija omogoča integrirane Hall elemente, GMR elemente in integrirane mikromehanske komponente. Končni cilj razvoja tovrstnih tehnologij je zagotoviti robustnost, visok izplen in kakovost, ki zadovoljuje stroge zahteve avtomobilske industrije.

Podali bomo primer razvoja ene takih tehnologij. Pogoj za doseganje visoke kvalitete je uporaba znanih in kvalificiranih procesov ter znanja in izkušenj proizvodnje.

V primeru SMM komponent je osnova 0.5um BiCMOS proces. V povzetku naštejemo ustrezne izdelke in možnosti uporabe.

1. Infineon Sensors

The Infineon Technologies sensor product portfolio can be described within two main sensor principles, magnetic sensors and mechanical sensors.

Today most of the magnetic sensor are realized with a simple n-doped well integrated in a 0,5µm BiCMOS logic process.

This base technology is operating with 5 to12V and produced with a 2 to 3 layer metallization on 8 inch wafers

Due to the construction of the n-well resistor and the Hall Effect the sensor is sensitive perpendicular to magnetic fields. The advantage of this approach is the easy integration in existing basic logic technologies, which allows a great diversity of applications and interfaces.

A new and promising technology for measuring magnetic field is the GMR (Giant Magnetic Resistor) technology. The resistance of the layer stack is sensitive to magnetic field components in plane to the sensor.

The advantage of this effect is a higher sensitivity for higher resolution or reduced application / packaging requirements. This technology is integrated in a 0,25µm logic technology. This technology is in ramp up.

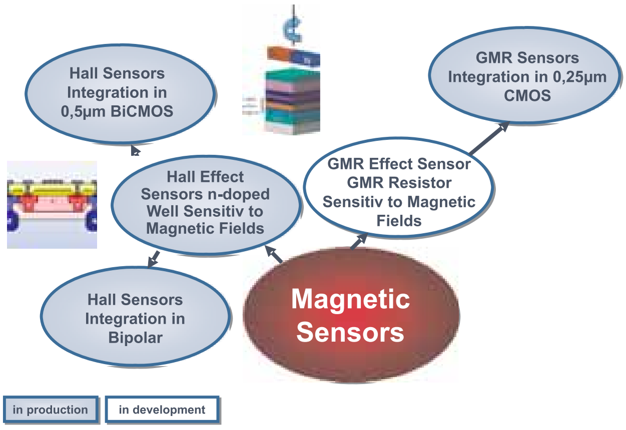


Fig 1: Magnetic Sensors

For mechanical sensor within Infineon Technologies, the inertia sensors are produced with a BMM (Bulk Micromachining) technology with no integration of logic circuitry. This technology allows access to Mono-Silicon cantilevers and beams. The movement of the beam is detected on one side with piezoresistive resistors placed in the stress maximum of the beam. This concept is applied for pressure sensors and acceleration sensors.

Demonstrated in the TPMS product (Tire Pressure Monitoring System) a membrane pressure sensor and cantilever acceleration sensor can be realized on the same chip in one production flow.

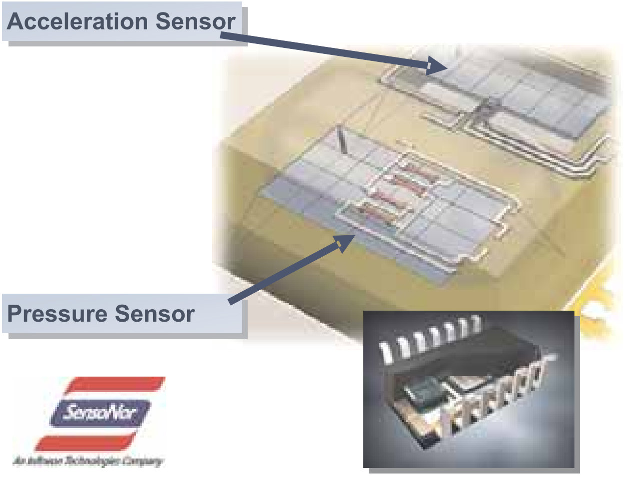


Fig 4: BMM TPMS Sensors

On the other side the signal can be realized with measuring the capacitive signal between the two moving electrodes. This concept is applied for the Gyrometers.

Overall mechanical sensors allow sensing of multiple physical parameters. For example Pyrho-Arrys with detecting temperature differences below 1°C or microphones with HIFI quality in µm dimensions.

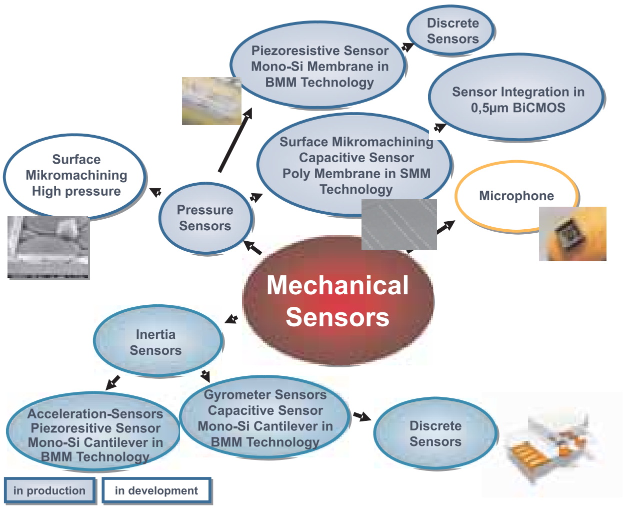


Fig 2: Mechanical Sensors

The application of these technologies within the product portfolio is described in the following overview

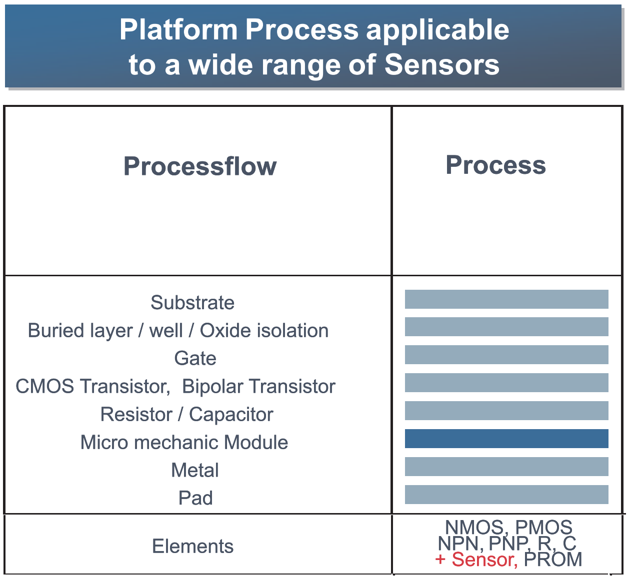
	Sense	Compute	Actuate
Powertrain - Diesel Engine Mgmt. - Gasoline Engine Mgmt. - Transmission Control - Starter / Alternator	▪ Pressure Sensors ▪ Hall Sensors	▪ 16 bit µC ▪ 32 bit TriCore® (µC + DSP)	▪ MOSFETs ▪ IGBTs ▪ Regulators ▪ Transceivers ▪ Smart Power ▪ System ICs
Safety Management - ABS / Traction Control - Suspension - Airbag + Restraint Systems - Power Steering - Tire Pressure Monitoring	▪ Pressure Sensors ▪ Hall Sensors ▪ RF ICs	▪ 8 bit µCs ▪ 16 bit µCs ▪ 32 bit TriCore® (µC + DSP)	▪ Diodes ▪ Transistors ▪ MOSFETs ▪ Regulators ▪ Transceivers ▪ Smart Power ▪ System ICs
Body & Convenience - Light Control - Heating, Ventilation, Air Condition - Door & Seat - Smart Battery Terminal	▪ Hall Sensors ▪ Temp. Sensors ▪ RF ICs	▪ 8 bit µCs ▪ 16 bit µCs	▪ Diodes ▪ Transistors ▪ MOSFETs ▪ Regulators ▪ Transceivers ▪ Smart Power
Infotainment - Telematics - Navigation - Multimedia - Car Audio - Dashboard	Microcontrollers, Wide Range (GSM/GPRS) and Short Range (Bluetooth, WLAN) communication solutions, GPS, High Frequency ICs, CAN/MOST Transceivers, Plastic Optical Fibres, Multimedia Cards, Power ICs, Security ICs		

Fig 3: Product Portfolio

2. SMM Pressure sensor technology

The technology of the SMM pressure sensor is described in more detail within the following chapter.

Bases of the technology is a well known 0,5µm state of the art BiCMOS technology which is already in production. The process flow of the technology consists of different process modules. The base process providing vertical NPN's, lateral PNP's, 5V CMOS, Poly resistors and Poly-Poly Capacitors can be expanded by adding process moduls and such adding devices.



Platform Process applicable to a wide range of Sensors

Processflow	Process
Substrate Buried layer / well / Oxide isolation Gate CMOS Transistor, Bipolar Transistor Resistor / Capacitor Micro mechanic Module Metal Pad	
Elements	NMOS, PMOS NPN, PNP, R, C + Sensor, PROM

Fig 4: Processflow SMM Pressure Sensors

In this way the Hall probe, vertical PNP's, PROM devices and high voltage devices up to 30V have been added. In the same way a module for fabricating the pressures sensor has been added.

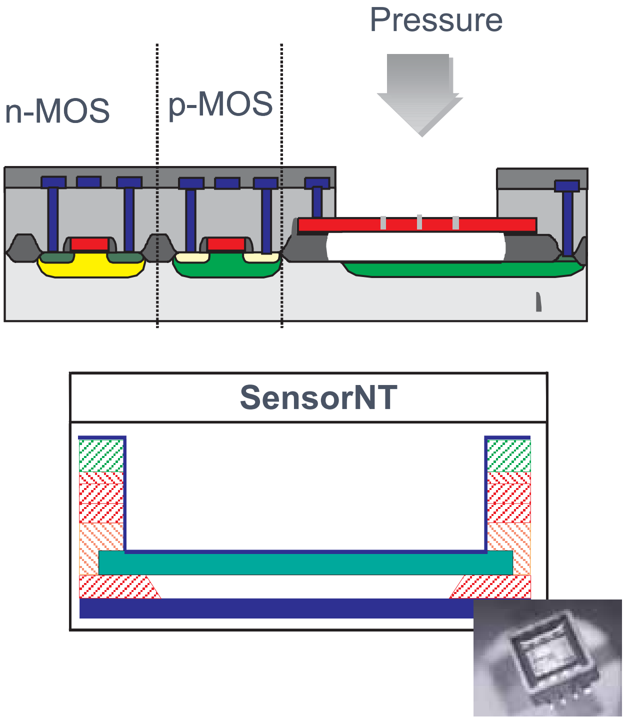


Fig 5: Sensor concept

This module consists of a sacrificial layer, providing the cavity after having been etched; it consists of a Poly silicon layer working as a membrane; it consists of the cavity sealing process and last not least it consists of the final passivation of sensor and circuitry. All this steps are done in a standard CMOS fab with no extra equipment or special processes.

After completing the process the sensor consists of a 0,8µm Polysilicon membrane. The cavity hight is 0,3µm with an inside pressure of <2hPa and a maximum bending of the Poly membrane of about 20nm.

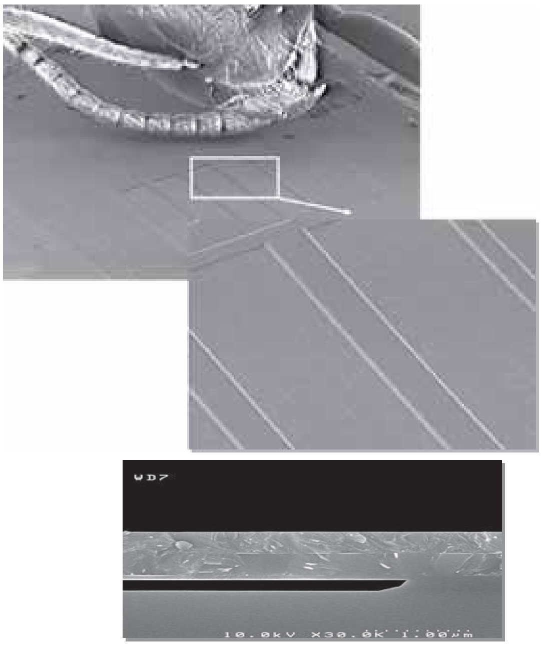


Fig 6: Cross Section SMM Presssure Sensor Device

2 sensor arrays and 2 non movable reference arrays are arranged in a wheatstone bride. Each array consisting of 42 independent pressure sensor cells.

The pressure sensor product is applicated for 0,1bar to 3 bar with 1% overall accuracy. The accuracy is achieved with on chip signal conditioning

This sensor is used for side airbag detection and motor management

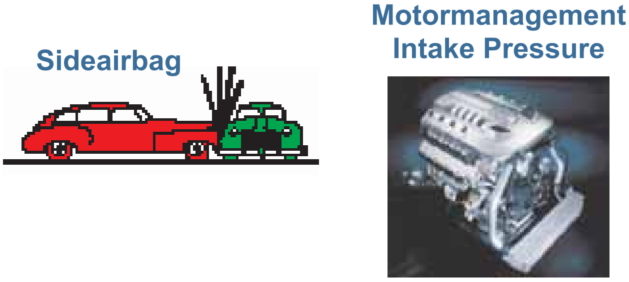


Figure 5: SMM Pressure sensor applications

3. Technology Development, Example SMM Pressure Sensor Technology

The technology development process is controlled by project management and during ramp up by a dedicated ramp up team.

The technology development team provides the unit processes, the process integration the process flow and the equivalent devices for controlling process and device parameters.

The product development team provides the product design, the test engineering and the logistics during development.

For a parallel development of technology and product a test chip design has to be done.

The analyses departments provides physical analyses, stress tests, simulations and parameter extractions

The qualification department provides process and product qualification.

After the release of technology and product the responsibility is handed over to the fab which takes care for yield and quality.

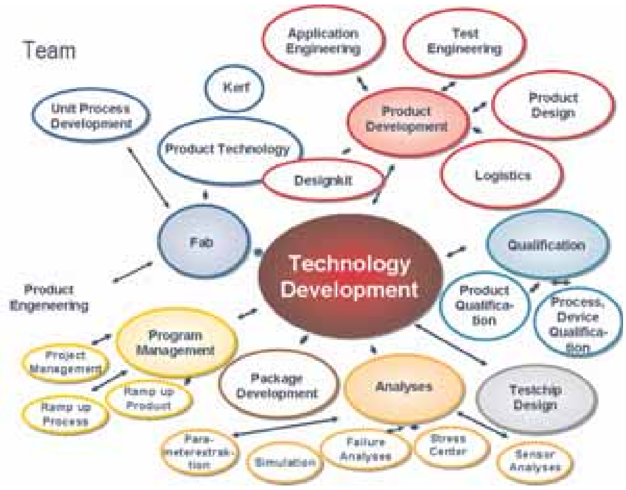


Fig 6: Technolgy development process, involved teams

The main targets of the development are:

Qualification of the technology, verifying the technology robustness in terms of variations in the fabrication process and of course a stable yield.

The most important development tools to archive this are simulation, FMEA (failure methods and effect analyses) and process window evaluations.

The simulation of the Sensor Device is mainly done with FEM and must result in a model applicable within the product development. For the model is based on process parameters, this allows an in depth understanding of the product performance and it allows a fast analysis of deviations.

The FMEA Method is a method for classifying all risks in a cross functional team. Measures taken for device or process can be tracked by the team and the problem solving is documented.

Below, a short overview of the development process and its deliverables are given.

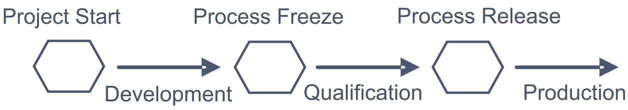


Fig 7: Overview development process

The project starts with the process and product idea. If the target of the development is the development of a new platform technology the technology may be done parallel to the product development

The deliverables at this status are:

- Consolidated project plan
- Technology and development concept created
- Feasibility proven
- Target specification of devices fixed
- Risk analysis done

The freeze of the process flow can be done when the stability of the process is proven and no major changes are necessary. It enables the production of engineering samples.

The deliverables at this status are:

- Feedback from pilot product including package
- Final process flow for qualification
- Preliminary device characteristics and Design Rules
- Process window results on critical parameters
- Early Hardware reliability results available

The developed process is released in agreement with the involved partners and with the final qualification of process and product.

The deliverables at this status are:

- Device characteristics and Design Rules finished
- Process flow Construction analysis finished
- Technology documentation finalized
- Production Robustness proven
- Qualification finalized, Qualification Report & Record available.

Within the qualification a complete technology qualification has to be done once per technology or process line and a product qualification has to be done for each product or product family

A technology qualification consists of:

- Devices qualification (e.g. drift at bias / temperature stress)
- Dielectrics qualification (e.g. time to breakdown)
- Metallization qualification (e.g. maximum current densities, electromigration stability)

The result of the technology development process is a Technology Platform established for Application in Products with:

- A qualified and standardized process line with process flow and equipment recipes for production
- The necessary device library, design documents and tools for product development
- The equivalent kerf

4. Summary

The Technology portfolio of Infineon provides MEMS processes for products in automotive applications.Magnetive sensing with Hall sensors and GMR sensors "Moving Mass Sensing" with Gyrometers, Accelerometers and Pressure sensors.

The Technology Development provides Technologies for automotive products Platform Technologies result in stable quality Standard Development flow result in robust processes

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INTEGRATED MICROSYSTEMS

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Key words: microsystems, 3D packaging, MEMS, SiP technology

Abstract: *Integrated Microsystems are essential enablers of a smart environment. Two important trends are increasing miniaturization and wireless and autonomous operation. The prominent ingredients of such wireless autonomous transducers are ultra-low power sensor readout architectures consuming microwatts of power, and powerMEMS or energy scavenging technology (generating microwatts of power). Miniaturised 'cubes' in the cm3 range have become possible by antenna integration and 3D SiP integration and packaging methods Truly unobtrusive integrated sensor systems require further downsizing to the mm3 range. This is envisaged by advanced 3D- packaging , and thin film integration of RF and MEMS components. For RF systems and RF-MEMS applications, IMEC's work is a generic extension of its current advanced packaging and interconnect technology RF platform For physical, kinematic as well as optical MEMS applications, a fully CMOS compatible generic above-IC polySiGe MEMS technology is presented. Examples of technology platforms will be given, including reliability of some demonstrated microsystems. Such extremely miniaturized systems will lend themselves to integration into flexible and even stretchable embodiments. This talk will summarize IMEC's efforts positioned within worldwide developments*

Integrirani mikrosistemi

Kjučne besede: mikrosistemi, 3D pakiranje, MEMS, tehnologija SiP

Izvleček: Integrirani mikrosistemi so ključni členi pametnega okolja. Kažeta se dva pomembna trenda pri razvoju mikrosistemov : minaturizacija ter brezžično, oz. avtonomno delovanje. Pomembne sestavine takih avtonomnih brezžičnih pretvornikov so senzorska čitalna elektronika z majhno porabo reda velikosti nekaj mikrowatov in močnostne strukture MEMS, ki lahko proizvajajo energijo v razredu moči nekaj mikrowatov. Izvedbe mikrosistemov z volumnom blizu cm3 so že realnost s pomočjo integracije anten in silicijevih čipov v ustrezno tridimenzionalno ohišje. Cilj zmanjševanja volumna proti mm3 je dosegljiv s tehnologijo tridimenzionalnega pakiranja in izvedbe struktur RF in MEMS s tankoplastno tehnologijo. To področje je pravzaprav nadaljevanje IMECovih raziskav tehnologij povezovanja in pakiranja. V prispevku predstavimo CMOS združljivo tehnologijo s polySiGe materialom za izdelavo MEMS struktur nad končanim inegriranim vezjem. Predstavimo različne primere tehnoloških platform in zanesljivost izdelanih mikrosistemov. Taki izredno majhni sistemi so primerni za integracijo na upogljive in celo raztegljive podlage. V prispevku predstavimo tudi IMECova prizadevanja in njihovo umestitev v svetovne razmere in razvoj.

1. Introduction

It is expected that by the year 2010, technology will enable people to carry their personal body area network (BAN) /1/ that provides medical, sports or entertainment functions for the user. This network comprises a series of miniature sensor/actuator nodes each of which has its own energy supply, consisting of storage and energy scavenging devices (see Fig. 1) /2/. Each node has enough intelligence to carry out its task and is able to communicate with other sensor nodes or with a central node worn on the body. The central node communicates with the outside world using a standard telecommunication network infrastructure. This network can deliver services to the person using the BAN.

One of the main challenges is power. Power consumption of all building blocks of the wireless sensor node has to be drastically reduced to be compatible with energy densities achieved using energy scavenging. An upper limit of the scavenged power (e.g. using thermo-electric generation) is

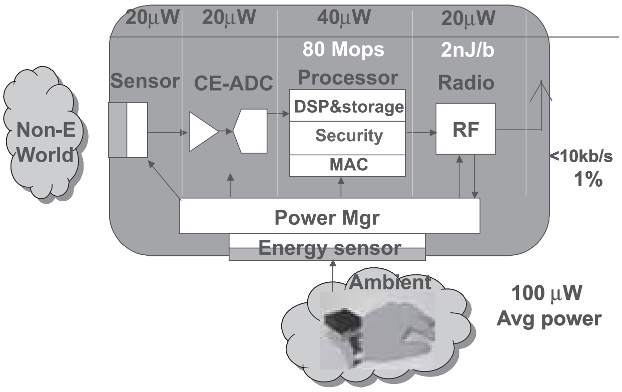

Fig. 1: Building blocks of the smart sensor environment: autonomously powered miniature wireless sensor module. The key ingredients and their tentative power budget are indicated: sensing, analog front-ends, local signal processing, bi-directional ultra-low-power radio, energy generation and management.

