Project III. 2: MECHANICAL AND CHEMICAL SENSORS

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- EU, IST, IP, GOODFOOD, “Food Safety and Quality Monitoring with Microsystems”, Contract N^o 508774, 1/1/2004-30/6/2007
- GSRT-PENED 03ED630, “Micromachined chemical sensors for controlling food safety and quality”, 1/11/2005-1/11/2008
- GSRT- ENTER 05EP032, “Development of MOSFET type chemical sensors for wireless sensor networks”, 1/12/2005-1/12/2007
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Research orientation:

- Development of micromachining processes for the realization of novel chemical and mechanical sensors.
- Development of low power silicon sensors based on new materials and new processes
- Design, fabrication and testing of microsystems using silicon sensors.
- Realization of sensors for specific industrial applications with emphasis on medical, food and automotive fields.

Main results in 2005:

The main results obtained in 2005 within the different tasks of the project are given below.

Task 1 Alternative micro-hotplate design for low power metal-oxide (MOX) sensor arrays

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One major requirement for the fabrication of low power sensors, especially for integration in arrays, is the reduction of thermal losses. This can be achieved by the fabrication of the active elements of the sensors on suspended structures (micro-hotplates). Two different types of micro-hotplates have been used in the literature: The *closed-type membrane*, where the membrane overlaps the silicon substrate along its periphery and the *suspended-type* membrane, where the membrane is supported on the Si substrate by means of supporting beams. In the latter case, the thermal losses to the substrate take place only through the supporting beams, and thus they are minimized compared to the closed type membrane.

During this year we performed design and optimization of suspended micro-hotplates, using two alternative technologies: a) *silicon-nitride technology* (fig III.2.1a) and b) *porous silicon Technology* (fig III.2.1b). Release of the micro-hotplates is performed by dry or wet techniques. There is one important advantage to use porous silicon as material for the micro-hotplates. Since the thermal conductivity of porous silicon is very low, *thicker* micro-hotplates can be fabricated, with improved mechanical characteristics, compared to the thin and more fragile nitride/oxide membranes. This permits us to implement *alternative* micro-hotplate designs (fig III.2.2a), with two or even one supporting beam (fig. III.2.2b).

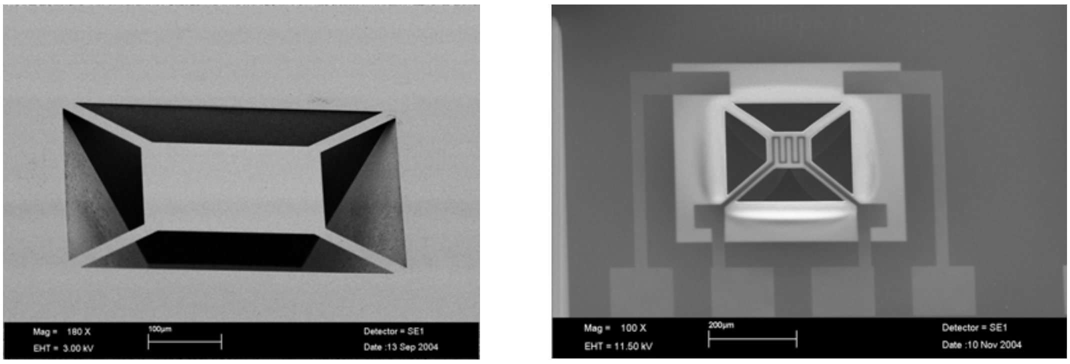

Fig. III.2.1: (a) *SEM image of a silicon nitride membrane released with wet etching of the substrate in TMAH solution,* ***(b)*** *SEM image of a Porous Silicon micro-hotplate, with integrated heater and electrodes, released with dry etching. Both micro-hotplates have four supporting beams.*