100uW but in practice, the average power scavenged will be even lower. The successful realization of this vision will therefore require innovative solutions to remove the power obstacles and bring down the power consumption of each component down below the levels indicated in Fig. 1.

Second, the overall size should be compatible with the required formfactor and take the shape of a small cube or of a smart bandaid. This requires new integration and packaging technologies. Figure 2 shows a schematic system integration roadmap and the need for wafer-level integration technologies to achieve overall volumes around $10mm^3$.

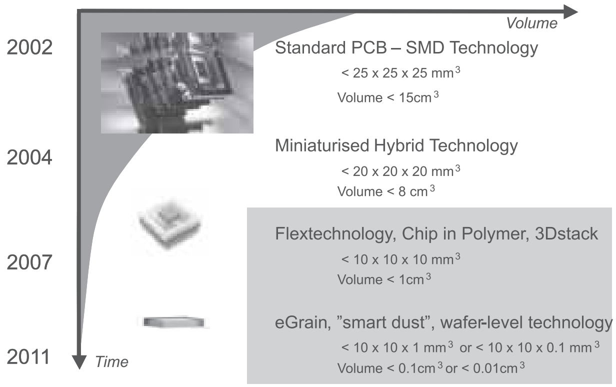

Fig. 2: System integration roadmap for the coming decade: the development of 3D System-in-a-Package technology, chip-on-flex technology, followed by full wafer-level 3D System-on-Chip integration. The latter will bring 2 orders of magnitude reduction in volume and enable smart unobtrusive autonomous sensor systems.

2. Wireless sensor systems-in-a-package (SiP)

One form factor suitable for many applications is a small cube sensor node. To this end, we have developed a generic and modular wireless sensor node in a cubic centimetre. Compared to standard PCB technology this leads to a volume reduction of a factor of 3…4 (Fig. 3),. In this so-called *three-dimensional system-in-a-package* approach (3D-SiP) /3/, the different functional components are designed on separate boards and afterwards stacked on top of each other through a dual row of fine pitch solder balls. This system has the following advantages: (i) modules can be tested separately, (ii) functional layers can be added or exchanged depending on the application, (iii) each layer can be developed in the most appropriate technology.

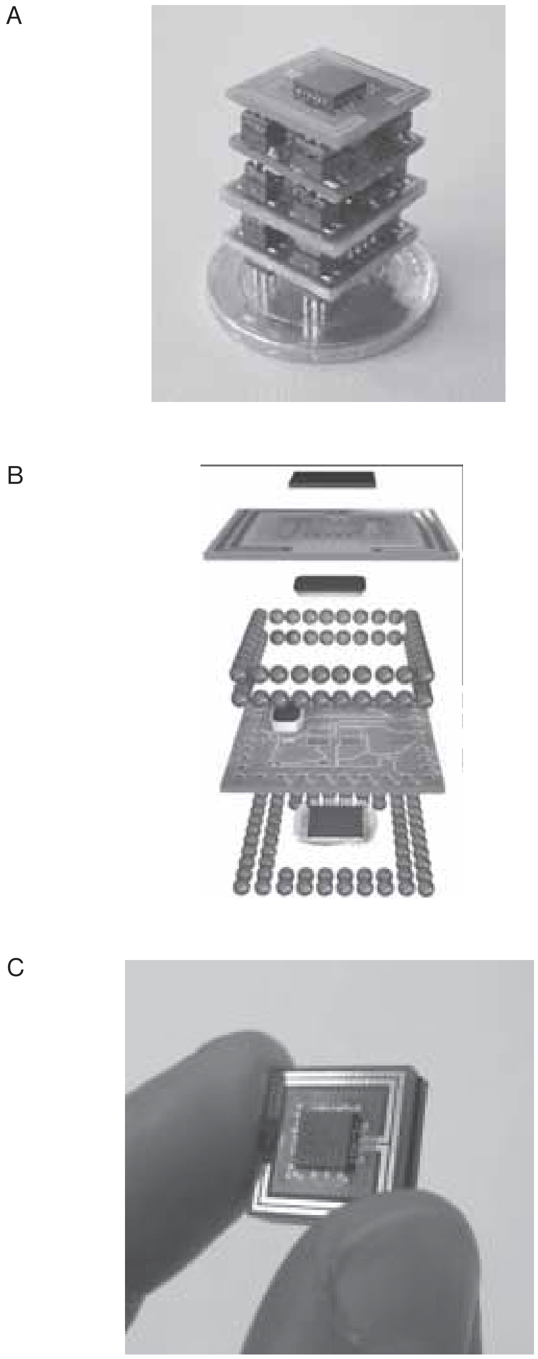

Fig. 3: (A) Wireless sensor module as miniaturized but conventionally-connectorized module or (B, C) as integrated $1cm^3$ volume 3D stack. The dedicated folded dipole integrated antenna is located on top of the stack.

A key element was the development of a $14x14mm^2$ electrically small antenna at 2.4GHz. Two 1.6mm standard FR4-layers were selected as base material for the 3D module and antenna as the use of a standard board-material reduces the module cost while allowing reasonable antenna properties at 2.4GHz. The antenna design required special attention as it directly influences the power consumption and range of the radio link. The design optimally uses the limited module volume to optimize the antenna bandwidth and efficiency. The antenna is therefore placed at the perimeter of the module by double-folding it around the RF transceiver. Shielding layers are inserted below the antenna to protect the low-power microcontroller at the bottom of the module from the radiated output power generated by the antenna. The antenna design takes the influence of the packaged transceiver and shielding layers and the effect of antenna placement on the human body into account.

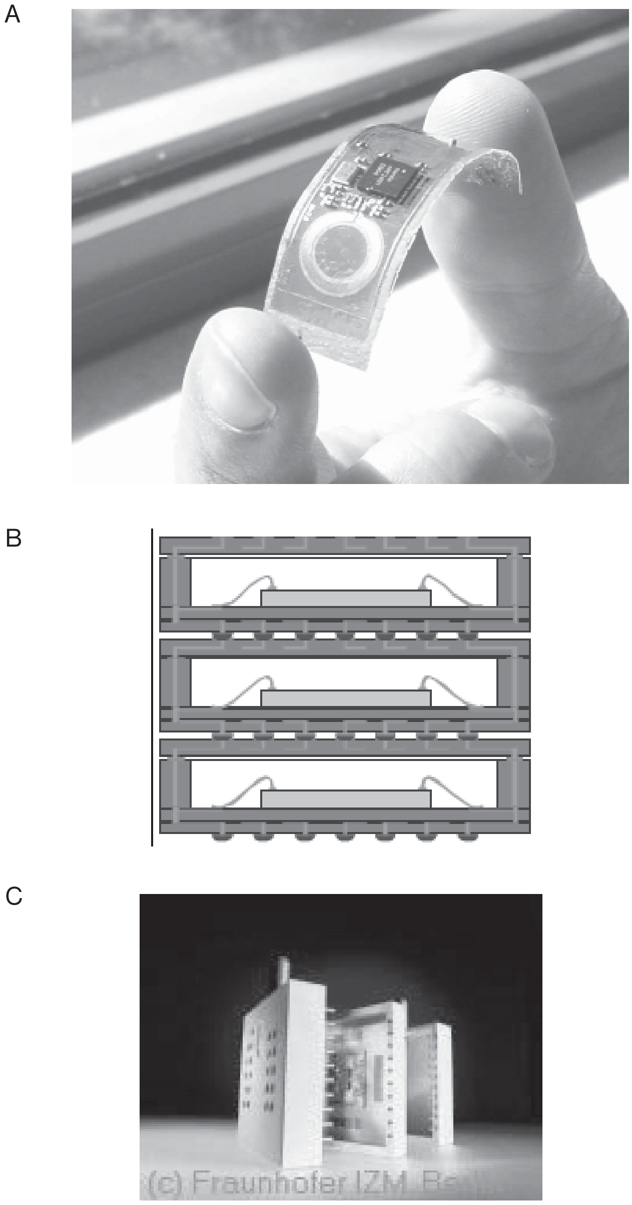

Fig. 4: (A) IMEC Wireless sensor module and as component on flex, featuring a loop antennas; (B and C) Sensor node building blocks of Match-X.

For wearable applications, a thinner embodiment may be desired, and a degree of mechanical flexibility is advantageous. We have integrated the same wireless functionality on a flexible substrate (Fig. 4), a so-called 2D SiP embodiment.

Using commercially available components, a network of the above 3D SiP was demonstrated where the sensors share a single communication medium (a radio-channel in the 2.4GHz band) /4/ The resulting average power consumption for long measurement intervals (minutes) , a single channel sensing of temp. w/io data processing, and in practical operating conditions, i.e. including the occurrence of synchronization errors, was 100µW.

Functional prototypes have also been demonstrated by other groups. The working group Match-X in the German Engineering Association VDMA developed another small but modular device (Fig 4). It consists of different building blocks, measuring 12.5x12.5 mm, each having a different functionality. A re-configurable sensor system has been developed at Philips under the name SAND (Small Autonomous Network Device), like the IMEC system, also around 1 cm^3.

Future research areas concern the physical packaging of the sensors, RF and processor, such that application specific parts can be added. The package should be small enough to fit in different types of applications specific packages for easy deployment.

3. Ultra low power sensor read-out: case study of biopotential measurement

EEG is a monitoring tool used by neurologists to measure the electrical activity of the brain and trace neurological disorders such as epilepsy. In hospitals, it is typically used during several days and involves hospitalization of the patient. A small-size, ultra low-power, and portable biopotential acquisition system capable of measuring the EEG, ECG, and EMG signals will not only improve the patient's quality of life but can also extend the device applications to sports, entertainment, comfort monitoring and etc.

Fig. 5a shows the architecture of an ASIC single readout channel configurable for extracting EEG (electroencephalogram), ECG (electrocardiogram), and EMG (electromyogram) signals. It includes an AC-coupled chopped instrumentation amplifier, a spike filtering stage, a constant gain stage, and a continuous-time variable gain stage, whose gain is defined by the ratio of the capacitors. Such circuit consumes 20µA from 3V. Equivalent input referred noise density of the circuit is 60nV/√Hz, and common-mode rejection rate of the channel is higher than 110dB while filtering 50mV DC electrode offset. The gain of the channel can be digitally set to 400, 800, 1600 or 2600. Additionally, the bandwidth of the circuit can be adjusted via the bandwidth select switches for different biopotentials. Figure 5b shows the extracted EEG, ECG, and EMG waves from the single-channel biopotential readout front-end and summarizes the measured results. This circuit has achieved the lowest reported power for the given high performance /5/.

The complete ASIC read-out has 8-readout channels, which are multiplexed at the back-end. Each channel of the ASIC is similar to the single channel biopotential readout front-end ASIC and optimized for EEG acquisition. In addition to single channel front-end, this front-end includes a bias generator circuit. The total current consumption of the circuit is around 100µA from 3V, including bias circuitry.

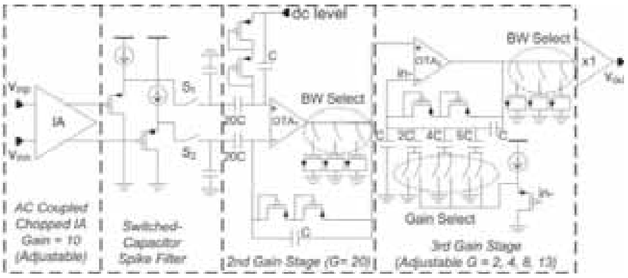

Fig. 5a: Schematic of a single channel biopotential readout

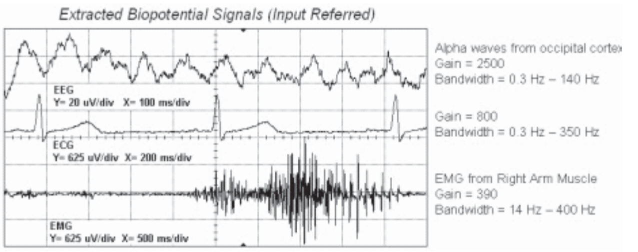

Fig. 5b: Extracted biopotential signals using the single-channel readout front-end.

4 Ultra-low power wireless communication

Ultra-low-power radios are an essential ingredient for body-area network sensors. These radios are providing the last meter connection from a central body-worn pda-like device to the sensor nodes. In short range wireless systems with low data rate, the baseline power dominates the dynamic power. This baseline power is strongly dependent on the chosen architecture. Low power radios such as Bluetooth and Zigbee cannot meet the stringent Wireless BAN power requirements.

The power budget in the sensor node and in the master device are also very different. The sensor has an extremely tight power budget, whereas the master has a slightly more relaxed power budget. In the air interface definition this asymmetry is exploited by shifting as much complexity as possible to the master device.

For these reasons we have chosen to make use of Ultra-Wideband modulation. This allows us to use an ultra-low-power, lowest-complexity transmitter and shift as much as possible the complexity to the receiver in the master. An UWB transmitter has been designed in 90nm CMOS, enabling a reduced power consumption (30pJ per 1GHz pulse) as well as a high frequency range including the 3-5 and 6-10GHz high UWB band. A corresponding receiver was designed in 0.18µm CMOS (Fig. 6). Next to the front-end components responsible for (low-noise) amplification and down-conversion, an analog approach of the base-band design was used.

Selecting accurately starting and stopping instants for the integration enables an excellent correlation with the transmitted pulse (0.94) while keeping a very low complexity thanks to delay-line based generation of multiple clock signals. On top of that, this analog matched filtering reduces the required sampling rate to the pulse repetition frequency (nominally 40MHz) while other systems require GHz sampling with problems of clock generation and ADC power consumption.

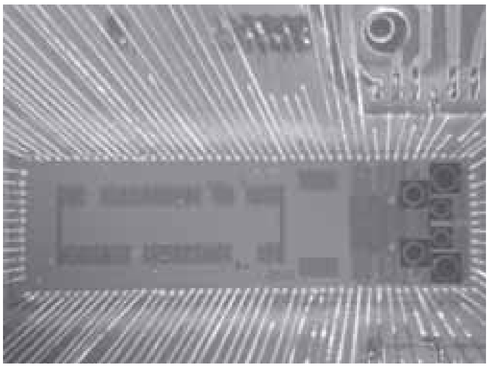

Fig. 6: UWB receiver ASIC. /6/

Fig. 7: Thermoelectric bracelet plus flex on which the radio and the sensor electronic are implemented.

5. Micropower generation

While modern electronic components become smaller and smaller, the scaling down of traditional batteries faces technological restrictions. For this reason a worldwide effort is ongoing to replace batteries with better performing, miniaturized power sources. For devices with relatively high power consumption the advantage is made by using fuel based power systems, as fuel has a much higher energy density than batteries. Examples of these systems are microturbine /7/, micro fuel cells /8/, microcombustor /9/. Low power applications, like, for example, the sensor node of a wireless sensor network, might benefit instead from generators that harvest wasted ambient energy. These so-called *energy scavengers* exploit energy sources like light, temperature or mechanical vibrations. The generated power strongly depends on environment conditions. In the majority of the cases, it is sufficient to fulfil the average power demand of a micro-device, but it can hardly handle the power peaks occurring during operation (e.g. the power needed for wireless data transmission in a sensor node). For this reason a storage device, as a supercapacitor or a rechargeable battery, will still be needed. The dimension of the power storage device will be anyhow smaller than the primary battery necessary to power the system without the contribution of a scavenger; furthermore the system will be capable to operate unattended for a very long time. IMEC is developing thermal scavengers for human body applications /10/ and vibration scavengers for industrial applications /11/. In both cases the target power is in the 10-100 µW range for systems having a footprint of a cm^2. A 100 µW device will generate in a few months the same energy contained in a primary lithium battery of the same dimensions.

In this contribution we focus on thermal energy scavengers. Thermal energy scavengers exploit the Seebeck effect to transform the temperature difference between the environment and the human body into electrical energy. As this temperature difference is low the development of such scavengers is not straightforward. This problem is amplified by the fact that the thermal resistances of the body and of the air are much larger than the one of the thermoelectric element, further reducing the useful temperature drop that it experiences. A sizeable power can be obtained only by means of an efficient thermal design. During the last years IMEC has improved performances and decreased dimensions of this type of thermo-electric generators for human body application. Generators are mounted on a bracelet and closely resemble to a wristwatch in terms of weight and dimensions (see Fig. 7). The prototype delivers 150µW when worn on one's wrist. A flexible wireless sensor module especially developed is attached to the strap and powered by the thermoelectric generator, which was sufficient to feed a sensor node which can transmit simple quantities (like heart beat or body temperature) with a sample frequency of 0.5 Hz.

The heart of the bracelet is a custom made, commercial bismuth telluride thermoelectric block, consisting of about 3000 thermocouples. The large cost of this block makes impossible the penetration of this device in a large consumer market. A possibility of cost reduction resides in the use of batch fabricated MEMS thermoelectric generators. Micromachined thermopiles are not new in the scientific literature, and are used, e.g., in miniaturized commercial thermoelectric coolers /12/. Micromachining has the potential advantage of scaling down the lateral size of the thermocouple thus increasing their surface density. Unfortunately, at the same time, the thermocouples height is reduced to a few micrometers only. This drastically decreases the thermal resistance of the generator, the temperature drop on the device becomes very small and the generated power becomes negligible. In order to overcome this difficulty, IMEC has developed a special design of a micromachined thermoelectric generator for application on humans, which combines a large thermal resistance of the device with a large number of thermopiles. The schematic is shown in Figure 2a. Several thousands of thermocouples are mounted on a silicon rim. The function of this rim is to increase the overall thermal resistance between the hot and cold side of the generator. If Bi_2Te_3 is used as thermoelectric material an optimized device fabricated according to this scheme and positioned on the human wrist can generate up to 30 µW/cm^2. Fig. 8 show a realization of such a device based on SiGe thermocouples. Because of the inferior thermoelectric properties of this material with respect to Bi_2Te_3, an optimized device is expected to generate 4.5 µW/cm^2.

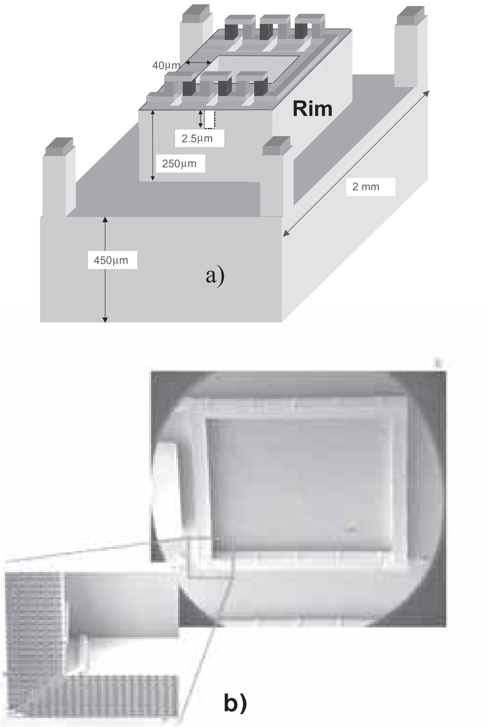

Fig. 8: Schematic (a) and an implementation (b) of MEMS thermopile for use in human body applications

6 Above-IC MEMS

MEMS components provide miniaturized sensing functionality to integrated microsystems.. Ultimate miniaturization requires the MEMS component to be monolithically integrated with electronic circuits, by post-processing MEMS on top of the electronics. However, post-processing restricts the available thermal budget for MEMS processing.

Poly-SiGe provides the desired mechanical and electrical properties for MEMS applications at significantly lower temperatures compared to Poly-Si (≥ 800°C). This is made possible using poly-SiGe as the MEMS structural material. The poly-SiGe material is very comparable to the poly-Si used for surface micro-machining, except that it can be processed at much lower temperatures.

The use of poly-SiGe for processing MEMS above CMOS has been described /13/. Within the SiGeM project an integrated gyroscope with dedicated MEMS and ASIC designs targeted for low-noise, high-resolution applications (0.015degree/sec for 50Hz bandwidth) was demonstrated (Fig. 9). The CMOS used is a high voltage (20V) 0.35µm commercial double poly CMOS process with five wiring levels and 500nm Si-oxide/Si-nitride passivation. It was also found that poly-SiGe is, as expected, a very reliable material exhibiting no creep (tested 20 days) or fatigue (tested 1.6E10 cycles) over the duration of the tests done, making it an excellent MEMS structural layer.

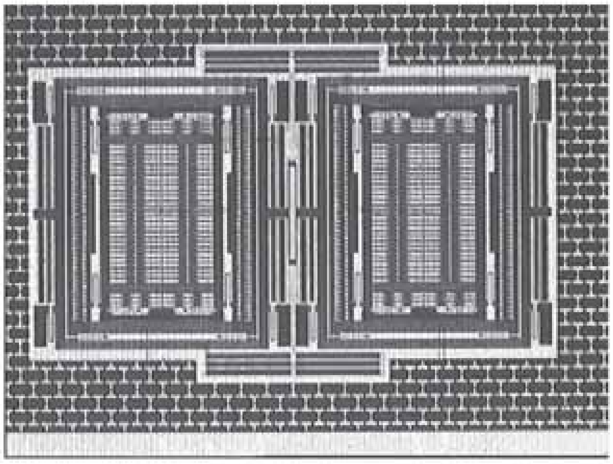

Fig. 9: Optical microscope picture of free standing SiGe gyroscope processed above CMOS.