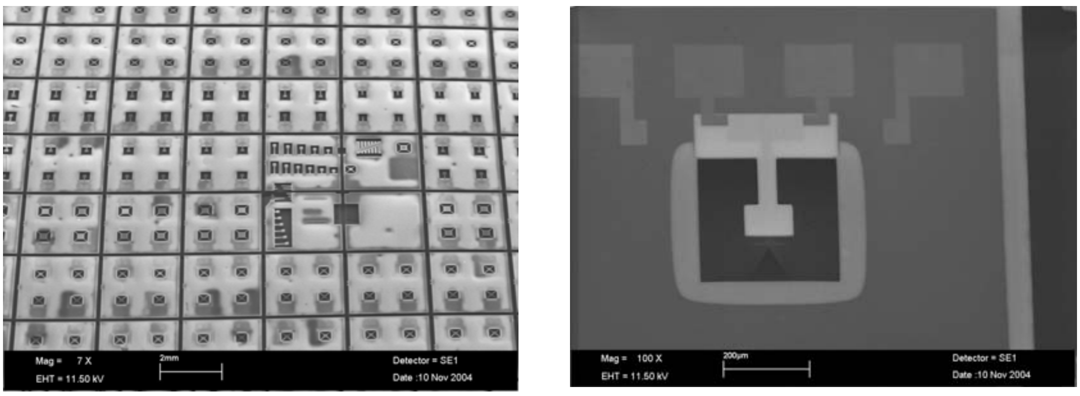

Fig. III.2.2: (a) *Fully processed wafer that contains various alternative micro-hotplate designs with four, two and one supporting beam, for improved thermal isolation,* ***(b)*** *SEM image of a Porous-Silicon cantilever-type micro-hotplate, with one supporting beam.*

Task 2 Electronic ASIC for MOX Chemical Sensors

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The correct operation of metal oxide (MOX) sensors requires precise control over the operating temperature of the device simultaneously with the read-out of the chemically sensitive resistance. To this end, an electronic ASIC (fig. III.2.3) has been developed able to interface a quad gas sensor array to a microcontroller and thereon to a PC or E-nose system. The chip contains in a single IC all the necessary analog electronics to operate four MOX sensors while the control logic will be implemented on the microcontroller (fig. III.2.4). The ASIC has been successfully implemented in a single-poly, double-metal, 0.7μm CMOS process (fig. III.2.3) and first measured results are in agreement with simulated values. Provision has been taken for both polysilicon and Pt heater control.

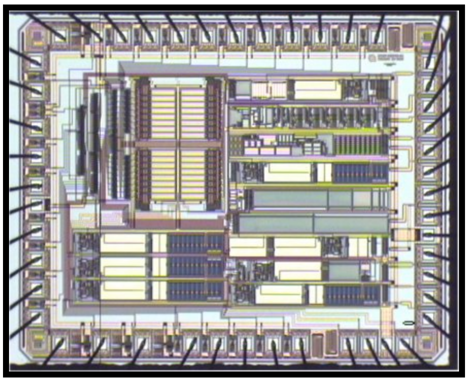

Fig. III.2.3: *Fabricated ASIC chip*

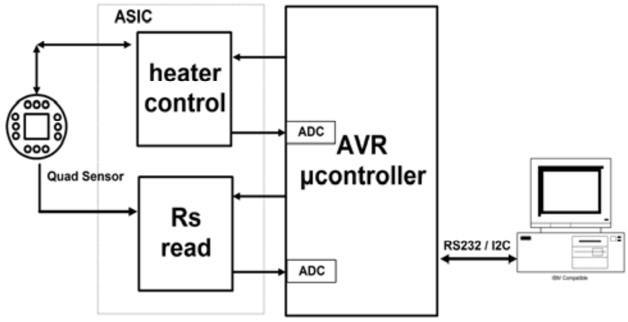

Fig. III.2.4: *Schematic of the MOX electronic control system.*

Typically the sensitive element of MOX sensors consists of a semiconductive metal-oxide layer whose resistance is a function of the concentration of specific gases in the sensor ambient and could range from a few hundred Ohms up to several MOhms, depending on the catalytic material used. The read-out circuit measures the resistance of each sensitive element in the quad sensor array by forming a voltage divider between the sensor and one of the internal on-chip resistors. The signal is then filtered and amplified before being made available for off-chip sampling by one of the 10-bit ADCs of the AVR (fig. III.2.5). The temperature control circuit provides the necessary heating power to each of the four micro-heaters until they reach the ideal operation temperature. Heater resistances are known to vary between a few Ohms up to a few KOhms depending on the heater material used. Therefore, the output of each D/A converter is fed to a buffer, which either drives the heater directly or through a high current external buffer for the case of low resistance Pt heaters.