The use of poly-SiGe is envisioned for many more above-IC applications. Other interesting applications are accelerometers, resonators, micromirrors etc. The poly-SiGe material is also suited for use as a *thin-film* cap - thus reducing the total thickness of the MEMS device – including the cap - to less than 50 um.

7 Roadmap for further integration

While today's 3D-"System-in-Package" integration is limited to relatively low packaging density, it is the most mature technology and already available in high volume production. Further scaling requires altogether different platforms: dies and wafers will be thinned and stacked on one another. This is referred to as 3D- Wafer Level Packaging (WLP) technology. Using fully finished wafers as a starting material, which are further processed by techniques such as wafer thinning, flip chip bumping, and deep anisotropic Si-etching (Fig. 10) 3-D electrical connections can be realized at the wafer level with very high-density.

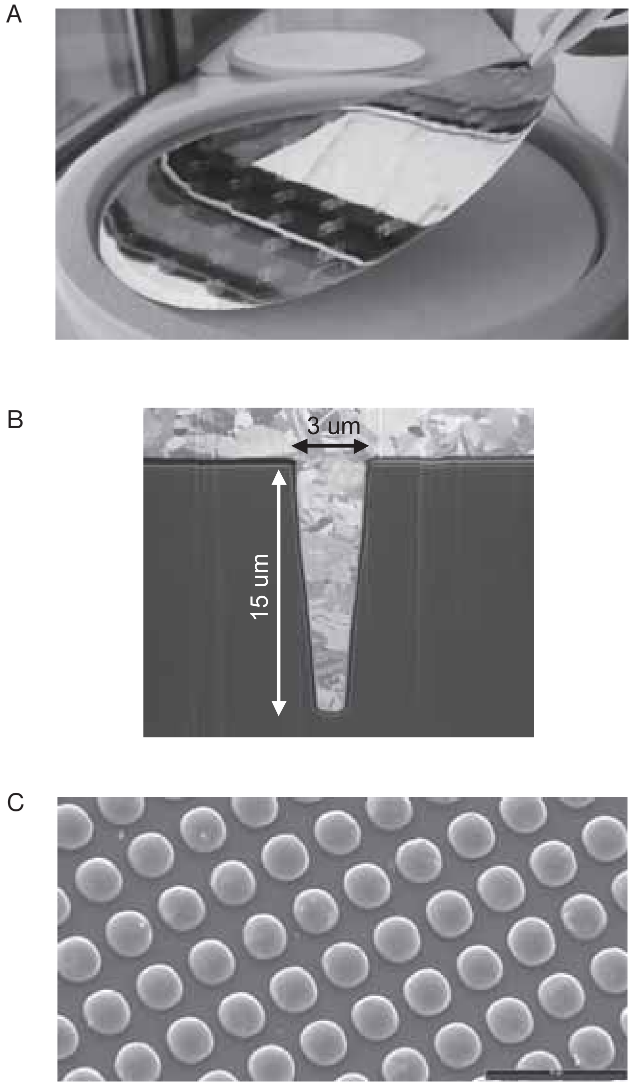

Fig. 10: Ingredients of 3D Integration technology that will enable further microsystem integration: thinned wafers (A), micro-via holes (B) and 7 micron In bumps on 10 micron pitch. (C)

Again two different form factors are developed: die stacking and thin chip embedding. In die stacking technology, through wafer vias are realized using deep reactive ion etching, conformal dielectric deposition, and (partial) filling using electroplated Cu. This via process is carried out before or after wafer thinning to a final thickness of 50 – 100 micron. After dicing, the dies are flip-chip assembled using solder or an intermetallic compound as the electrical interconnect. In the die embedding flow, the wafers are thinned down to 10…20 µm, and subsequently transferred to a host substrate. The electrical interconnection is realized by MCM processing using thick dielectric layers and Cu electroplating. Both methods allow vertical interconnect densities of 10 – 20 per millimeter and 100 …500 per square millimeter.

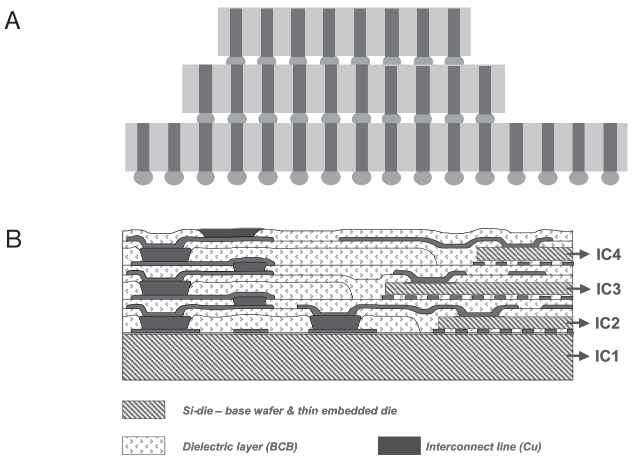

Fig. 11: Different interconnect approaches for 3D-WLP: using through wafer vias and bump interconnects (A), and thin chip embedding (B).

Research in the area of integration is also oriented to stretchable embodiments of wireless sensor nodes as stretcheability and bendability are required in many applications “on-and-around-the-body”. Silicone is a suitable carrier material in view of his high stretcheability and biocompatibility, and can be processed by various means including thin film technology. Based on FEM modelling, metal tracks embedded in such a silicone matrix can be designed to stay functional upon more than 50 % stretching. (Fig. 12)

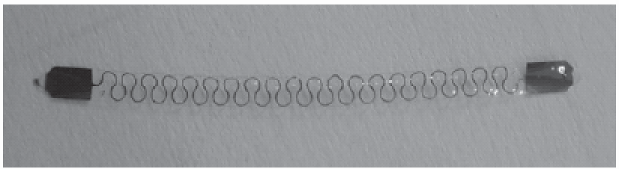

Fig. 12: Stretchable metal conductors integrated in a silicone “wire” /14/.

8. Conclusion

The revolution that has started in sensor networks will bring about truly autonomous, highly miniaturized, multiparameter sensing. This paper gave an overview of autonomous sensor research at IMEC and worldwide. Several working prototypes have been discussed, such as micropower generation devices and a 1cm^3 low-power wireless sensor node. This modular wireless 3D stack is now used as a platform for the integration of future developments (sensors and actuators, energy scavenging devices, ultra-low-power local computing and transceiver) in order to realize fully integrated, autonomous ultra-low-power sensors nodes for body area networks. Cost reductions will broaden commercial applications from fitness and medical to automotive, consumer, building… New integration technologies are key in order to reduce system size beyond today’s System-in-Package technology. Future technology directions using poly-SiGe MEMS and 3D –WLP technologies were indicated.

9. Acknowledgments

The authors acknowledge the contributions of B. Gyselinckx, P. De Moor, E. Beyne, A. Witvrouw, W. De Raedt and P. Fiorini.as well as all members of the Integrated Systems Department and the Human ++ and APIC programs.

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POROUS SILICON FOR SENSORS AND ON-CHIP INTEGRATION OF RF COMPONENTS

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Key words: sensors, porous silicon, micro-plate, RF components

Abstract: In this paper, porous silicon technology for use in bulk silicon micromachining and sensors will be described and examples of micro-hotplates, thermal sensors and microfluidic devices based on porous silicon technology will be presented. Another interesting emerging application of porous silicon technology that will be presented is its use as micro-plate on silicon for on-chip integration of RF-components (inductors, resonators). Examples of design, fabrication and characterization of integrated inductors on porous silicon micro-plates using standard CMOS technology will be presented. The properties that make porous silicon very appropriate for the above applications will be described.

Porozni silicij kot material za integracijo senzorjev in RF komponent na čipu

Kjučne besede: senzorji, porozni silicij, mikro-grelci, RF komponente

Izvleček: V prispevku opisujemo možnosti uporabe poroznega silicija pri mikroobdelavi silicija in izdelavi senzorjev. Opisali bomo primere izdelave mikro-grelcev, termičnih senzorjev in mikro-naprav za pretok tekočin. Kaže se še ena zanimiva uporaba tehnologije poroznega silicija pri izdelavi mikro-plošč na siliciju za integracijo RF komponent (rezonatorji, tuljave). Predstavimo primere načrtovanja, izdelave in karakterizacije integriranih tuljav na mikro-ploščah iz poroznega silicija v standardni CMOS tehnologiji. Pokažemo na lastnosti, ki omogočajo, da je porozni silicij izredno priemeren material za vse naštete uporabe.

1. Introduction

Porous silicon is a material with tunable properties, depending on the electrochemical conditions used in its fabrication and the resistivity and type of the silicon substrate used as starting material /1/. It may by macroporous, with large vertical pores of diameter from few hundreds of nanometers to several micrometers, or mesoporous/microporous with randomly distributed pores in the micron or nanometer range. High porosity mesoporous silicon is a nanostructured material with properties strongly related with its low dimensionality.

Intensive research in the early nineties has been devoted to nanostructured silicon for application in silicon optoelectronics, due to its bright visible luminescence at room temperature /2/. However, a lot of other interesting applications emerged later from this intensive research, including different sensor devices and different active and passive components on a silicon substrate /3-8/. In parallel, other types of porous silicon were investigated in detail, including macroporous silicon on different silicon substrates /9/ and combinations of macroporous and mesoporous (nanostructured) silicon /10/.

This paper will first describe the general properties of porous silicon that make it appropriate for use in silicon micromachining and sensors. It will then focus on the following applications:

a) Fabrication of micro-hotplates on silicon by porous silicon bulk micromachining in thermal sensors for gas flow, gas composition and acceleration measurements
b) RF isolation on bulk crystalline silicon for the integration of RF inductors and
c) Fabrication of buried microfluidic channels on silicon for sensors, microfluidic devices and lab-on-chip applications.

2. Results and discussion

2.1 Fabrication and properties of porous silicon

Porous silicon is formed by electrochemical dissolution of bulk crystalline silicon. For mesoporous silicon formation, aqueous or ethanoic HF solutions are mainly used. The structure and morphology of the obtained material depend on the type and resistivity of the silicon substrate and on the electrochemical parameters used. Porosity, pore size and pore distribution are essential parameters that characterize the material.

Chemical etching of slightly oxidized porous silicon in an HF-containing solution is highly selective to bulk or polycrystalline silicon. This property makes porous silicon very appropriate for use as sacrificial material in bulk silicon micromachining.

Highly porous silicon is a highly resistive material (ρ>1MΩcm) Oxidized porous silicon shows dielectric properties equivalent to those of thermal SiO_2. In comparison with thermal SiO_2, porous silicon is very rapidly oxidized due to its extremely high reactivity, so that much thicker layers of oxidized porous silicon compared to SiO_2 are grown on silicon within the same time. This property was tentatively used in the seventies for DC isolation on a silicon substrate /11/, mainly applied to bipolar devices. More recently, porous silicon is investigated for use in RF isolation on silicon /12/, for which it shows important advantages that will be described below.

2.2 Applications

2.2.1 Porous silicon for bulk silicon micromachining and suspended microstructures fabrication.

Due to the high growth rate of porous silicon on a silicon substrate, thick PS layers may be fabricated at relatively short times. This property of porous silicon, combined with its high chemical etch selectivity to bulk or polycrystalline silicon makes the material very appropriate for use as sacrificial layer in bulk silicon micromachining. On the other hand slightly oxidized porous silicon shows etch resistance to dry silicon etchants. This property is used to fabricate suspended porous silicon membranes by etching isotropically the silicon layer underneath. The produced structures are very useful in several applications.

Different interesting processes were developed at IMEL for fabricating suspended micromechanical structures (suspended membranes, cantilevels or resistors over a cavity on the silicon substrate), as follows:

a) A 3-step process for the fabrication of polycrystalline silicon suspended micromechanical structures /5, 13/ by: local formation of porous silicon on the bulk substrate, polycrystalline silicon deposition and patterning, and finally porous silicon dissolution to release the structures. An example of structures fabricated using this technology is given in fig.1.

b) A 4-step process for the fabrication of suspended porous silicon microstructures on Si was also developed /14/, involving: Local growth of porous silicon, photo resist deposition and patterning, isotropic etching of bulk silicon underneath porous silicon for membrane release, and finally resist stripping.

c) A process was developed for fabricating buried microfluidic channels and sealed cavities on silicon in a single two-step electrochemical process. Details are given in reference /15/.

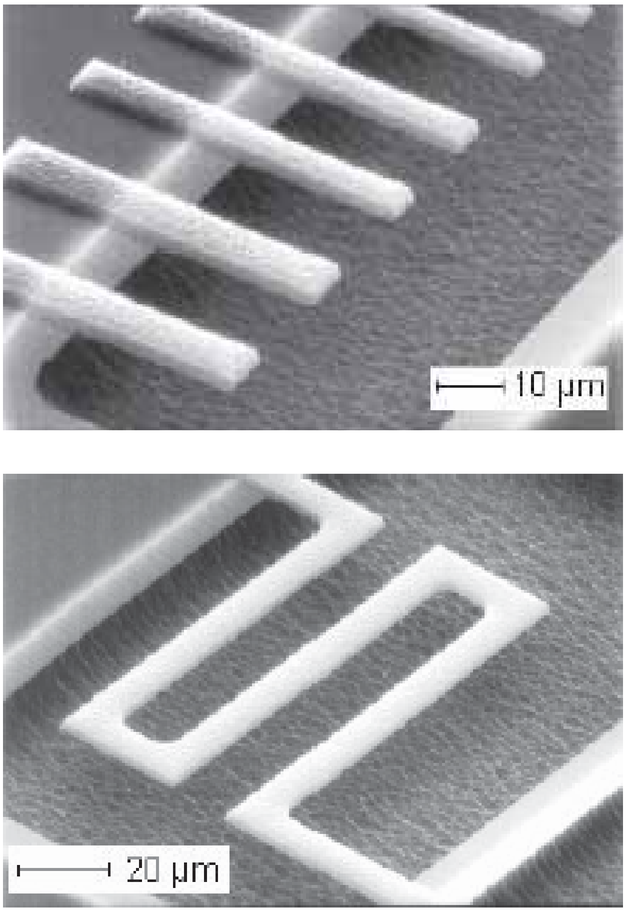

Fig. 1: Polycrystalline silicon micromechanical structures over cavity on a silicon substrate, fabricated with porous-silicon-sacrificial-layer technology

2.2.2 Porous silicon in micro-hotplate technology. Application in thermal sensors

Different types of micro-hotplates on bulk silicon may be fabricated using porous silicon technology, as illustrated in fig. 2. A thick compact porous silicon film, fabricated on a pre-defined area on the silicon substrate /16/ as illustrated in fig. 2 (a_1,a_2) is a simple and reliable micro-hotplate on bulk silicon allowing temperature increase on a heater on top of it up to 100-200°C at relatively low power consumption, depending on the porosity of the material used. For example, with 65% mesoporous silicon, a thermal conductivity as low as 1.2 W/mK is obtained /17/). Thermal isolation on bulk silicon may by further improved by opening a cavity underneath the porous layer, as indicated in fig. 2 (b_1,b_2). This is possible by using a simple, two-step electrochemical process of porosification and electropolishing of Si /17/. When very low power consumption is needed (for example in the case of sensors working in an explosive environment) a process for the fabrication of porous silicon membranes suspended over an open cavity /14/ may be used, as indicated in fig. 2 (c_1,c_2). In this case, the fabrication process is slightly more complicated /14/. It involves porous silicon membrane formation and membrane release by dry etching of silicon through mask windows.

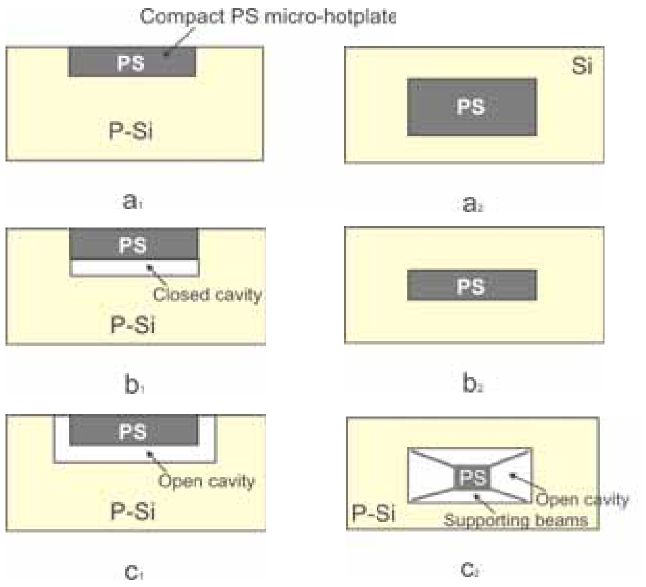

Fig. 2: Schematic representation of three different cases of porous silicon (PS) micro-hotplates on a silicon substrate. (a_1, b_1, c_1): cross sectional representation, (a_2, b_2, c_2): plan view.

2.2.3 Silicon thermal sensor using PS micro-hotplate technology

An example of thermal flow sensor using PS micro-hotplate is illustrated in fig. 3. A porous silicon (PS) micro-hotplate is used to integrate on top a heater and the hot contacts of two series of thermocouples (Th_1 and Th_2), their cold contacts being on bulk crystalline silicon (c-Si). This sensor shows high sensitivity and fast response and it finds different interesting applications. One such application is gas flow measurements. The sensor is placed in an appropriate housing and it is appropriate for measuring both laminar and turbular flows /18, 19/, due to its fast response. An example of housing is that of fig. 4, in which the sensor is placed in the center of a hemi-spherical tube, used as bypass to a larger tube (fig. 4a). This housing has been design for use in a flow meter for respiration monitoring developed at IMEL /20/. The external tube and the corresponding electronics are shown in fig. 4b. An example of sensor response in a large range of gas flow (from -200 to +200 slpm (standard liters per minute)) is shown in fig. 5. It is interesting to note that the response of the system is almost linear in the whole range of gas flow. This is an important advantage of this system compared to other micro-electromechanical (MEMs) systems commercially available.

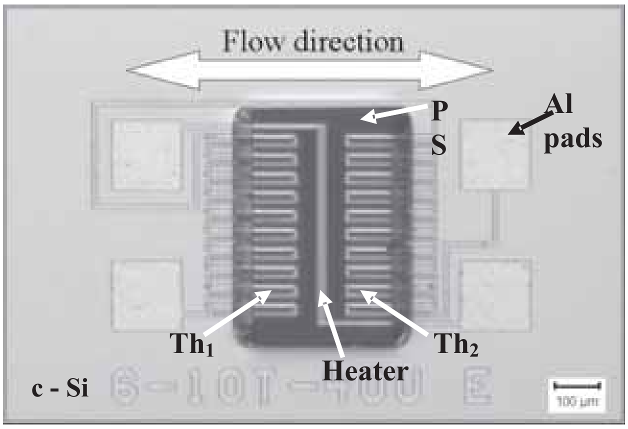

Fig. 3: Thermal sensor using porous silicon thermal isolation composed of a heater integrated on the porous silicon layer and two series of thermocouples (Th_1, Th_2) their hot contacts lying on porous silicon (PS) and their cold contacts on bulk crystalline silicon (c-Si)

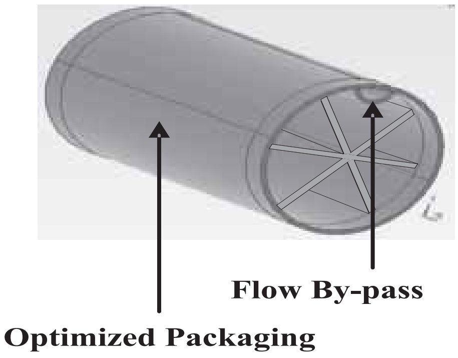

Fig. 4(a): Internal view of the housing of a gas flow sensor in a system for respiration monitoring. The sensor is based inside a bypass (hemi-spherical tube inside the larger tube), so as to assure laminar flow conditions.

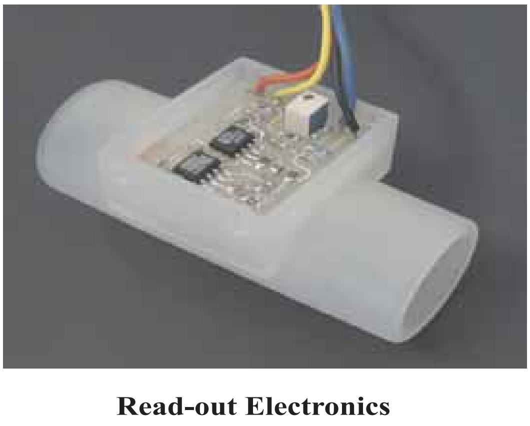

Fig. 4(b): External view of the housing with control electronics.

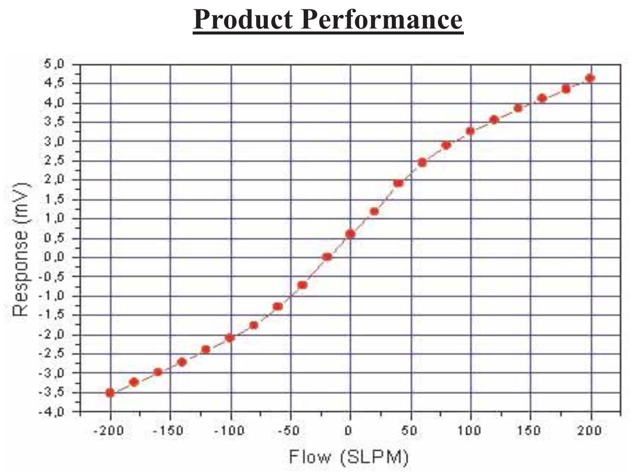

Fig. 5: Example of response of the system for respiration monitoring of fig. 4.