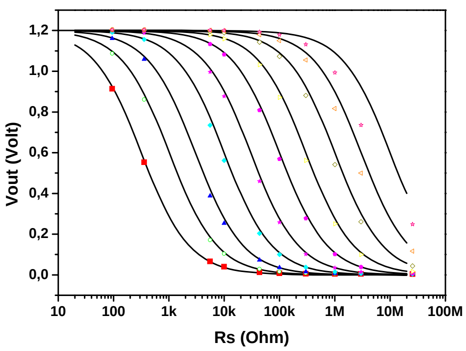

Fig. III.2.5: *Simulated R_s (line) versus measured R (symbols) resistance sweep (100 Ohm to 20 MOhm).*

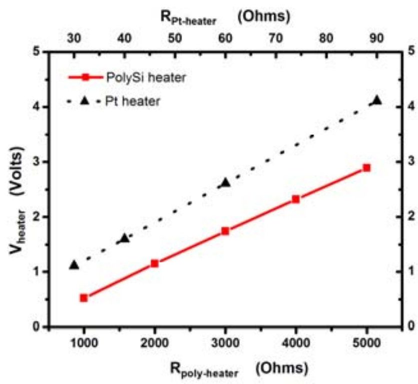

Fig. III.2.6: *Heater Resistance Circuit Response*

Task 3 Materials and processes for polymer based chemical sensors

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A simple process to deposit up to four polymers in selected areas to be used as sensitive layers in chemical sensor arrays was developed. The process (fig. III.2.7) is based on photolithographic processes and takes advantage of the balance between UV exposure dose, material tone and developers used. Furthermore, the discriminating capability of the constructed array is further expanded by engineering the sensing properties of two of the deposited polymers by selective exposure to DUV irradiation. The sensing properties of the deposited films in the array were characterized by monitoring in situ the volume expansion upon exposure to volatile organic compounds using white light interferometry (fig. III.2.8). The swelling properties of processed films were compared to the unprocessed ones for the purpose of examining the variation induced by the exposure and development circles and was found to be negligible. The lithographic process developed offers good control of the lateral dimensions and the thickness of the polymeric films and facilitates the fabrication of sensors operating with different transduction mechanisms including mass sensitive and stress induced bending chemical sensors.

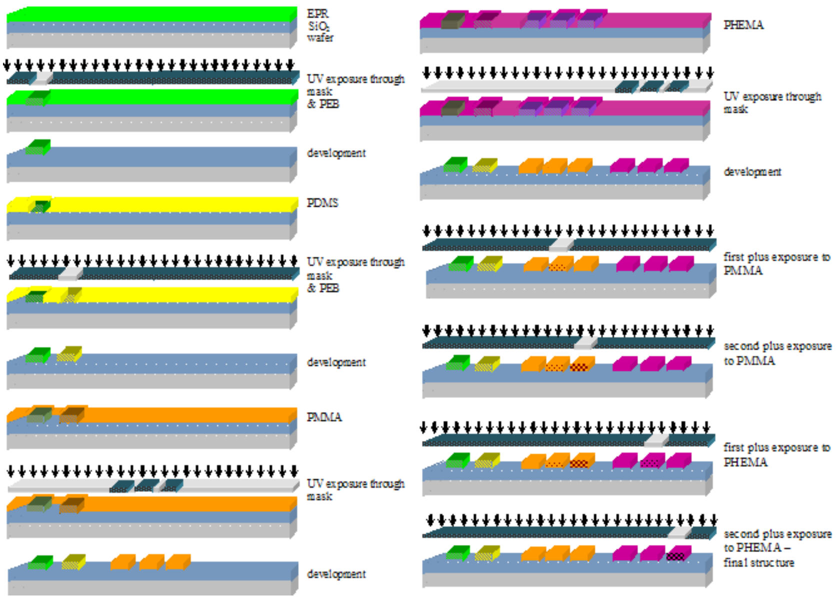

Fig. III.2.7: *Fabrication flowchart of the polymer array and processing*

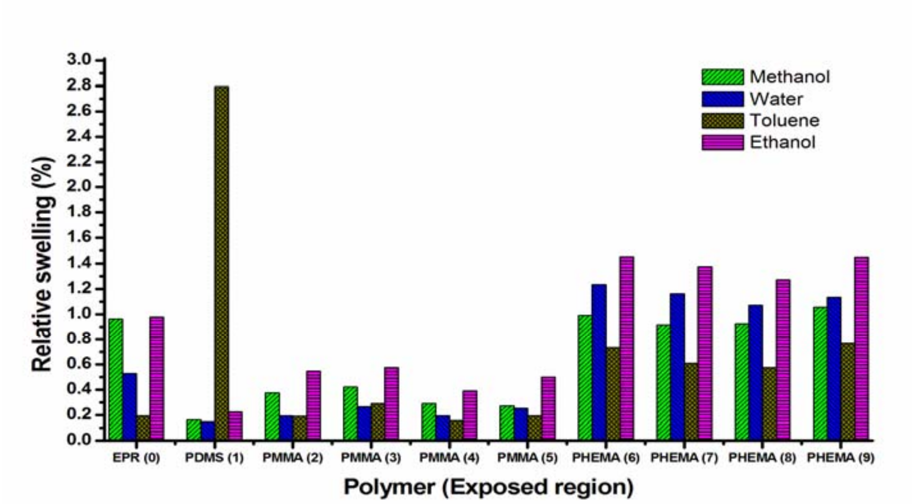

Fig. III.2.8: *Relative swelling of all polymer regions. The numbering of each polymer is in accordance with the configuration in fig. III.2.7.*

Task 4 Capacitive Type Sensors

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Pressure Sensors

In 2005 our industrial cooperation in the field of pressure sensors was carried on by involving the Institute in the development of a modified version of the capacitive-type-sensors (U.S patent 6,704,185) we produced since 1998 for new applications in the medical field.

Also in 2005 the stress induced buckling and sensor diaphragm behavior have been extensively studied by developing finite element models (see fig. III.2.9). This activity aims at evaluating the deflection of the pressure sensor diaphragm upon exposure to an external pressure differential also taking into account the stress induced due to the heavy doping with boron as well as the stress induced on the diaphragm from the various structural layers of the device.

Substantial efforts were also devoted to the fabrication of capacitive pressure switches based on the use of strain compensated heavily boron doped SiGeB diaphragms. The process relies on the silicon fusion bonding of two silicon wafers to seal the pressure sensor cavity. Pressure switches operating at different pressure thresholds have been successfully realized. Current flowing through the switch jumps over six orders of magnitude when its two plates come in contact (see fig. III.2.10)

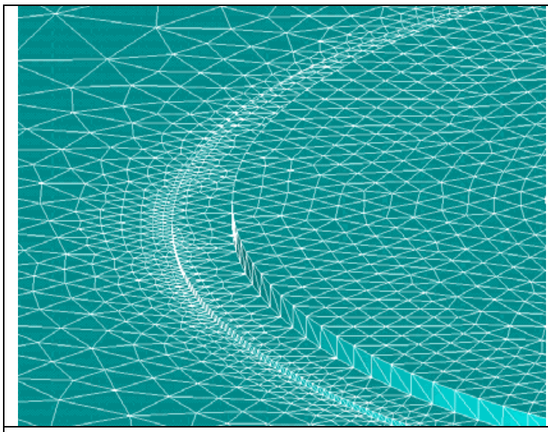

Fig. III.2.9: *Capacitive pressure sensor meshing*

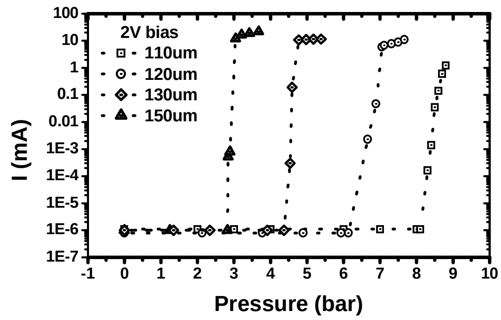

Fig. III.2.10: *Pressure switches operating in the 3 to 8 bar range*.