A more advanced device than that of fig. 3 uses a porous silicon membrane over cavity micro-hotplate, the rest of the technological steps being the same /17/. This introduces an improvement in local thermal isolation, thus allowing for higher temperatures on the heater, using the same power consumption. Comparative curves of temperature distribution around the heater for the two cases of compact porous silicon and porous silicon over air-gap micro-hotplates for an applied power of 35mW are shown in fig. 6. We see a substantial increase of maximum temperature on heater when we add an air-gap underneath the porous silicon layer.

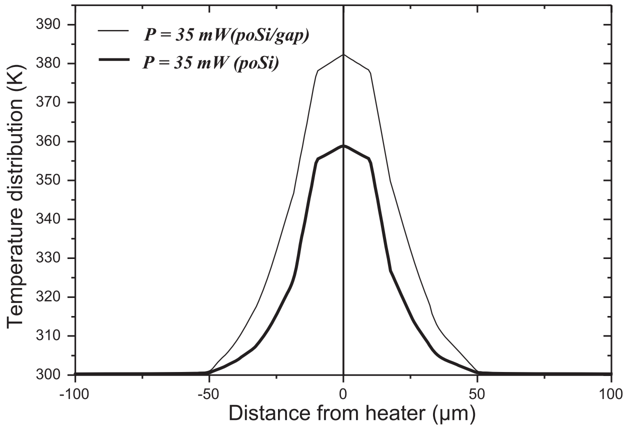

Fig. 6: Temperature distribution around a heater for two cases of micro-hotplates on silicon: a) a compact porous silicon micro-hotplate (black line) and b) a porous silicon over air gap micro-hotplate (grey line).

Thermal flow sensors using porous silicon suspended-membrane-over-cavity micro-hotplates at low power may operate at much higher temperatures, consumption. They are so appropriate for use as gas sensors in combination with catalytic materials, where an operation temperature above few hundreds of degrees C is in general needed for high sensitivity catalytic reactions. An example of conductometric gas sensor for the detection of methane, ethane etc. in an explosive environment /21/ is shown in fig. 7a. A platinum resistor is integrated on the porous silicon membrane, whose resistance charges with temperature. A temperature on the heater above 500°C may be achieved with an applied power of few tens of mW (fig. 7b) shows an image of a glowing Pt heater on a 60 μm^2 PS micro-hotplate as seen in an optical microscope, with a power of 50mW supplied to the heater. The heater started to emit detectable light when the supplied power exceeded 30mW.

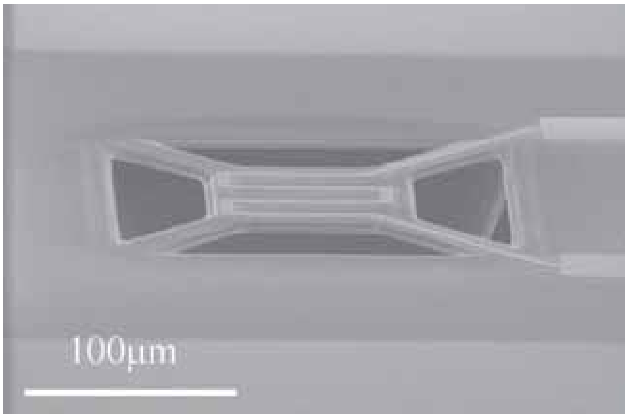

Fig. 7(a): Conductometric gas sensor with a platinum heater on a porous silicon micro-hotplate.

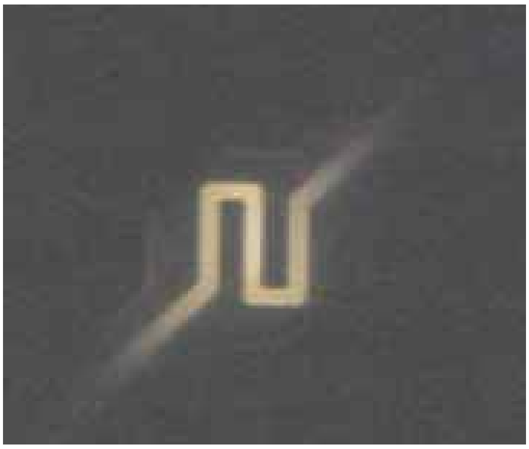

Fig. 7(b): Optical microscopy image of a glowing Pt heater on PS micro-hotplate, under 50mW power supply.

A microfluidic flow sensor based on a microchannel capped with a porous silicon membrane, on top of which the sensor active elements are integrated /12/, was also developed at IMEL (fig. 8), The sensor active elements are 3 resistors on the porous silicon capping layer as in fig. 8. The flow passes through the microchannel and thus the sensor is very appropriate for microflow measurements.

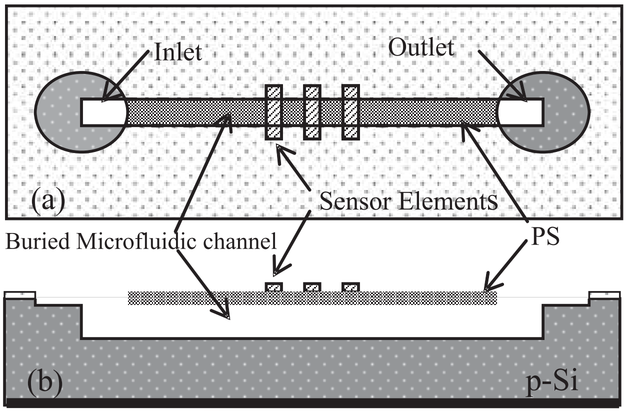

Fig. 8: Schematic representation of a plan view (a) and cross section (b) of a micro-flow sensor using a microfluidic channel capped with porous silicon, on top of which 3 sensor elements are integrated

2.2.4 Integrated inductors on porous silicon dielectric layers

The properties that make porous silicon appropriate for local RF isolation on a silicon substrate are the following:

- Its relative dielectric constant and loss tangent are adjustable by changing the porosity and surface passivation of the material
- The porous silicon layers may be fabricated on selected areas on the silicon substrate
- Low stress material may be fabricated
- The thermal expansion coefficient of porous silicon is similar to that of bulk silicon

By employing a fairly thick porous silicon layer and a standard 2-metal CMOS process, optimized RF inductors on Si were designed and their properties were simulated /12/. An example of inductor's layout is shown in fig. 9b (light grey: metal 1, dark grey: metal 2), while in (a) the technology diagram for CMOS-compatible porous silicon integration is shown. The simulated inductance function (L(w)) and quality factor (Q) for Cu metallization are shown respectively in figs. 10 (a) and (b). Black lines correspond to the case of bulk silicon substrate, while grey lines to the case of porous silicon RF micro-plate. Q increases by a factor of 2 when using porous silicon instead of bulk silicon as substrate.

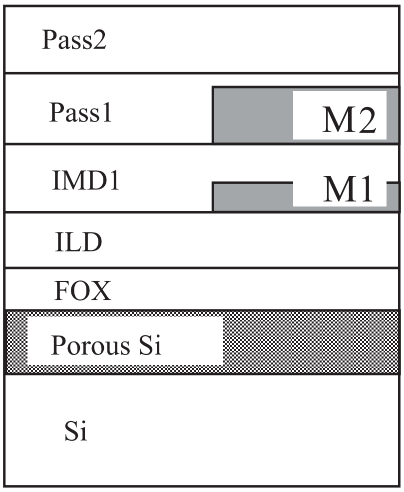

Fig. 9(a): Technology diagram for CMOS-compatible porous silicon integration.

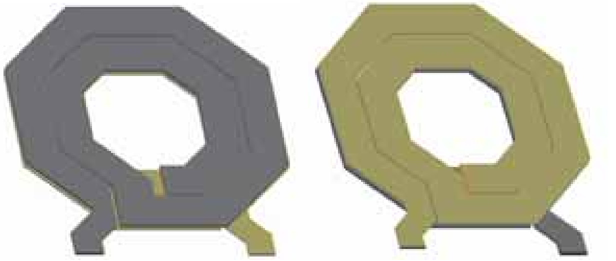

Fig. 9(b): 2-metal layer optimized inductor layout: light grey: metal 1, dark grey: metal 2.

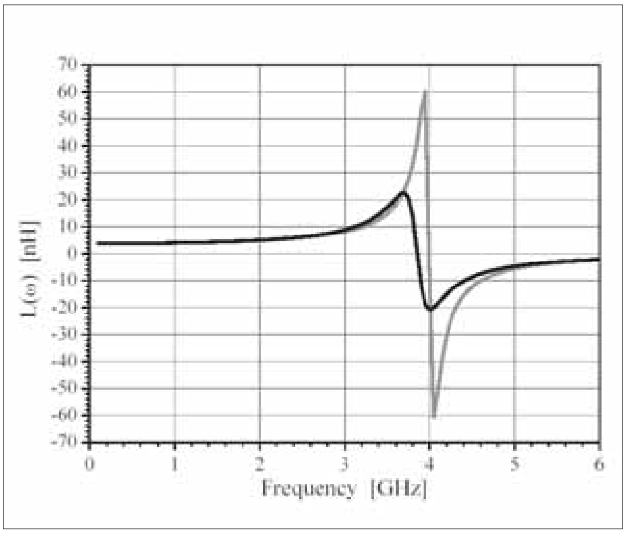

Fig. 10 (a): Simulation results of Inductance function for Cu metallization on bulk Si (black line) and on porous silicon RF micro-plate (grey line).

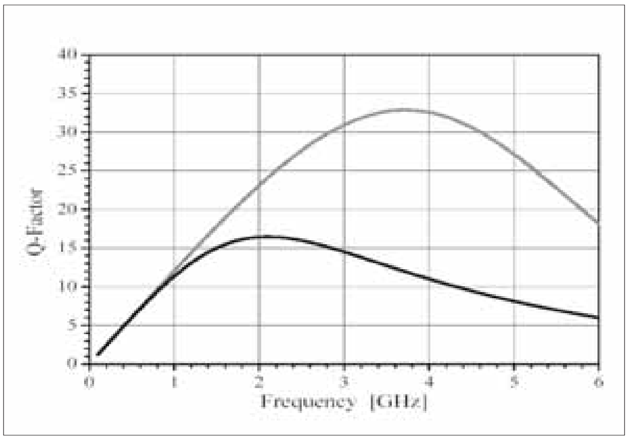

Fig. 10 (b): Simulation results of Q-factor when using Si (grey line) or porous Si (black line) substrate. The technology used in simulations was 0.13 μm-compatible, two-metal CMOS technology with Cu metallization.

2.2.5 Macroporous silicon technology

Mocroporous silicon layers may be fabricated on p-type silicon using an HF:DMF solution /23/. Ordering of the pores may be introduced by appropriate pre-patterning of the anodized area, in order to form pore initiation pits. An example of non-ordered porous silicon layer is shown in fig. 11 ((a) plan view, (b) cross sectional SEM image). In fig. 12 we see an example of ordered macroporous silicon structures, fabricated by first creating ordered inverted pyramids on the silicon surface, followed by anodization for macroporous formation /10/.

A process for fabricating macroporous silicon membranes over a mesoporous layer or a cavity on a pre-defined area of the silicon substrate has been also developed at IMEL /24/. The process (fig. 13) consists in fabricating macroporous layers on a selected area on the silicon substrate (fig. 13 a), followed by porosification under electrochemical conditions for mesoporous silicon formation (fig. 13b).

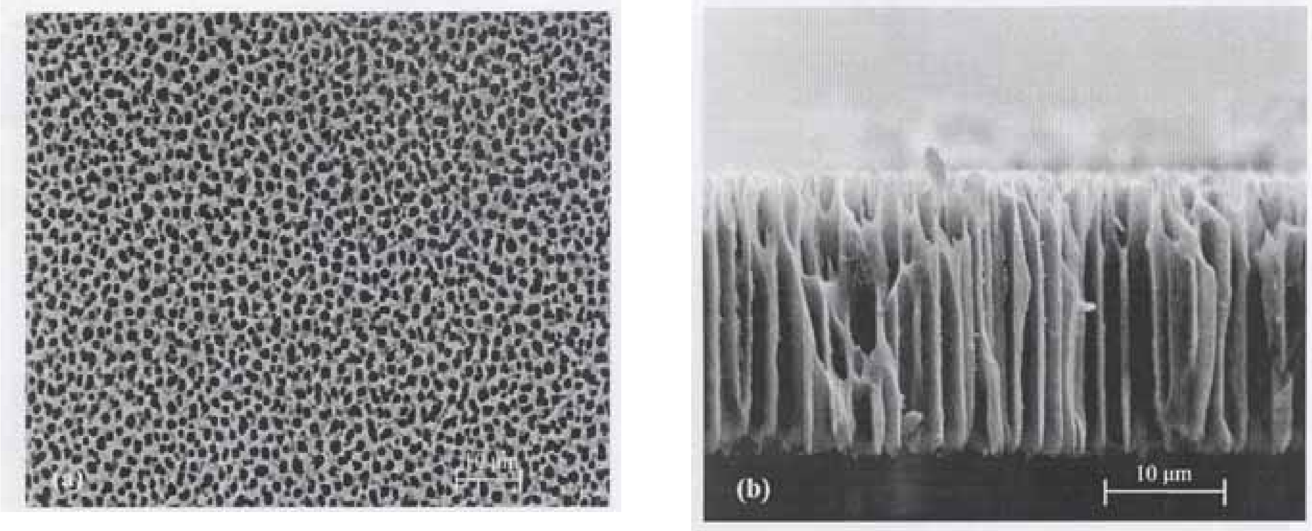

Fig. 11: (a) Plan view and (b) cross-sectional SEM images of macroporous silicon layers on bulk silicon

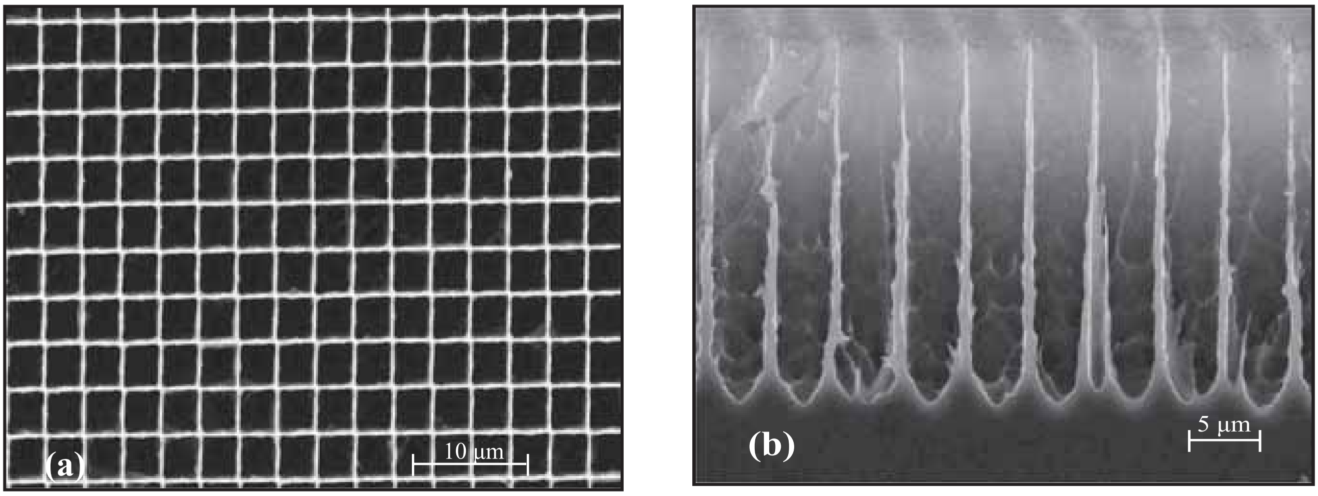

Fig. 12: Top view (a) and cross section (b) of a typical ordered macroporous Si layer

If the mesoporous layer is removed by chemical etching, a cavity is formed under the macroporous layer (fig. 13c).

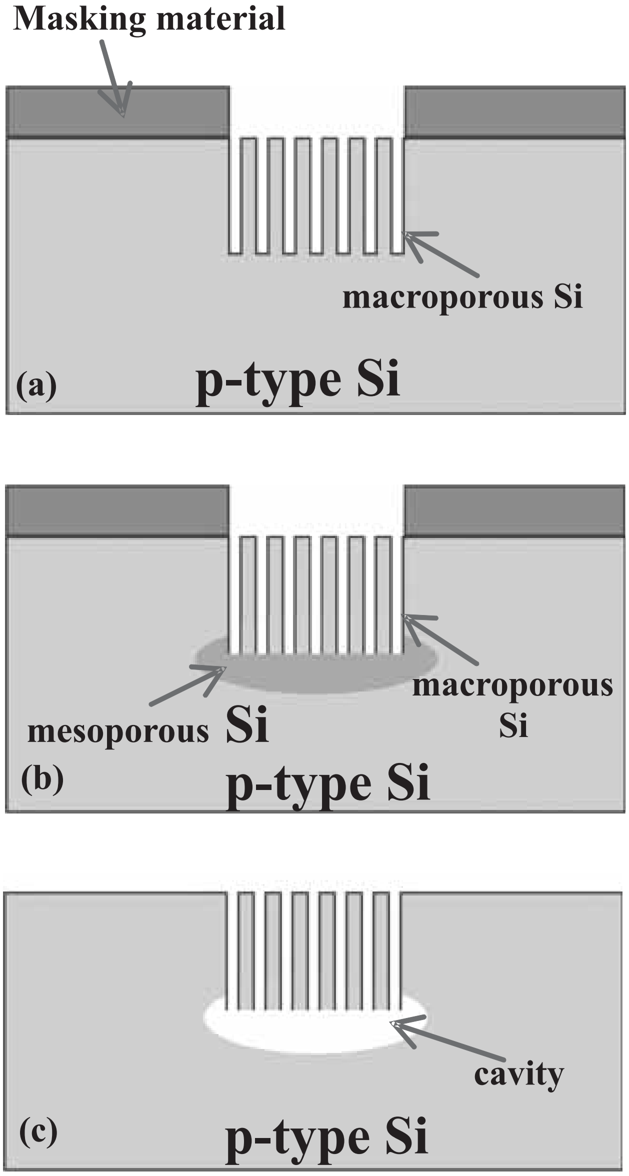

Fig. 13: Schematic representation of (a) a macroporous silicon layer on a pre-defined area on the Si-substrate (b) a macroporous silicon layer over a mesoporous layer, both fabrication a single two-step electrochemical process, (c) air cavity underneath the macroporous layer, fabricated by chemical dissolution of the mesoporous layer shown in (b).

3. Conclusion

Different technologies for bulk silicon micromachining using porous silicon technology were described. Their application in silicon sensors, microfluidic devices and RF isolation on a silicon substrate were also discussed.

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MICROFLUIDICS IN GLASS: TECHNOLOGIES AND APPLICATIONS

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Key words: microfluidics, glass etching, bonding, dielectrophoretic filter

Abstract: The paper presents technological aspects of patterning and assembling of glass wafers for microfluidic applications as well as three applications of the developed technologies. Special masking layer (Cr/Au/Photoresist and a:Si/SiC/Photoresist) were design, fabricated and tested for deep wet etching of glass. As a result an 1mm-thick Pyrex glass wafer was etch-through using an a:Si/SiC/Photoresist mask. Also, a HF(49%)/HCl(37%) solution in ratio 10/1 was found to be optimal for achieving a good surface roughness of the generated surface. Experimental results regarding dry etching of Pyrex glass on ICP reactors show that vertical sidewall can be generated using C_4F_8/He as process gasses. The best result was achieved for silicon (single crystal) mask.

Microfluidic applications require bonding over metallization deposited on silicon wafer. Adhesive bonding can be a solution for direct assembling of glass-to-glass (especially at low temperature- below 200^{O}C). A special adhesive bonding technique, with SU8- negative photoresist applied by contact imprinting, was developed for glass microfluidic applications.

Design considerations, fabrication process and experimental results of microfluidic devices such as: dielectrophoretic (DEP) chip with bulk silicon electrodes, 3D DEP filter as well as a microfluidic chip for cell impedance spectroscopy are also presented.

Mikrofluidika v steklu: tehnologija in uporaba

Kjučne besede: mikrofluidika, jedkanje stekla, vezava, dielektroforetični filter

Izvleček: V prispevku predstavljamo tehnologijo jedkanja in montaže steklenih rezin za uporabo v mikrofluidiki, kakor tri primere uporabe tako razvite tehnologije. Preizkusili smo posebne maskirne plasti (Cr/Au/fotorezist in a:Si/SiC/fotorezist) za globoko mokro jedkanje stekla. Uspeli smo pojedkati skozi 1mm debelo rezino iz pyrex stekla z masko a:Si/SiC/fotorezist. Ugotovili smo, da je raztopina HF(49%)/HCl(37%) v razmerju 10/1 optimalna za doseganje dobre površinske hrapavosti. Eksperimentalni rezultati dobljeni s suhim jedkanjem pyrex stekla v ICP reaktorju kažejo, da lahko dosežemo navpične stene z uporabo mešanice plinov C_4F_8/He. Najboljše rezultate smo dosegli z masko iz silicija.

Mikrofluidika zahteva vezavo silicijevih rezin prekritih z metalizacijo. Vezava z lepljenjem je lahko rešitev za direktno montažo steklo na steklo (sploh pri nizkih tempareturah pod 200 ^{O}C). Razvili smo posebno tehniko vezave z lepljenjem s SU-8 negativnim fotorezistom, ki smo ga natiskali na podlago.

V prispevku predstavimo načrtovanje, izdelavo in eksperimentalne rezultate mikrofluidnih komponent: DEP čip z elektrodami iz silicija, 3D DEP filter, kakor tudi mikrofluidni čip za celično impedančno spektroskopijo.

1. Introduction

Microfluidic devices and systems have become essential elements for biomedical instrumentation and it is considered one of the most promising MEMS application area. Microfluidic dispensing and controlling devices, such as micro pressure/flow sensors /1/, monolithic membrane valve/diaphragm pumps /2/, have been developed with integrated glass components. DNA related microfluidic devices, such as micro flow cells for single molecule handling of DNA /3/, micro injectors for DNA mass spectrometry /4/, and µPCR devices for DNA amplification /5/, have also been presented. Being transparent under a wide wavelength range, glass is a prime candidate for microbioanalytical devices such as microcapillary electrophoresis /6/ or dielectrophoretic devices for cell trapping /7/ or sorting /8/.

The paper presents an extensive investigation of glass microfabrication with focus on wet and dry etching of glass, proposing solution for improving the performances of wet and dry etching process. A second part is dedicated to new techniques for adhesive bonding of processed glass wafer: adhesive bonding using contact imprinting. Finally, three applications are presented: a dielectrophoretic device for cell trapping and sorting, a dielectrophoretic filter and a microfluidic chip for impedance spectroscopy.

2. Micropaterning of glass

Glass is a very suitable material for microfluidics due to its characteristics: good mechanical and optical properties, high electrical insulation and high chemical resistance to many chemicals. The main requirements for the glass used in microsystem technology are: microstructurable using standard lithography process, suitable for metal deposition, transparent for wide range of wavelength, apt for bonding to silicon.

2.1 Paterning of glass

There are three major groups of technique used for glass etching: mechanical, dry and wet. Mechanical methods include traditional drilling, ultrasonic drilling, electrochemical discharge or powder blasting. However, smooth surfaces cannot be generated using such methods. Dry etching of glass had been reported in /9/ using SF_6. However the etching rate is relatively low. Wet etching remains the most common and low cost method. The etching solution is based on HF. The masking layer depends on the application and on the “thermal budget” of the fabrication process of the device. Photoresist is very often used as mask layer /10-12/, but its area of application is limited. A very commonly used mask is Cr/Au /12, 13/, where Cr layer is used to improve the adhesion of gold to glass. Bu et al /14/ reported etching through 500 µm-thick glass wafer using a multilayer of metal, Cr/Au/Cr/Au, in combination with a thick SPR220-7 photoresist, by etching from both sides of the wafer. Another very commonly used mask material for glass etching is silicon, deposited by different methods: PECVD (amorphous silicon) /12, 15/, LPCVD (polysilicon) /12, 16/ or even bulk silicon /17/. The maximum reported depth was 320µm by Bien et al /12/ with a mask of polished polysilicon (1.5µm) and SU-8 (50µm) as etching mask.

2.2 Wet etching of pyrex glass

2.2.1 Etch rate

In the wet etching of glass, the main material used as masking layer (Si and Au) are inert in the HF-based etchant. As a result the etch rate become an important parameter: a fast etch rate will lead to a deeper etching, while the defect generation will be maintained at the same rate each time. The main solution used for glass etching is based on HF. The etch rate is characteristic for each type of glass, especially due to the different oxides and compositions used during fabrication. Meanwhile, the etch rate is determined by the concentration of HF enchants. To achieve a high etch rate, a maxim concentration of 49% should be used. It should be noted that, for Corning7740, by increasing the HF concentration from 40% to 49%, a rapid increase of 50-60% of the etch rate can be achieved (4.4µm/min to 7.6µm/min). The annealing process has a strong influence on the etch rate of glass. For annealed Pyrex glass the etch rate was from 9.1µm/min (for HF40%) and increase to 14.3µm/min when the HF concentration increases to 49%. Warming the solution to 40-50^{O}C can also increase the etching rate but the method is not recommended for safety reason (an increase quantity of HF vapours). Using ultrasonic for agitation the masking layer can be damage.

2.2.2 Masking layers

The main problems of wet etching are the pinholes and notching defects on edges. These could be observed after certain etch time, and were the result of the interaction between the etchant and mask. These defects presented in Figure 1 limit the etch depth of glass. The main reasons of defect generation are: the residual stress in the masking layer /15/, the stress type (tensile or compressive), the gradient of stress and the hydrophilicity of the surface. We will present in this chapter an analysis of the main masking layer that can be used for the wet etching of glass. The glass etchant was HF 49%.

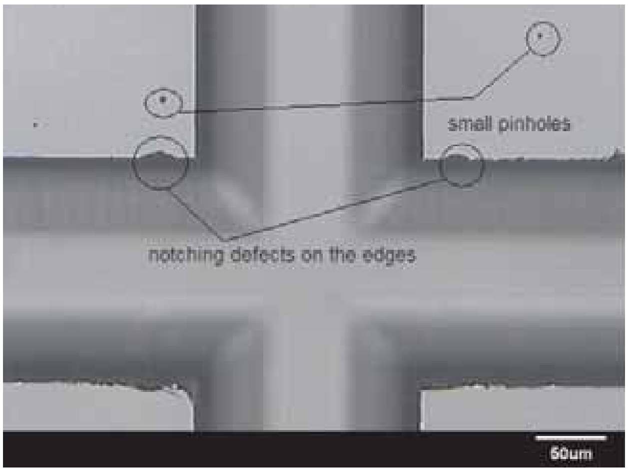

Fig. 1: Optical image of 100µm-deep etched in glass with Cr/Au mask

Photoresist masking layer. For our experiment, we used positive photoresist AZ7220 (from Clariant). In highly concentrated HF solutions, the quality of the photoresist mask was very poor. The maximum etching time – appreciated to be around 3 minutes (equivalent with a depth etch of 22 µm) – was achieved after the photoresist was hard-backed at 120^{O}C for 30 minutes on a hot plate. A huge isotropy was noted (5:1). After etching for a long time, the photoresist mask would peel off. The technique could be used in cases where up to 20 µm deep etching is required such as capillary electrophoresis.

Amorphous silicon (a:Si). Silicon is an inert material in HF-based solutions. It also has the advantage of being a hydrophobic material. Hence, the penetration of etchant through the small impurities of the mask is relatively difficult. The a:Si masking layer presents the advantage of deposition at low temperatures (almost room temperature for sputtering and 300^{O}C for PECVD deposition), but as we analyzed in /15/, the high value of compressive stress induced in this layer (600MPa) limited its application to 20min. The annealing of the masking layer could reduce the value of the stress and improve the performance to up to 30 minutes – equivalent of 200µm /15/. The isotropy of the etching was 1:1.2. The influence of stress is presented in Figure 2, where wet etching of glass was performed using the same a:Si mask, but this was annealed at 400°C at different times, resulting in a different residual stress in the masking layer.

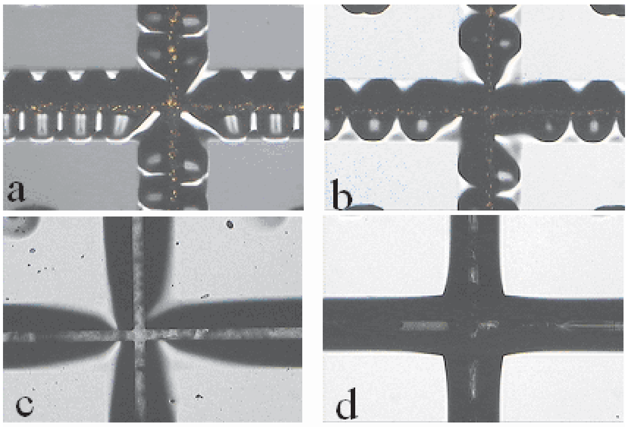

Fig. 2: Optical image glass etching using a:Si mask with different stress values: a) 600MPa b) 300MPa c)100MPa d) 100MPa (tensile)

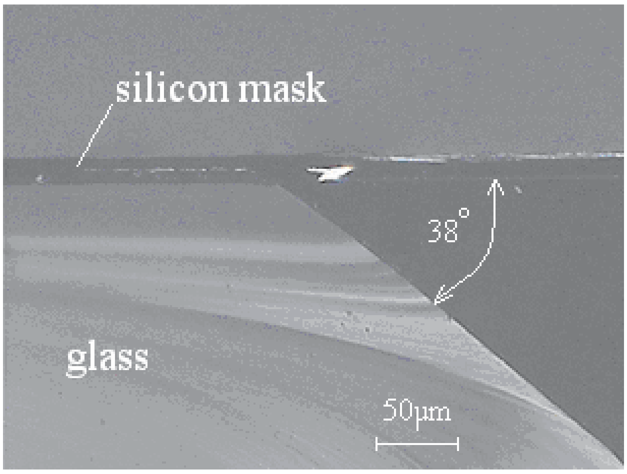

Fig. 3: Etching results with bulk silicon mask.

Polysilicon. The test layer was deposited at 530°C in a furnace. The resulting stress in the layer was 50MPa compressive. The resistance of the mask in HF solution was 30min. (similar to results using a:Si). The isotropy of the etching was very good – 1:1.

Bulk silicon layer. Single crystal silicon can also be used as a mask for glass etching. Wet etching with bulk silicon mask was first reported by Corman *et al* in /17/. In tests, a silicon wafer was anodicaly bonded on a glass wafer on an EVG 601 bonding system. The silicon wafer was thinned up to 30μm in an Adixen ICP-Deep RIE system. After patterning with photoresist, the mask was defined in the silicon layer using a classical Bosch process. The etching result indicated that the mask was perfectly inert in HF solution, but a huge isotropy of the etching process was observed. Figure 3 presents the results of wet etching in HF 49% solution of a Pyrex glass using a bulk silicon mask. The resulting angle between the mask and glass surface (38°) indicated that the interface layer was removed quickly. The main reason for this could be the poor quality of the silicon oxide interface layer (between the silicon mask and glass wafer), which presented an increased etching rate. Similar results had been reported in /17/.

Cr/Cu. The first reported result of etching with the Cr/Cu (50 nm/1 μm) masking layer is presented in /15/. The maximal time for a good quality etching process was around 15 minutes (about 100μm-deep etch). The low value of residual stress of the Cr/Cu layer (50-80MPa tensile) and the good selectivity of Cu in the HF etchant can make this layer very suitable for microfluidics applications, where the required depth is below 100μm. If the photoresist mask (AZ7220 from Clariant) used for Cr/Cu layer patterning is hard baked and kept for the glass wet etching process, the etching results can be improved sensitively.

Cr/Au. One of the most commonly used metal masks is Cr/Au. The best results initially obtained with the Cr/Au masking layer were in the range of 50-100μm depth /15/ (7-15 minutes), as a function of the layer thickness. The mechanism of defect generation is very simple: due to the tensile stress in the deposited layer (250-300MPa) the masking layer creped and a large number of defects were generated in the mask. The Au mask surface is hydrophilic. Therefore, once the etchant solution was in contact with the mask, it would penetrate easily, through the mask defects and generate pinholes. To minimize the effect of these cracks in the thick Au layer, a series of deposition/ cooling actions can be applied. After depositing 200-250nm of Au, the deposition was stopped for 10min. The temperature of the wafer would change and possible cracks were generated. The deposition process would then continue. The possibility of generating defects in the same position was reduced when the next layer of Au was deposited. This method of deposition generates a 1.2μm-thick Au layer, and the etching time can be increased to 50 minutes. If the photoresist mask used for Cr/Au mask patterning is hard baked, the performance of the masking layer can also be improved. The photoresist will penetrate and fill the cracks generated by the tensile stress in the Cr/Au layer. Furthermore, the hard baked photoresist surface will make the mask surface hydrophobic. Figure 4 presents a hole with a diameter of 700 μm that was etched through a 500μm Pyrex glass wafer Corning 7740 (annealed). The etching was performed in a Teflon beaker in the same HF solution, with magnetic stirring for 85 minutes. No defect was observed after the removal of the Cr/Au mask.

Low stress a:Si/SiC/photoresist. The target was to generate a mask with low residual stress, no stress gradient along the thickness and a hydrophobic surface. Finally, a multilayer mask consist of low stress a:Si/ SiC/ photoresist was found very suitable for glass etching. Both a:Si and SiC layer were optimized for a low stress value /18/. The hydrophobic surface was generated by keeping and hard baking the photoresist mask. The results of the etching process using a:Si/SiC/photoresist masking layer in

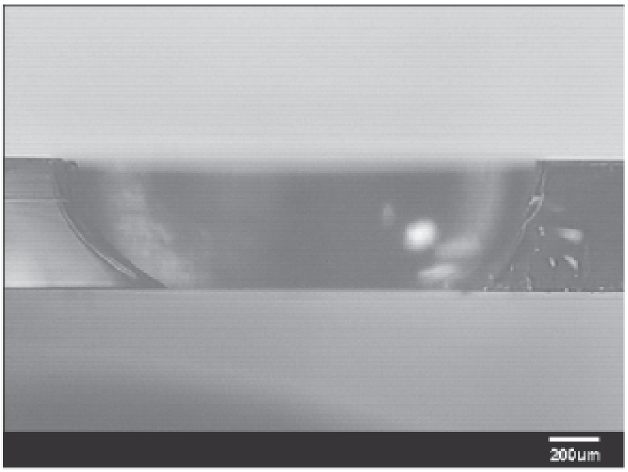

Fig. 4: Cross-section view of the through-etched hole with a Cr/Au/ photoresist mask for an annealed glass.

HF49% are presented in Figures 5, 6. The protection of the backside of the wafers was assured by a wax bonding on a dummy silicon wafer.

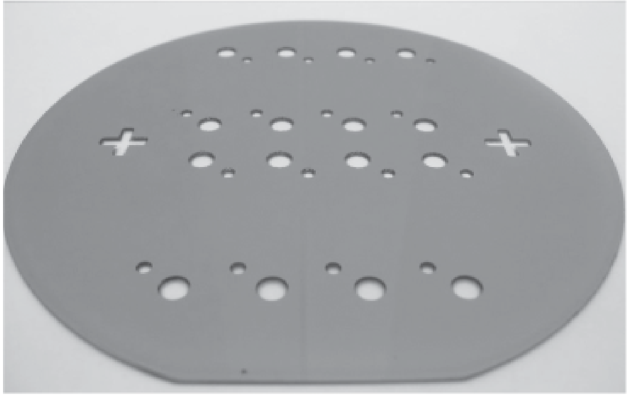

Fig. 5: 500µm-thick Pyrex glass wafer etch-through using a:Si/SiC/ PR mask (the mask was kept on the wafer)

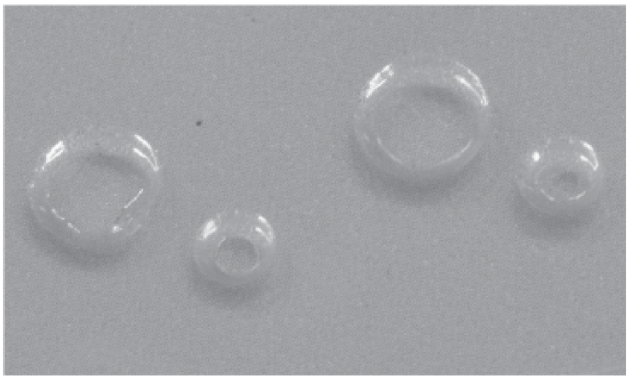

Fig. 6: 1 mm-thick Pyrex glass wafer etch-through in HF49% after removal of using a:Si/ SiC/PR mask

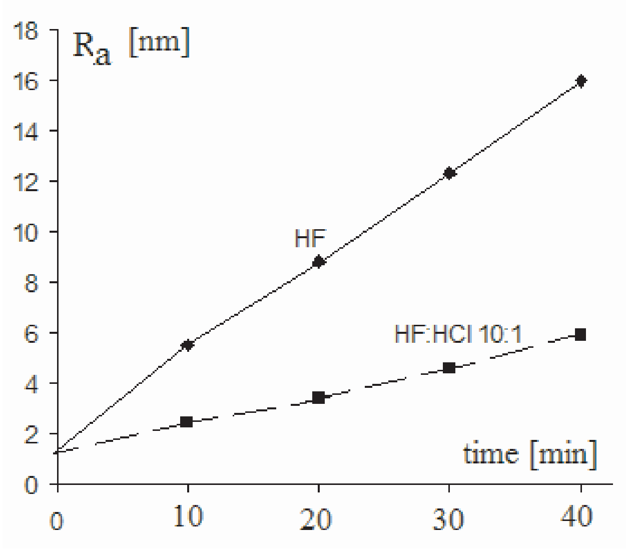

Fig. 7: Improving of surface roughness using HF/HCl solution

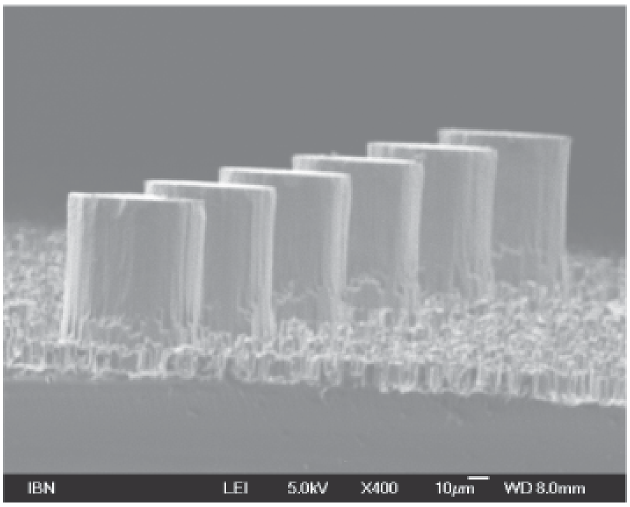

Fig. 8: Glass pillars etch in Deep RIE system using C_4F_8.

2.2.3 The roughness of generated surface

The roughness of generated surface can be an important issue for the wet polishing and deep wet etching of channels. Figure 7 shows the variation of roughness for Corning 7740 versus time for HF solution and when HCl was added (HF/HCl 10/1) solutions. The graph is almost linear for both solutions but with small values for HF/HCl solution. The purpose of HCl was to remove the insoluble products.

2.3 Deep dry etching of pyrex glass

Previous work reported the etching of Pyrex glass using SF_6 and electroplated Ni as the mask /9/. In our experiment we used a Fluorine gas C_4F_8 as the gas etchant. The main advantage of using this gas is the presence of the generated plasma carbon-based radicals that can passivated the trench's walls and result in a profile with vertical walls. The experiments were performed on an Adixen Deep RIE ICP (oxide etcher). Other critical parameters were the pressure (we performed our experiments at 0.5Pa) and coil power (we use the maximal RF power 2800W). We tested our experiment Al (6µm) and bulk Si (40µm) masks. For the Al mask, a selectivity of 1/10 was achieved, but after long processing (1 hour) we observed that the protected surface (after the mask removal) became rough and mate due to the ion bombardment. For this reason, we looked for a material that could be easily deposited and patterned in the thick layer: bulk silicon. Even though the selectivity was relatively similar (1:15), this masking layer presented some important advantages: its ability to work with a thick layer, good patterning (vertical walls) using classical Bosch process in Deep RIE systems and easy removal in KOH solutions. The results of the etching of 80µm-tall glass pillars using a 40µm bulk Si mask is presented in Figure 8.

3. Assambling at wafer level using adhesive

Assembling technology at wafer level is another key feature in glass microfluidics fabrication. One solution can be wafer-to-wafer anodic bonding of glass to silicon, a well establishes technology that can assure a hermetic sealing. For special applications, glass/silicon/glass a double wafer-to-wafer bonding can be performed /19/.

Adhesive bonding can be another solution for microfluidic devices. It enables joining of silicon or glass wafers at lower temperatures. The technique is less dependent of the substrate material, particles, surface roughness and planarity of the bonding surfaces. Several lithographic patternable materials such as BCB or positive and negative photoresists have already been studied as intermediate layers for adhesive wafer bonding. Beside BCB the epoxy based negative photoresist SU-8 provided very promising results in bonding experiments /20, 21/. The advantages of SU-8 are its flexibility in choosing the layer thickness, its high chemical and thermal stability as well as its good mechanical properties. However, for devices with nonplanar or micromachined surfaces the adhesive layer cannot be applied directly using classical spin-coating methods as these would result in undesirable major non-uniformities of the deposited layer which can affect the functionality of the device. Therefore, in such cases the only solution available for an adhesive bonding is stamping the layer on one of the surfaces, followed by the alignment and bonding process.

A new imprinting technique was developed specially for devices where the bonding area is quite large. In such cases, if the imprinting is performed directly from a dummy wafer, the strong adhesion between the dummy wafer and the bondable surface would make very difficult the detachment of the dummy from the device wafer. The proposed solution to this major problem is to use a Teflon cylinder for first transferring indirectly the SU8 adhesive from the dummy wafer and then imprinting the adhesive layer further on the bonding surface. The process is illustrated in Figure 9. First a thin layer of SU8-5 is applied on a dummy silicon wafer. The SU-8 photoresist was spun on it at 3000 rpm/60 seconds, resulting in a SU-8 layer 12µm-thick (Figure 9a). The next step is the transfer of the adhesive layer onto the surface of a Teflon cylinder with a diameter of 38mm and a length of 120mm (Figure 9b). The process is also illustrated in Figure 10. Further, the cylinder is rolled on the bonding surface and the adhesive layer is partially transferred on this surface (Figure 9c). In the next step, both structured wafers were aligned and brought in contact (Figure 9d). The last step is the wafer-to-wafer bonding, which was performed at different temperatures between 20 and 100°C for 30min at an applied force of 1000N in vacuum (Figure 9e).

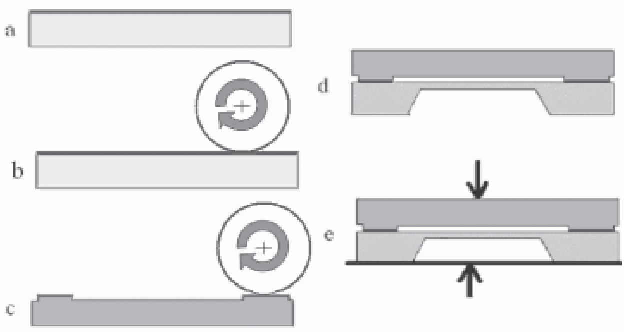

Fig. 9: *a) Spinning of SU8-5 photoresist on a dummy wafer, b) Contact imprinting of SU8 on a Teflon cylinder, c) Imprinting of SU8 from the Teflon cylinder on the wafer surface, d) Alignment and contact, e) Wafer bonding.*

The measured average residual stress indicated an overall value in the range of 20 to 40MPa (tensile). These low values as well as the good elastic properties and high chemical and thermal stability of the SU-8 show that it is a most suitable material for wafer-to-wafer adhesive bonding. Figure 11 presents the optical image of cross-section through the bonding region, clearly showing both fully bonded and partially bonded areas. The yield of bonding process was high (95- 100%).

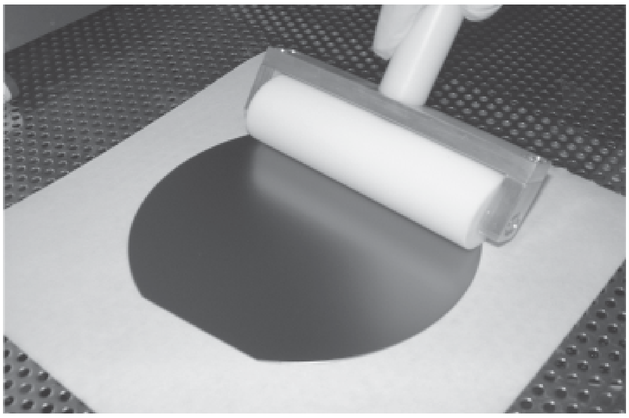

Fig. 10: *Imprinting of the SU8 from a dummy wafer to the Teflon cylinder.*

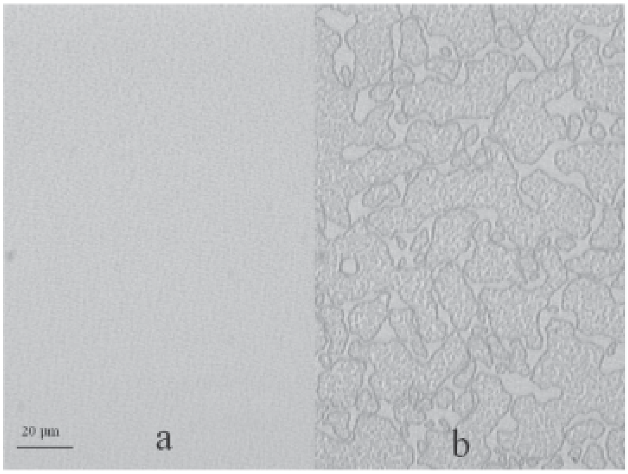

Fig. 11: a) Fully bonded area and b) partially bonded area.

Figure 12 presents the results of the wafer-to-wafer bonding process while in Figure 13 the cross section through a microfluidic channel is presented (at the top corners residual SU-8 can be observed).

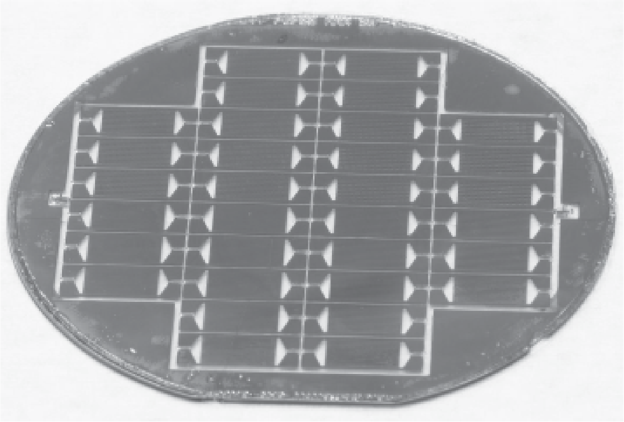

Fig. 12: Bonded wafers using contact imprinting and SU-8 photoresist as adhesive.

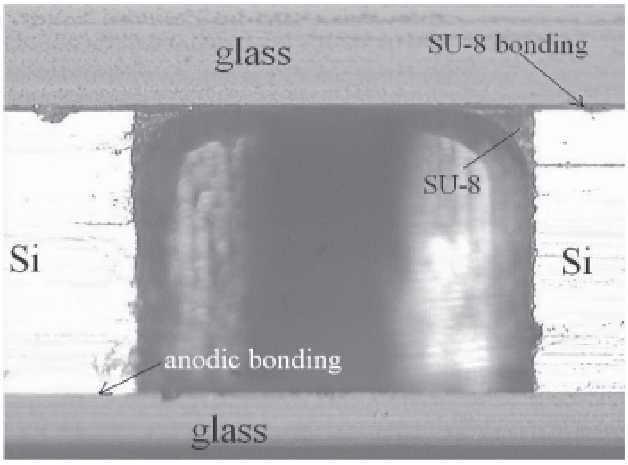

Fig. 13: Microfluidic channel with bulk silicon walls and glass as ceiling and floor.

4. Applications

4.1 Dielectrophoretic device packaged at wafer level

An application of the above describe techniques was the fabrication of a microfluidic device for dielectrophoresis (DEP). The device consists of three functional layers, where two of them are insulators made of glass and the third is a conductive silicon die in which electrodes and the microfluidic channel are patterned. The assembly was performed at the wafer level by anodic bonding. A metallization, performed on the bottom glass layer, provides the electrical connections of the bulk silicon electrodes through via holes etched in the glass with PCB. A detail view of the fabricated device (top with the inlet/outlet tubes and bottom with metallized via holes) is presented in Figure 14. The main steps of the fabrication process are presented in Figure 15.

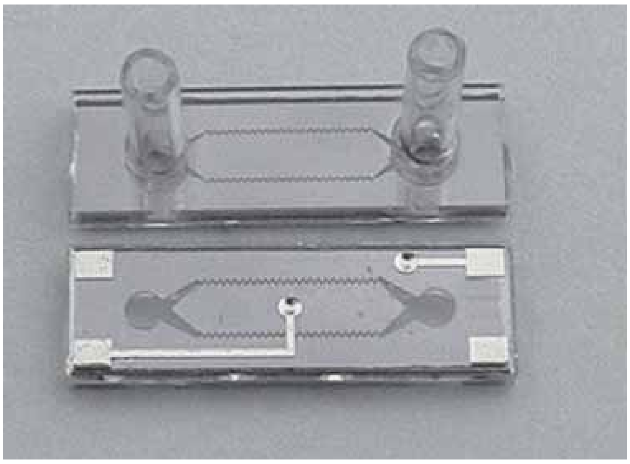

Fig. 14: Photo with the microfluidic DEP device

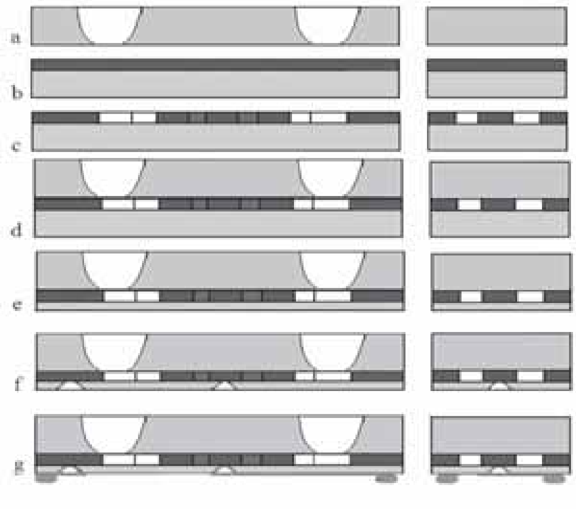

Fig. 15: Main steps of the fabrication process

The fabrication process start with the fabrication of inlet/outlet holes using a low stress a:Si/photoresist mask- Figure 15a. An anodic bonding process is performed between an 100µm-thick silicon wafer (heavy doped) and a 500µm-thick glass wafer (Figure 15b). In the next step the geometry of the microfluidic channel and electrodes are defined in silicon, using a classical Bosch process on an ICP deep RIE system (Figure 15c). A second adhesive bonding (Figure 15d)-previous described is performed between the wafer with inlet/outlet holes and the wafer with the electrodes. Via-holes must be generated in the bottom glass in order to assure the electrical contact of the silicon electrodes with the PCB. These via-holes are usually defined using a wet etching process. Even the dimension of the mask for via holes is relatively small (diameter of 50µm), due to the isotropy of the process, in a 500µm-thick wafer, the final dimension can reach more then 1 mm. For this reason a thinning process of the bottom glass wafer is required. The bottom glass wafer was thinned from 500µm up to 100µm in the HF/HCl solution -Figure 15e. The mask for via holes was performed using Cr/Au and photoresist. The etching of via-holes (Figure 15f) was performed in the same HF/HCl solution. After the deposition of the metallization layer (Cr/Au) the photoresist masking layer was applied using a spray-coating process (Figure 15g). The device was successfully tested using yeast cells and the results are presented in Figure 16.

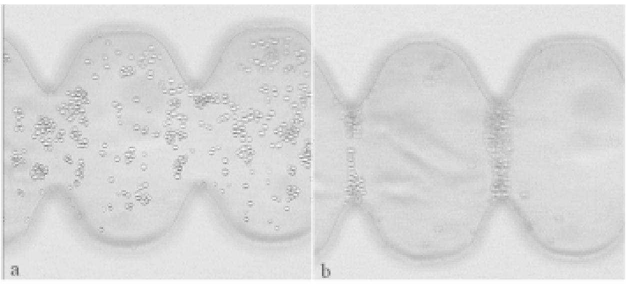

Fig. 16: Trapping of the yeast cells in a DEP device

4.2 Dielectrophoretic filter

The fabrication process of a DEP filter for bacteria trapping will be presented in this section. An 1mm-thick glass wafer was etch-through simultaneous from the both sides using the previous described Cr/Au and photoresist mask. The target was to generate a thick glass frame with metallization on the both sides. After removing the photoresist in a classical resist stripper, and dicing of the wafer, two stainless steel meshes was soldered on the both sides of the frame. Before the second soldering process, the frame was field with silica beads (100µm-diameter). The device acts as an electromechanical filter for cell trapping. An image with the glass frames as well as the funnels used for filter testing is presented in Figure 17.

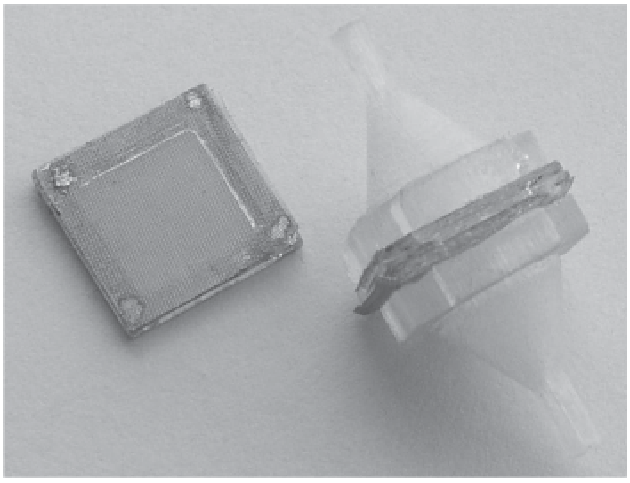

Fig. 17: Image with DEP filter-chip device

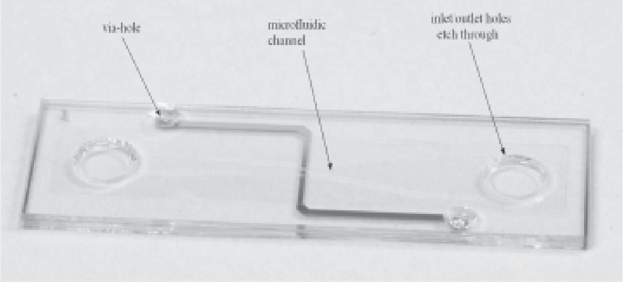

Fig. 18: Image a microfluidic device for electrical impedance spectroscopy

4.3 Microfluidic device for impedance spectroscopy

In Figure 18 a microfluidic device for electrical impedance spectroscopy analysis of biological sample is presented. The device consist of two glass dies: the top one with inlet/outlet holes performed with the technique described before and the bottom die with a 25µm-deep microfluidic channel and metal electrodes. The dies were bonded at wafer level using the adhesive bonding technique previous described.

5. Conclusions

The paper presents two main technologies for fabrication of glass microfluidic devices: wet and dry patterning of glass as well as a new technique for adhesive wafer-to-wafer bonding. Three applications of the described techniques are also presented.

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ADVANCED METHODS AND TOOLS FOR HANDLING AND ASSEMBLY IN MICROTECHNOLOGY - A EUROPEAN APPROACH IN THE FRAME OF THE FP6 MARIE CURIE RESEARCH TRAINING NETWORK ASSEMIC

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Key words: mikrosystems, handling, assembly, training, ASSEMIC network

Abstract: Mechatronic competences represent a strong component in Microsystem Technologies, especially in micro-handling and micro-assembly, a field with challenging requirements. An adequate training system for preparing researchers to work in this field must not only integrate all scientific and technical disciplines involved, such as mechanics, control theory, material physics, electronics and micro-systems design, but also provide an industrial perspective and additional skills. The European Research Training Network "Advanced Methods and Tools for Handling and Assembly in Microtechnology ASSEMIC" addresses this need at the European scale, offering an advanced training scheme for early-stage and experienced researchers within an ambitious collaborative research project.

Napredne metode in orodja za montažo in rokovanje v mikrotehnologijah – Evropski pristop v okviru FP6 mreže šolanja raziskovalcev ASSEMIC

Kjučne besede: mikrosistemi, rokovanje, montaža, šolanje, ASSEMIC mreža

Izvleček: Mehatronika predstavlja pomembno sestavino v mikrosistemskih tehnologijah, še posebej pri rokovanju in montaži, področju polnem zahtevnih izzivov. Ustrezni sistem šolanja, ki bi pripravil raziskovalce za delo na tem področju naj ne bi vseboval samo šolanja s področja vseh vpletenih tehničnih disciplin, kot so mehanika, kontrolna teorija, fizika materialov, elektronika in načrtovanje mikrosistemov, ampak naj bi tudi postregel z ustreznim industrijskim pogledom in ustreznimi znanji. Prav Evropska mreža šolanja raziskovalcev ASSEMIC na evropskem nivoju ponuja napredne programe šolanja za mlade in izkušene raziskovalce v okviru ambicioznega raziskovalnega projekta.

1. Introduction

Handling and assembly of hybrid microsystems has a strongly multidisciplinary nature, requiring a large number of technologies and tools. For tasks relating to microsystem technology alone, it is necessary to integrate expertise in the field of MEMS design, devices for high-resolution positioning and micro-actuators for gripping systems, etc. In addition, many other scientific and technical fields are also involved: material physics (for optimising tool/component interaction and reducing adverse adhesive effects), laser technology (for joining processes, curing glue, etc.), advanced control theory (including artificial intelligence control techniques and visual pattern recognition), and many others.

Micromanipulation techniques can include not only handling of micro-components for assembly of MEMS, but also application fields and challenging tasks. Some examples are microsurgery, manipulation of biological material and micro-robotics. One of the aims of this project is to explore and develop new methods, tools and applications for micromanipulation beyond the limits of traditional assembly techniques for micro-components.

In the last years, MST has turned out to be considered one of the most important technologies. Hybrid MEMS are composed of micro-components with different working principles and functionalities (electronic, optical, fluidic, mechanical…), which need to be integrated and combined into a complete system. As has already mentioned, microhandling and -assembly of MEMS is an issue of relevant importance, since a great part of the total costs in micro-system production is actually derived from the assembly phase.

1.1 State of the art

A number of micro-handling stations have been presented in the last years by different institutions and companies. Most of them include on-line image processing, with object recognition and position detection of the tool for closed-loop feedback control, and they can perform certain easy operations in automatic mode. Existing implementations prove the potential and capabilities that such automated micro-assembly stations can offer. However, a number of problems still impede their broad introduction. Some of the topics currently under research include methods to override the limited depth of field in optical microscopes, stereoscopic 3D vision algorithms and calibration procedures for microscopes with adjustable magnification. Relative little work has been made on practical implementation of methods for dealing with the sticking effects in automated systems. On the other hand, some research groups have proposed and tested the use of specific control methods based on artificial intelligence techniques for certain micro-manipulation operations, but the possibilities of these technologies have not yet been fully exploited.

An approach to industrial applications was aimed by a consortium of German institutions (including one of the ASSEMIC participants) in the frame of a national project devoted to the assembly of hybrid Microsystems "Sonderforschungsbereich SFB 440 - Montage Hybrider Microsysteme", focusing on handling and assembly techniques for fabrication of small and medium volumes.

1.2 Micro-grippers

In the last years, many research teams have concentrated on the development of new micro-gripper designs. As a result, currently there exist a large variety of tools for micro-handling based on different gripping systems: vacuum, mechanical jaws, making use of the adhesive properties of liquids or ice, etc. The utilized actuation principles also cover a wide range of technologies: a mechanical gripper can be actuated by a piezoelectric element, SMAs, electrostatic combs and many others. However, most methods show disadvantages too, such as hysteresis, heating, too small displacements or limited maximum force. This demands further research to find optimal designs or novel techniques offering improved performance and adaptable functionality.

Some state-of-the-art gripper prototypes comprise also integrated position and force sensors, although most designs are application specific and suitable for laboratory experiments, but lacking the flexibility, robustness and long term performance reliability required for industrial production processes. An effort must be done to create optimised micro-tools with a view to modularisation, exchangeability and closer potential of standardization.

1.3 Micro-robotics

In the frame of the project MINIMAN (Nov 1998-Jan 2002), a micro robot was developed with 5 degrees of freedom and a size of a few cm^3, able of performing certain manipulation tasks in semi-automated mode. The prototype developed didn't have an immediate short-term market expediency, but the attained experience and results open the way to innovative micro-manipulation technologies with a clearly identifiable route for its take-up by the industry. Further research has been recently started in a concept for a manipulating system consisting of a cluster of miniaturized co-operative robots equipped with wireless communication systems (Micron Project). This and other state-of-the-art results demonstrate the potential of this promising technology. However, it is apparent that a lot of research effort will be needed to bring micro-robotics to a level of maturity, which will enable the real exploitation of its capabilities.

Tele-manipulation is also a topic rising a great interest in the research community. On one hand, it facilitates the task of manual manipulation, as the motion of the operator's hands connected to an adequate haptic interface can be transferred at the proper scale into fine and precise movements needed for micromanipulation. The latest research topics in this field comprise advanced control systems for reduction of hand tremor movement, novel haptic interfaces, 3-D virtual reality systems and utilisation of complementary image systems (such as ultrasound).

2. Learning by doing: ASSEMIC's research dimension

The project is structured in several work-packages, defined to address the following main research objectives: ultra-precision positioning, innovative tools for handling and assembly, advanced control methods, application requisites and industrial production. A brief description of the workpackages' content is given below:

WP 1. Micropositioning: Positioning stages and elements with integrated sensors and feedback control, autonomous and mobile systems, microrobotics.

WP 2. Microhandling: Development and test of tools and methods for handling in different environments (normal room conditions, clean room, vacuum, fluids) and applications

WP 3. Microassembly: Innovative tools, special strategies and alternative approaches for efficient high precision and micro-assembly

WP 4. Automation for industrial production: Including production chains, quality assurance, test and characterization issues, etc

WP 5. Know-how management: Technology transfer and dissemination

Some of the expected achievements include the development of a number of system and tools prototypes for handling and assembly in MST, such as an ultrahigh positioning stage using a novel approach, various microgrippers and a haptic interface device for telemanipulation. A number of studies and experiments will be performed to propose and analyse new approaches and improved methodologies (artificial intelligence control, enhanced haptic feedback, optimised industrial production, strategies to prevent adhesion, etc). Finally, several experimental setups will be built to demonstrate and evaluate the developed tools and processes for advanced microhandling operation under different environments (normal room conditions, vacuum, within a fluid…) in various application fields, such as assembly of MEMS and biological applications.

Table 1: Project partners

1.	Institute of Sensor and Actuator Systems, Vienna University of Technology; Co-ordinator	ISAS	Austria
2.	Fondation Suisse pour la Recherche en Microtechnique	FSRM	Switzerland
3.	ARC Seibersdorf research GmbH	Seibersdorf research	Austria
4.	National Institute for Research and Development in Microtechnologies	IMT	Romania
5.	Politechnika Warszawska (Warsaw University of Technolgy)	PW (WUT)	Poland
6.	Instituto de Desenvolvimento de Novas Tecnologias	UNINOVA	Portugal
7.	University of Oldenburg	Uni-OL	Germany
8.	Fundacion Robotiker	Robotiker	Spain
9.	Foundation for Research and Technology – Hellas	FORTH	Greece
10.	Progenika Biopharma	Progenika	Spain
11.	Council for the Central Laboratory of the Research Councils - Rutherford Appleton Laboratory	CCLRC-RAL	United Kingdom
12.	Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.v.	FhG/ILT	Germany
13.	Scuola Superiore Sant'Anna	SSSA	Italy
14.	Nanoscale Technologies GmbH	Nascatec	Germany

4 First research results

4.1 Micropositioning

Several issues have been dealt with in this Workpackage till now. The first issue concerning positioning stages was the definition of requirements for the micropositioning system, closely linked to the targeted final application. Thus, several potential target micromanipulation applications (handling of TEM slices, biomedical and biotechnology applications and assembly of optoelectronic components) have been identified with the aim of defining the concrete requirements. Uninova has reported a 3D optical position sensitive sensor, constituted by an array of 1D position sensitive detectors/4/. Further work will focus on its integration in static and/or dynamic positioning systems.

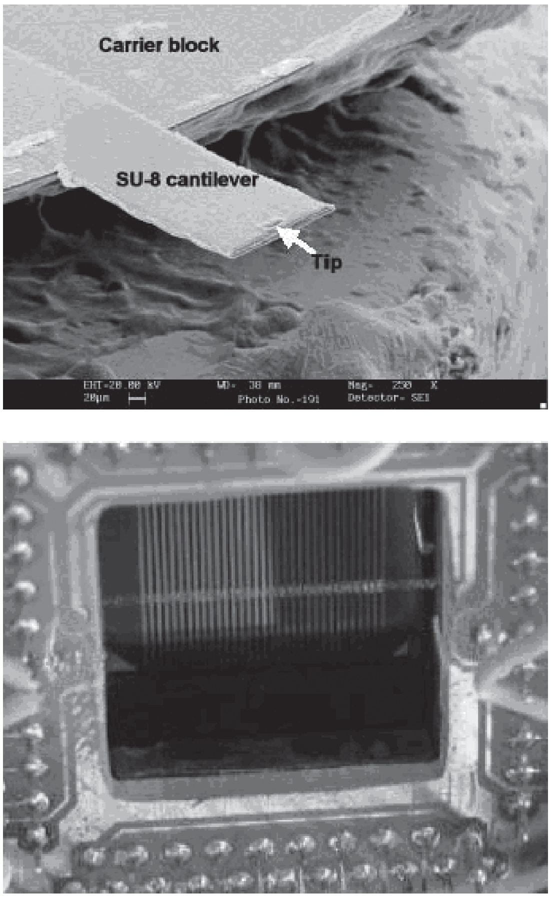

Fig. 1: Top CCLRC-RAL's cantilever; bottom Uninova's LATFPSD position sensor

University of Oldenburg has built a new nanomanipulation setup into the vacuum chamber of a Scanning Electron Microscope (SEM), modifying a mobile platform in order to enable its moving around and manipulating the probe on the probe holder.

In addition, work on material issues concerning micropositioning has been carried out by FORTH, including also surface roughness measurements on the microcomponents to analyze friction properties.

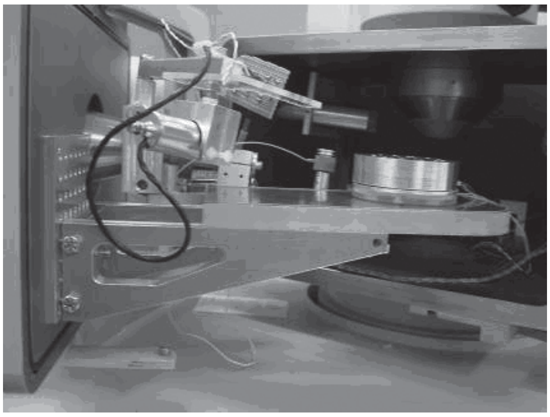

Fig. 2: University of Oldenburg's set-up for EBD experiments

4.2 Microhandling

Micromanipulation is performed with microgripping tools which can be based on different principles. The most common ones are vacuum grippers and micro-tweezers, but there exist many others, such as adhesive or cryogenic grippers, which make use of the adhesive properties of low viscosity fluids or ice to grip the objects; electrostatic and electromagnetic force grippers, able to handle non-conductive and ferromagnetic objects by exerting on them electrostatic and magnetic forces, respectively; and even more exotic approaches, such non-contact optical pressure object manipulation. Within the task devoted to the development of Advanced Microhandling tools, research has been done on different types of microgrippers, as well as special fabrication methods for such micro-grippers.

Nascatec has reported an electrostatic microgripper and performed additional mechanical simulations by means of Finite Element Analysis (FEM), in order to understand the key contributions to gripper distortion, evaluating the main variables of influence and determine optimum geometrical dimensions and fabrication parameters.

Seibersdorf research recently started experiments to test a microfabrication technology based on combination of LIGA (lithography, electroplating and molding) and PIM (Powder Injection Molding) for producing microgrippers. In contrast with the classical LIGA with injection moulding, used for producing polymer components, this approach enables low cost mass replication of microcomponents in a wide range of materials (including ceramic and metals).

The arms and tips of the microgripper in Fig 4 are fabricated using an amorphous alloy which exhibits excellent soft magnetic and mechanical properties (VITROVAC 7505). Cold laser cutting technique (wavelength λ=1064, repetition rate 3kHz and power rate P= 123 mW), is used in order to cut both the arms and the tips. The actuator consists of a double layer coil (120 windings in total, wire 70 µm diameter) wound around a highly oriented crystalline FeSi sheet. Since the easy axis of the FeSi sheet is along its length the core is magnetized longitudinally and therefore generating the desired magnetic field for the actuation of the gripper arms.

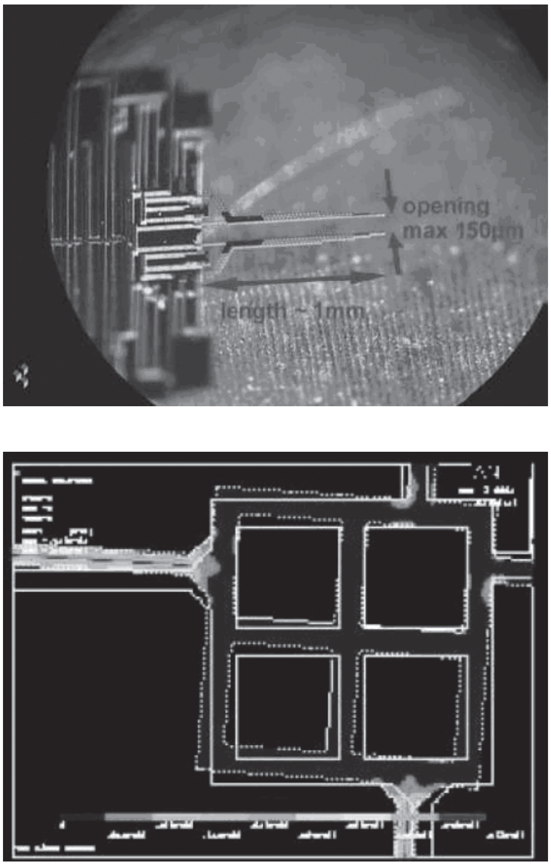

Fig. 3: Electrostatic gripper and FEM simulation (Nascatec)

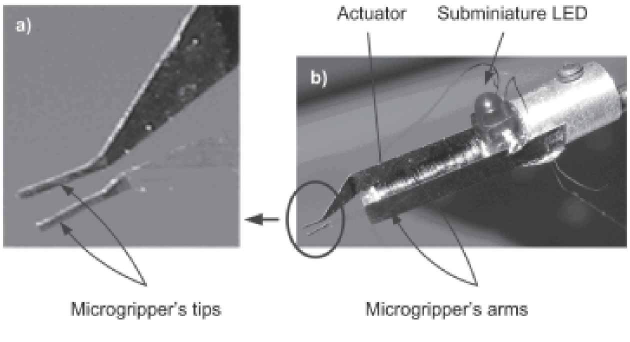

Fig. 4: Electromagnetic microgripper (TU Wien)

Politechnika Warszawska–WUT has proposed two solutions for special intelligent coating with controllable adhesion (biomimicry of the handling properties and nano-oscillation substrate of the intelligent coating), applicable for microgrippers. Models were studied and coatings fabricated and tested with AFM /7/. Scuola Superiore Sant'Anna, performed experiments to compare theoretical and real adhesion forces between sample and needle fingertip under different environmental conditions (normal and dry environment).

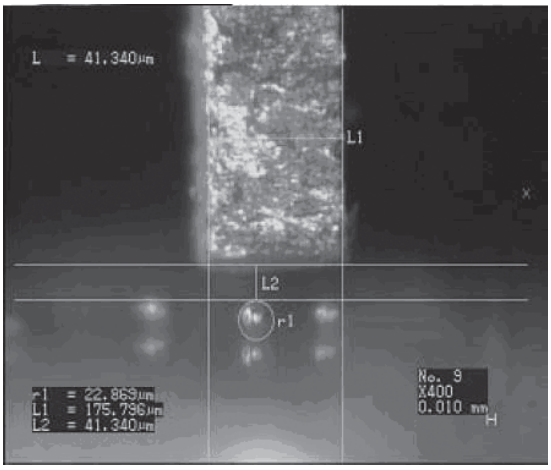

Fig. 5. Experiments with cubic needle fingertip and spheric object (Scuola Superiore Sant'Anna)

Sticking effects can be overridden by applying vibration, which helps release the handled object, but have a negative impact in the positioning accuracy. As regards microhandling applications, several application possibilities have been proposed and analyzed by the ASSEMIC participants, in order to test the tools and methods developed in the project. One of them, as reported by the University of Oldenburg, is the manipulation of TEM-lamella in the semiconductor industry. TEM-lamellas are very thin cross-sections of wafers, at specific x-y positions where a fabrication failure has been detected. Such section need to be milled out by using Focused Ion Beam (FIB), extracted from the substrate and finally brought to a Transmission Electron Microscope to be examined.

University of Oldenburg has also adapted and tested tools for manipulation of nanowires (gripping and bonding with the help of Electron Beam Deposition (EBD), with satisfactory results) see Fig. 7.

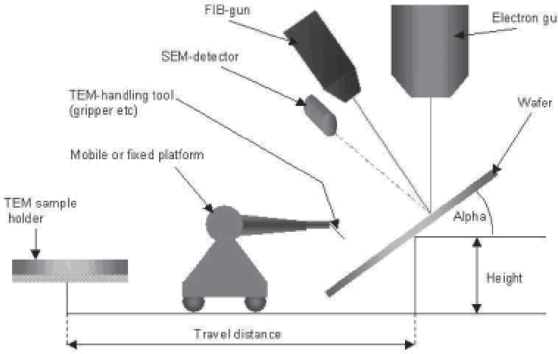

Fig. 6: General scheme of automated TEM-lamella handling set-up (University of Oldenburg)

Work has also been done concerning biological and medical applications. A miniaturised fluidic system, lab-on-a-chip (LOC), was designed and fabricated in view of an analytical study of the efficiency of photodynamic therapy on live single cells. Investigations on fabrication processes were performed and optimal process parameters for polymer SU-8 and over glass bonding technologies were stabilized /8/.

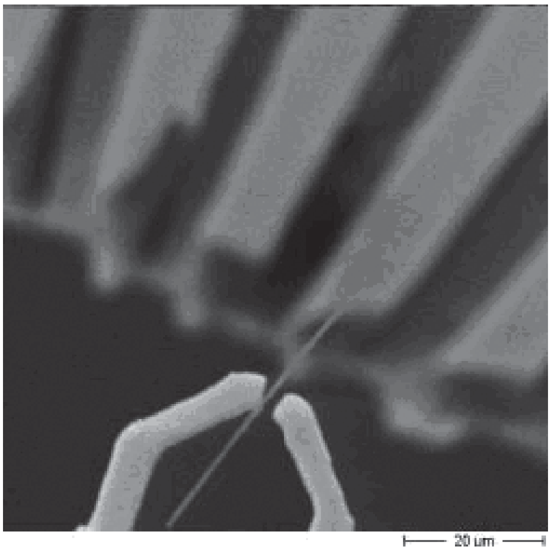

Fig. 7. Nanowire manipulation (University of Oldenburg)

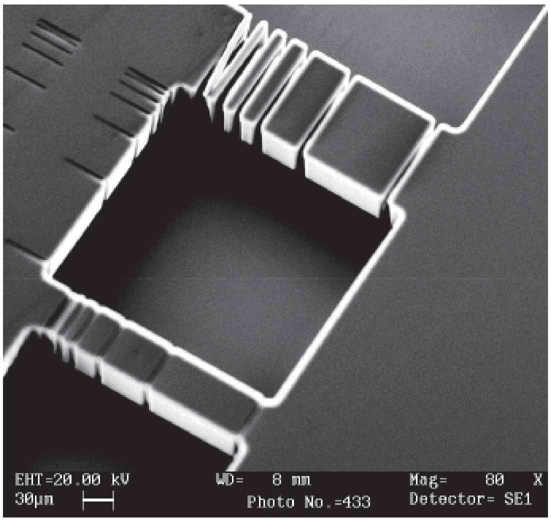

Fig. 8: SEM images of 5x35µm channels in SU-8 test structure

4.3 Microassembly

CCLRC/Rutherford Appleton Laboratories and ARC Seibersdorf research plan to cooperate for the use of microstereolithography (µSL) for micro-assembly and packaging applications. µSL technology offers high flexibility and versatility for creation of full 3D complex objects on a microscale.

Further, work related to the assembly, testing and improvement of the 4x4 and 8x8 cross connector switches for optical fibres was done in cooperation between FSRM and the University of Neuchatel. Steps involved in the assem-

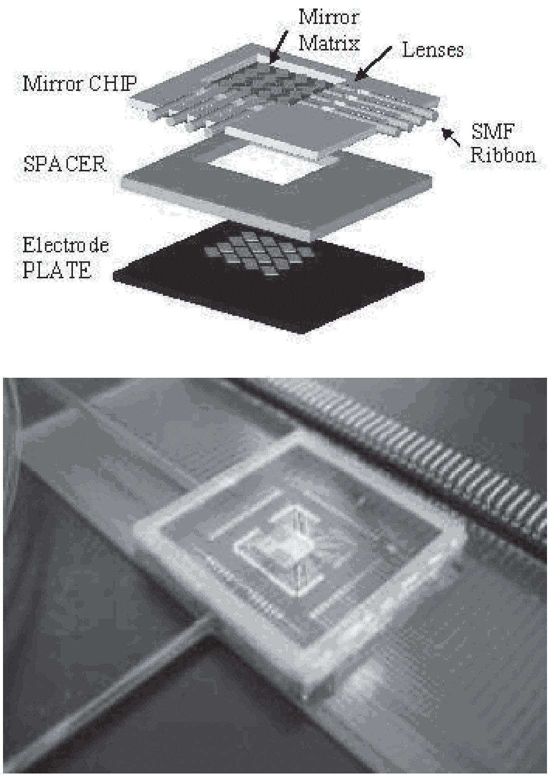

Fig. 9: Main components to assemble and side view of 8x8 packaged cross connection switch for optical fibre (FSRM/University of Neuchatel)

bly include cutting, aligning, gluing and testing the different components such as GRIN lenses, mirror chips and fibre ribbon, as well as sealing, wire bonding and integration on the PCB.

A new approach "Multilayer Adhesive Bonding under Hot Air Stream" to adhesive microbonding which can overcome restriction of the conventional MEMS packaging techniques has been investigated. The main advantages of this technique are: low process temperature, localised heating, multi material applicability, partial reversibility, and partial biocompatibility. In proposed technique, the adhesive is deposited on the substrate and then the micro-component is brought and placed at the requested position. Two kinds of adhesives – Polyurethane foil and hot melt glue on the Polyethylene base were investigated /5/.

4.4 Automation

A flexible micromanipulation system with stereoscopic imaging was designed, developed and tested aiming to automate the function of a commercially available micromanipulator (Kleindiek Micromanipulator MM3A) and optimize the automation of pick-and-place tasks in the real environment.

5. Contact

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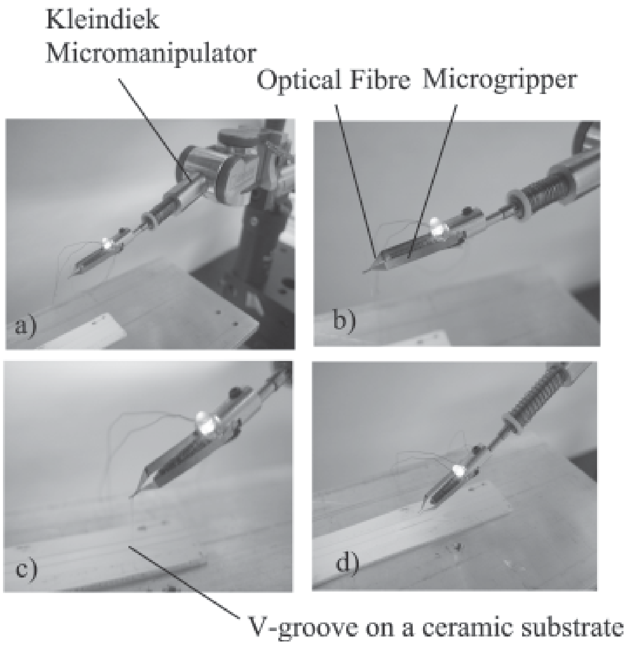

Fig. 10: Acquired images by the external CCD cameras (left and right camera respectively)

6. Acknowledgment

This FP6 Marie Curie Research Training Network "Advanced Methods and Tools for Handling and Assembly in Microtechnology" has been funded by the Commission of the European Community, Contract no MRTN-CT-2003-504826

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42. Mednarodna konferenca o mikroelektroniki, elektronskih sestavnih delih in materialih – MIDEM 2006
42nd International Conference on Microelectronics, Devices and Materials – MIDEM 2006

13.09. 2006 – 15.09. 2006, Hotel Svoboda, Strunjan, Slovenija

Dvainštirideseta mednarodna konferenca o mikroelektroniki, elektronskih sestavnih delih in materialih – MIDEM 2006 nadaljuje uspešno tradicijo mednarodnih konferenc MIDEM, ki jih vsako leto prireja MIDEM- Strokovno društvo za mikroelektroniko, elektronske sestavne dele in materiale.

Na konferenci je bilo predstavljeno 55 rednih in 7 vabljenih predavanj v petih sekcijah in delavnici na temo Mikro/nano-elektro-mehanski sistemi (MEMS in NEMS).

Na konferenci so bili predstavljeni najnovejši dosežki na naslednjih področjih:

- Fizika elektronskih elementov, modeliranje in tehnologija
- Debeli in tanki filmi
- Elektronika
- Optoelektronika
- Integrirana vezja

To leto je bila v okviru konference že devetič zapored organizirana enodnevna delavnica, tokrat na temo MEMS in NEMS, ki jo je letos organiziral LMSE - Laboratorij za mikrosenzorske strukture in elektroniko, Fakulteta za elektrotehniko, UL, Ljubljana. Na delavnici je 6 vabljenih predavateljev predstavilo nekatere najnovejše dosežke s področja načrtovanja, simulacije, izdelave in testiranja različnih tipov senzorjev, aktuatorjev in ostalih struktur, izdelanih v MEMS in NEMS tehnologijah. Poleg vabljenih predavanj je bilo v rednem delu delavnice predstavljeno še 9 izbranih prispevkov s tega področja.

42nd International Conference on Microelectronics, Devices and Materials is maintaining the tradition of successful annual international meetings organized by MIDEM - Society for Microelectronics, Devices and Materials, Ljubljana, Slovenia.

This year, 55 regular papers and seven invited presentations, in conference five sessions and in joint workshop on MEMS and NEMS, were presented.

The conference presentations were grouped in the following sessions:

- *Device Physics, Modeling and Technology*
- *Thick and Thin Films*
- *Electronics*
- *Optoelectronics*
- *Integrated Circuits*

Joint workshop was this year devoted to the advancement of high technologies in the field of Micro/Nano-Electro-Mechanical Systems (MEMS and NEMS). Six invited and nine regular speakers presented the selected topics covering design, simulation, fabrication and testing of different types of sensors, actuators and other structures, fabricated in MEMS and NEMS technologies. Workshop was this year organized by LMSE - Laboratory of Microsensor Structures and Electronics, Faculty of Electrical Engineering, UL, Ljubljana.

Letos so bili podani naslednji vabljeni referati:

M.Pizzi, V.Konyachkine, V.Lambertini, N.Li Pira, M.Paderi, L.Belforte, M.Pacifico
Centro Ricerche Fiat, Orbassano, Torino, Italy
MEMS/NEMS Technologies at Centro Ricerche FIAT

S.Kolb
Infineon Technologies AG, Munich, Germany
MEMS Products and MEMS Technologies for Automotive Applications at Infineon

D.Mihailović
Jozef Stefan Institute and Postgraduate School, Ljubljana, Slovenia
MoSIx Nanowires: a User-Friendly New Nano-material for Nanosensors and NEMS

Kris Baert, Chris Van Hoof
IMEC, Heverlee, Belgium
Integrated Microsystems

Androula G. Nassiopoulou
IMEL/NCSR Demokritos, Athens, Greece
Porous Silicon for Sensors and On-chip Integration of RF Components

C.Iliescu
Institute of Bioengineering and Nanotechnology, Singapore
Microfluidics in Glass : Technologies and Applications

W.Brenner, F.Suemecz, D.Andrijasevic, I.Giouroudi, K.Malecki
Institute of Sensor and Actuator Systems ISAS, Vienna, Austria
Advanced Methods and Tools for Handling and Assembly in Microtechnology – A European Approach in the Frame of The FP6 Marie Curie Research Training Network Assemic

Pred konferenco je bil izdelan zbornik referatov v obsegu 25 ap (približno 400 strani), ki je podobno urejen kot prejšnja leta.

Nekaj statističnih podatkov:

- Število udeležencev: 63, iz tujine 8
- Število referatov v zborniku: 55, iz tujine 8

Following invited papers were presented on this conference:

M.Pizzi, V.Konyachkine, V.Lambertini, N.Li Pira, M.Paderi, L.Belforte, M.Pacifico
Centro Ricerche Fiat, Orbassano, Torino, Italy
MEMS/NEMS Technologies at Centro Ricerche FIAT

S.Kolb
Infineon Technologies AG, Munich, Germany
MEMS Products and MEMS Technologies for Automotive Applications at Infineon

D.Mihailović
Jozef Stefan Institute and Postgraduate School, Ljubljana, Slovenia
MoSIx Nanowires: a User-Friendly New Nano-material for Nanosensors and NEMS

Kris Baert, Chris Van Hoof
IMEC, Heverlee, Belgium
Integrated Microsystems

Androula G. Nassiopoulou
IMEL/NCSR Demokritos, Athens, Greece
Porous Silicon for Sensors and On-chip Integration of RF Components

C.Iliescu
Institute of Bioengineering and Nanotechnology, Singapore
Microfluidics in Glass: Technologies and Applications

W.Brenner, F.Suemecz, D.Andrijasevic, I.Giouroudi, K.Malecki
Institute of Sensor and Actuator Systems ISAS, Vienna, Austria
Advanced Methods and Tools for Handling and Assembly in Microtechnology – A European Approach in the Frame of The FP6 Marie Curie Research Training Network Assemic

Conference proceeding of volume 23 app. (approximately of 400 pages) was published prior to conference, organized similar as previous years.

Some statistical data:

- *number of participants: 63, 8 from foreign countries*
- *number of contributions in proceedings: 55, 8 from foreign countries*

Ljubljana, september 2006

D. Vrtačnik, S. Amon

Dejavnosti na področju nanoelektronike v Sloveniji
Activities related to the field of nanoelectronics in Slovenia

/ order of appearance: by time of contribution arrival ! /

A. R&D institutions in Slovenia

LMSE, FEE UL - Laboratory of Microsensor Structures and Electronics, Faculty of Electrical Engineering, University of Ljubljana, Trzaska 25, 1000 Ljubljana, Slovenia

LMSE is active in research and development of silicon devices, sensors and micro/nano electromechanical systems (MEMS, NEMS). Internal properties and external characteristics of microstructures are studied using analytical and computer modeling. Processing technologies, together with micromachining available in LMSE allows investigations of basic technological processes and microstructures (mask design and fabrication, photolithography, diffusion, thin films depositions, cleaning, an/isotropic etching etc.). Design and fabrication of active and passive sensor structures e.g. photosensors, pressure sensors, temperature sensors, radiation sensors, sensors for nuclear physics, 3D structures such as piezoelectric and piezoresistive micro/nano sensors and actuators, micro/nano tips etc. is performed. Technological research is supported by appropriate measurement equipment and characterization techniques.

LMSE as an independent university lab offering complete research and development services in the field of microsensor and microactuator devices, from theoretical analysis and simulation to development of test structures and prototyping, their characterization and optimization. Partial R&D services are also available.

LMSE is open for any kind of cooperation with other laboratories and industry. Contact person: prof.Slavko Amon, email: slavko.amon@fe.uni-lj.si

More info on web: http://lms.fe.uni-lj.si/

Plasma Laboratory, Department F4, Jozef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia

Lab has developed methods for synthesis of large quantities of meta-oxide nanowires as well as methods for modification nanomaterials. The method for synthesis of nanowires is based on oxidation of metals under extremely non-equilibrium conditions found in fully dissociated cold oxygen plasma. Details are found in our recent paper:

A method for the rapid synthesis of large quantities of metal oxide nanowires at low temperatures, Mozetic M, Cvelbar U, Sunkara MK, Vaddiraju S, ADVANCED MATERIALS 17 (17): 2138-+ SEP 5 2005

Modification of surface as well as bulk properties of nanomaterials (for instance wettability, functionalization, structure…) is peformed by exposure of these materials to a well-defined flux of different radicals. The radicals are created in low-pressure plasmas of different gases or gas mixtures.

Contact persons:
Dr. Uros Cvelbar (uros.cvelbar@guest.arnes.si)
Prof. dr. Miran Mozetic (miran.mozetic@guest.arnes.si)

LEN- Laboratory for epitaxy and nanostructures, University of Nova Gorica, Vipavska 13 Nova Gorica, Slovenia

At the core of activities of LEN are electronic, optical and structural properties of thin organic semiconductor layers. Current activities include studies of initial stages of growth of pentacene, rubrene and 3,4,9,10-perylenetetracarboxylic dianhydride on nanostructured substrates such as vicinal sapphire [0001] surface. We are active also in the area of in situ measurements of charge carrier mobility during growth of pentacene as a constituent of organic thin film transistors. In the area of organic solar cells we are exploring venues to improve the device efficiency through the use of doped polymers as active layers.

The available equipment and related expertise include scanning probe microscopy, organic molecular beam epitaxy, electric transport measurements and synchrotron radiation photoelectron spectroscopy.

LEN is open for any kind of cooperation with other laboratories and industry.

Contact Person: Prof.Gvido Bratina

More info on web:
http://www.p-ng.si/en/research/epitaxy-nanostructures/

Department for Surface Engineering and Optoelectronics, Vacuum Laboratory, Jozef Stefan Institute, Ljubljana

For several years, the lab was active in the field of optoelectronics and R&D work related to professional vacuum electron tubes. In the last few years, studies of novel nanostructured materials became important since they open wide potential benefits compared to present day materials and solutions. The motivation was triggered by novel inorganic nanotubes and nanotube films, synthesised last years at Jozef Stefan Institute

General motivation for the research of electron field emission from nano-structured materials could be defined simply by: "obtaining a high value of field emission (FE) current at moderate electric field, being stable enough to apply them in various vacuum opto-electronic devices". There are two main areas relating field emission and nanoelectronics. The first area is to realize a point-like electron source which is a key element for electron guns being able to generate a few nm diameter electron beam at only a few kV. It is known that when electrons provoke chemical activation of the polymer resist, this may lead to much narrower diameter of exposed line that can be achieved by UV lithography. This topic is thus directly related to technologies offering further miniaturization of electronic circuits. The second field is Flat Broad Area Field Emission Cathodes (FBAFEC) having some specific advantages compared to thermionic cathodes: electrons are emitted at room temperature, their energy spectrum is narrow, emission current from individual site manifests an extremely high local current density. Potential application of FBAFEC is great, ranging from ultra-fast electronic circuits, x-ray tubes to flat electronic displays.

The specific advantage of techniques developed in the lab is visualization of the emitting site pattern, realized by spreading electron paths emerging from a point source onto a distant luminescent screen, deposited inside a glass envelope of the FEM. Besides the emitting pattern, the electron field emission current-voltage relation of the emitting tip could be also determined.

The lab cooperates with a few groups worldwide and is open for further cooperation.

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NANO ELECTRONICS OF ORGANIC STRUCTURES, University of Maribor, Faculty of Civil Engineering, Maribor, Slovenia and Josef Stefan Institute, Ljubljana, Slovenia

LED's, FET's, and solar cells manufactured from organic semiconductors are already proven as novel nanostructured *electronic devices* /1/. It has been shown recently, that the organic semiconductor structures are very promising materials also in the area of *spintronic* research, where the ways to manipulate also the spin of a particle in addition to is charge in semiconductors are intensively investigated for information purposes, eventually leading to substantially improved performance and functionality of today's electronic devices /2/.

The investigation of capacitance-voltage characteristics of organic semiconductor nanostructures has revealed that at the cathode/organic interface a large, bias dependent, charge density is induced /3, 4/. This charge density represents an effective tunneling barrier that may represent an efficient means for spin polarization upon the injection of electrons from the ferromagnetic metal into the organic semiconductor /5/. It was recently shown that the spin polarization current critically depends on details of the disordered interlayer, its width and electrical properties that can be to a certain degree changed with ionized cluster beam technique. Likewise, it was recently established / 6, 7/ that the tunneling barrier of a thin electrically charged interfacial layer sandwiched between the metal and the *organic semiconductor* could serve as an important means for the injection of spin-polarized carriers.

Electron moving under electric field within the semiconductor creates internal magnetic field, which tends to align spins scattered at defects and impurities; accounting for the fluctuating magnetic field the spins that are on the average perpendicular to the electric current survive the charge transport /8/. Based upon our findings /4/ that at the bilayer metal/organic semiconductor structure a very strong gradient of the internal electric field at the organic/organic junction may exists, a question arises as to what extent such an electric field discontinuity may affect the polarization of spins.

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LMFE – LABORATORY OF MICROELECTRONICS

LMFE – LABORATORY OF MICROELECTRONICS at the Faculty of Electrical Engineering, University of Ljubljana is present with activities in microelectronic design and production since 1975. LMFE has long term cooperation with world leading manufacturer of ASICs. From national aspects, LMFE provides microelectronic technology platform to implement the physically smallest possible solutions everywhere.

Laboratory's major activities are focused on research of new integrated sensors structures mainly pressure, motion, temperature and liquid-flow sensors. The excellent results has been achieved in the area of acceleration measurement using capacitive principle (0.02G), precise temperature measurement (±0.1°C), bolometer and termopile sensors, all integrated into application specific systems on silicon including analog front-end and digital signal processing. We are doing basic research work and processing using in-house processing capabilities, where experiments based on CMOS technology. Through our core facility, LMFE provides for our partners open access to tools and expertise needed to explore the continuum from scientific discovery to the integration of sensors structures into the complex system on chip LMFE is European leading laboratory having the best solutions for very low signals processing as was used for gyro-system and precise current measurement in automotive industry.

One of the well discovered areas in the LMFE lab is integrated opto-array systems on chip. A number of different solutions have been completed for motion control. Current research based on system integration of a large number of smallest possible pixels at maximal available fill factor while looking for optimal pixel response for different light wavelength. We are focusing on technology based solution to find out low capacitive junctions, to reduce reflections without effecting the sensitivity reduction and on design based solutions to guaranty low pixel leaking and optimization of all parameters of interest. So, CMOS technology allows the capture and processing of an image on a single chip. Target processing for this kind of products are short channel (currently 120nm or 90nm) technologies.

The technologies research for new materials is crucial for LMFE programs for future integrated sensors. The nanotechnologies research is therefore the top priority in LMFE research program for next years and will be combined to all other technologies useful in microelectronic products.

The MOEMS structures are also in our research program. The basis for micromechanical system analysis is IntelySuite software package, which was used for micro-cantilever modeling and behavioral analysis. All those activities help LMFE contributing to national high-tech development while providing an invaluable resource for industries.

Contact person: Prof.Janez Trontelj, email: Janez.Trontelj1@guest.arnes.si

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HIPOT-RR

HIPOT-RR raziskave in razvoj tehnologij in sistemov, d.o.o. (in English: HIPOT-R&D Research and Development in Technologies and Systems)

Addresses: Trubarjeva 7, 8310 Šentjernej, Slovenia and c/o Josef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia

The HIPOT-RR Company is small size research organisation, which is responsible for research, development and technology transfer in the fields of hybrid microelectronics, sensors, (mostly sensors of mechanical quantities) and electronics. Research activities include application of silicon devices and ceramic materials in sensors and actuators, micro electro-mechanical systems, assembling and packaging technologies, design, multifunctional modelling and simulation, characterisation and reliability.

Researchers have experience also in application of nanoscale devices, design and fabrication devices based on (multi)functional materials with nanoparticles, and characterisation and use functional nanoscale layers.

HIPOT-RR works traditionally in harmony with the company HYB in Šentjernej and the Electronic ceramics department at Jožef Stefan Institute in Ljubljana. In some research project HIPOT-RR works also with the Laboratory of Microsensor Structures and Electronics, Faculty of Electrical Engineering, University of Ljubljana, and with other research institutions and technical associations both in Slovenia and Europe.

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Electronic ceramics department at Josef Stefan Institute

Address: Jamova 39, 1000 Ljubljana, Slovenia

The Electronic Ceramics Department is one of the research departments at Josef Stefan Institute. The Jožef Stefan Institute (JSI), founded 1949, is the biggest public research institute in Slovenia. About 800 people are employed by the Institute and about 400 employed are Ph.D. scientists. The main research areas are physics, chemistry, molecular biology and biotechnology, information technologies, reactor physics and technology, energy and environment.

The Electronic Ceramics Department is active in the research of the synthesis, properties and applications of materials for electronics, mainly multifunctional materials and structures. The materials of interest include ceramic piezoelectrics, ferroelectrics, relaxors, conductive oxides and materials for solid-oxide fuel cells (SOFCs). The emphasis is on controlling the properties governed by the chemical composition and structure on the nano-, micro- and macro-levels. The Electronic Ceramics Department is well equipped for powder synthesis, powder processing, technologies for shaping and sintering of ceramics and other materials (spin-coating, tape casting, screen printing, pressing, hot pressing, thick-film technology …), structural (XRD) and microstructural characterization (SEM/EDS, WDS, TEM/EDS), thermal analysis equipment (TG/DTA/EGA, DSC), and for electrical characterisation.

The research group of the Electronic Ceramics Department has got about 15 years of experience in the field of Chemical Solution Deposition (CSD) of ceramic thin films and the synthesis of (nano) particles of multi-component systems.

The researchers of the Electronic Ceramics Department work in many international and national research projects and is open to cooperate with other partners.

Contact person: Prof.Marija Kosec, email: marija.kosec@ijs.si

Department of Complex Matter, Josef Stefan Institute, Ljubljana, Slovenia,

Head: Prof. Dragan Mihailovic, M.A., Physics, (1979), University of Oxford, Doctorate: D.Phil., (1983), University of Oxford, U.K. Group leader and Chief Scientist at the J.Stefan Institute, Ljubljana, Slovenia, Professor at the Department of Mathematics and Physics, University of Ljubljana, Vice-Dean and Professor at the Josef Stefan International Postgraduate School.

Prof.Mihailovic presently leads a mixed experimental-theoretical group within the department of Complex Matter encompassing a variety of research fields, ranging from the synthesis of new materials to fundamental investigations of elementary excitations, self-organising behaviour and adaptive functionality in complex systems. These include anything from nano-biosystems and biomolecules to superconductors and nanowires. The experimental methods used are suitably diverse, from synthetic chemistry to biomedicine, femtosecond laser spectroscopy and magnetometry. The experimental research within the department is strongly supported by theory. Recently, the research activities on new nanomaterials and nanotechnology, such as nanolithography were greatly expanded. Apart from fundamental research, some viable applications have also emerged, particularly in the field of new nanomaterials such as Mosix nanowires.

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MIDEM Society

Society for Microelectronics, Electronic Components and Materials - MIDEM , located in Ljubljana, Slovenia, is an international society integrating experts from all over the world, working in the field of microelectronics, electronic components and materials.

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http://www.midem-drustvo.si/

B. Companies

There are many industrial companies in Slovenia with expertise in microelectronic devices, circuits, sensors, MEMS etc., with R&D as well as production potentials also in nanoelectronics. Here are just a few examples:

HYB

Name: HYB proizvodnja hibridnih vezij, d.o.o. (in English: HYB Hybrid Circuits and Sensors)
Address: Trubarjeva 7, 8310 Šentjernej, Slovenia

The HYB Hybrid Circuits and Sensors Company is a medium size enterprise with experience in the production of custom thick-film hybrid circuits from 1972 and experience in the production of pressure sensors from 1986. HYB is renowned European designer and producer of pressure sensors for medical and industrial applications. The company is capable to design, construct, develop and manufacture pressure sensors with silicon or ceramic sensor elements and required signal conditioning electronic circuit.

Research and development activities include also nanoelectronic application in following: integration of sensors, actuators, MEMS and NEMS; electronic circuits for sensors and actuators; smart sensors and structures; wireless sensor networks; sensors and systems powered by smart energy (energy harvesting, energy storage, energy management).

web: http://www.hyb.si/

IDS

IDS is a small semiconductor company specialized in RFID-enabled ASSPs, ASICs and IPs for current and emerging wireless and sensor applications with low power consumption. Company engineering center is located in Ljubljana, Gerbičeva 50, and Sales office in Dresden. Company roots are back in 1982. Today IDS employs a group of well experienced and highly motivated researchers and a group of young, creative and experienced system design engineers.

Company major activities are based on research work discovering new integrated sensors structures mainly pressure, motion, temperature, liquid-flow, micro-magnetic integrated structures and during the last couple of years - activities focused on integrated UHF frequency components and systems like tags and RFID readers. The impressive results has been achieved integrating airbag system for acceleration measurement using micro-machined capacitive principle, on a design of low-G sensor ASIC ($< 1e/\sqrt{Hz}$ noise) and highly precise temperature measurement used in Smart Active Label (SAL). IDS are doing basic research work and design for Application Specific Integrated Circuits ASICs. Through our core activity, IDS provides for our customers scientific discovery and circuit design including integration of sensors structures into the complex system on a chip. IDS is interested in nanotechnologies research as a source of new integrated sensors.

Besides the company leading area of interest in RFID, the activities are well grounded on designing the Scan-Field Opto-Arrays micro-structures, integrated with complex –

mix analog/digital system on chip. A number of different interpolators - sine/cosine to digital converters have been completed and are in serial production. Micro-machined based research work and other activities are based on co-operation with external partners and resources. IDS – a knowledge based company has a long term relationship with strategic semiconductor and OEM partners.

IDS d.o.o.
Gerbiceva 50
1000 Ljubljana, Slovenia
web: www.ids.si

Contact person: Andrej Vodopivec

RLS

RLS is a SME active in the motion sensing and control market for 15 years. RLS experience and knowledge combined with innovative ideas allows to develop advanced products based on micro/nano electronics.

With a vast team of experienced sales engineers our partner company Renishaw and our other distributors provide leading sales support for our products worldwide.

Typical products:

- Angular magnetic encoder ICs
- A range of encoder chips for on-axis measurement Interpolators
- Analogue interpolators for optical encoders
- Angular magnetic encoder modules
- Easy to integrate PCBs for up to 13 bit resolution Photodiode arrays
- Standard and custom designed photodiodes and modules
- Magnetic rotary encoders
- Non-contact magnetic rotary encoders

Recent RLS Reference: World's first 13 bit magnetic rotary encoder is NASA product of the month

RLS' new 13 bit magnetic sensor for rotary and angular positioning control has been named 'Product of the Month' for November 2006 by NASA Tech Briefs magazine, an official publication of the USA's National Aeronautics & Space Administration (NASA).

The magazine is the USA's widest read engineering magatzine, with a circulation in excess of 190,000, and reported to its readers that the RLS sensors provide 8,192 counts per revolution and are available in chip, chip-on-board, and ready-to-mount packaged versions.

In its description of the sensors, NASA Tech Briefs stated that they have a solid-state, non-contact design featuring an integrated circuit chip that senses the position of a separate two-pole permanent magnet. The sensors are reported as being suitable for difficult environmental requirements, providing an operational range of -40 °C to +125 °C, and shock and vibration resistance. Friction-less, low-inertia operation enables 0.3° positioning accuracy at speeds to 30,000 rpm.

The sensors are available in models providing absolute, incremental, analogue, or digital outputs, as well as simultaneous SSI and incremental output. Chip and chip-on-board models allow integration into machinery and equipment designs, whilst packaged versions enclose the chip and electronics in metal cases. NASA Tech Briefs noted that the enclosed units are used in rugged applications and environments, with waterproof, fully encapsulated versions also available.

more on web: http://www.rls.si/

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Prepared by:
Prof. Slavko Amon

LMSE, FE UL

Ljubljana, Dec, 8, 2006

Informacije MIDEM

Strokovna revija za mikroelektroniko, elektronske sestavine dele in materiale

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NAVODILA AVTORJEM

Informacije MIDEM je znanstveno-strokovno-društvena publikacija Strokovnega društva za mikroelektroniko, elektronske sestavne dele in materiale - MIDEM. Revija objavlja prispevke s področja mikroelektronike, elektronskih sestavnih delov in materialov. Ob oddaji člankov morajo avtorji predlagati uredništvu razvrstitev dela v skladu s tipologijo za vodenje bibliografij v okviru sistema COBISS.
Znanstveni in strokovni prispevki bodo recenzirani.

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3. Naslov dela v angleščini.
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5. Uvod, glavni del, zaključek, zahvale, dodatki in literatura v skladu z IMRAD shemo (Introduction, Methods, Results And Discsussion).
6. Polna imena in priimki avtorjev s titulami, naslovi institucij in firm, v katerih so zaposleni ter tel./Fax/Email podatki.
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Ostali prispevki, kot so poljudni cčlanki, aplikacijski članki, novice iz stroke, vesti iz delovnih organizacij, inštitutov in fakultet, obvestila o akcijah društva MIDEM in njegovih članov ter drugi prispevki so dobrodošli.

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Informacije MIDEM

Journal of Microelectronics, Electronic Components and Materials

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Authors should suggest to the Editorial board the classification of their contribution such as : original scientific paper, review scientific paper, professional paper…
Scientific and professional papers are subject to review.

Each scientific contribution should include the following:

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2. Key Words (5-10 words) and Abstract (200-250 words), stating how the work advances state of the art in the field.
3. Introduction, main text, conclusion, acknowledgements, appendix and references following the IMRAD scheme (Introduction, Methods, Results And Discsussion).
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6. Slovene authors writing in English language must submit title, key words and abstract also in Slovene language.
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Other types of contributions such as popular papers, application papers, scientific news, news from companies, institutes and universities, reports on actions of MIDEM Society and its members as well as other relevant contributions, of appropriate length , are also welcome.

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2. Illustrations should be in black on white paper. Their width should be up to 7.5 or 15 cm. Each illustration, table or photograph should be numbered and with legend added. Illustrations, tables and photographs must not be included in the text but added separately. However, their position in the text should be clearly marked.
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