Capacitive DNA Sensors Arrays

The recent deciphering of all human genes by the Human Genome Project has made apparent that the genetic determinants for most, if not all common complex diseases, including heart disease, cancer and diabetes, hypertension, hypercholesterolemia could now be identified and evaluated. As a response to these worldwide research efforts in health care, we recently oriented part of our activities to the development of DNA detector arrays based on capacitive detection. The Capacitive DNA Sensors Arrays to be developed will exploit the surface stress changes and subsequent bending of ultra thin silicon membranes induced by the receptor DNA deposited on the membrane surface (see fig. III.2.11). The membranes seal the capacitor plates from the electrolyte solution thus enabling capacitive detection. These activities will be conducted within the frame of the European Project Micro2DNA.

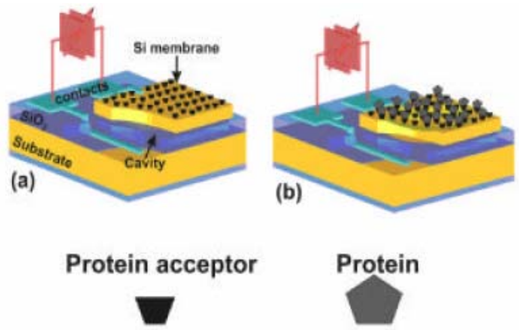

Fig. III.2.11: *Capacitive Biosensor principle*

PROJECT OUTPUT in 2005

PUBLICATIONS in INTERNATIONAL JOURNALS and REVIEWS

1. "Polymeric film characterization for use in bimorph chemical sensors", S. Chatzandroulis, D. Goustouridis, I. Raptis, Microelectron. Eng. 78-79 118(2005)
2. "Characterization of Polymer Layers for Silicon Micromachined Bilayer Chemical Sensors Using White Light Interferometry", D. Goustouridis, K. Manoli, S. Chatzandroulis, M. Sanopoulou, I. Raptis, Sens. Act. B 111-112, 549(2005)
3. "Alternative micro-hotplate design for low power sensor arrays", R. Triantafyllopoulou, S. Chatzandroulis, C. Tsamis, A. Tserepi, To appear in Microelectronics Engineering

PUBLICATIONS in CONFERENCE PROCEEDINGS

1. "Simulation of Capacitive type Bimorph Humidity Sensors", J. Fragakis, S. Chatzandroulis, D. Papadimitriou & C. Tsamis, J. Phys.: Confer. Series 10, 305-308,2005
2. "Characterization of polymers films for use in bimorph chemical sensor", S. Chatzandroulis, D. Goustouridis, I. Raptis, J. Physics: Confer. Series 10, 297–300(2005)

CONFERENCE PRESENTATIONS

1. "Alternative micro-hotplate design for low power sensor arrays", R. Triantafyllopoulou, S. Chatzandroulis, C. Tsamis, and A. Tserepi, Micro- and Nano-Engineering, MNE 2005, 19-22 September 2005, Vienna, Austria (Oral)
2. "Fabrication and characterization of Porous Silicon cantilevers for thermal sensors", S. Chatzandroulis, C. Tsamis and A. Tserepi, SPIE Conference on "Microtechnologies for the New Millenium 2005", 9-11 May 2005, Seville, Spain (Oral)
3. "Design and simulation of capacitive cantilever bimorph chemical sensors", J. Fragakis, S. Chatzandroulis, D. Papadimitriou and C. Tsamis, Eurosensors XIX, Barcelona, Spain, September 11-14, 2005 (Poster)
4. "Integrated interface IC for metal-oxide chemical sensor arrays", P. Robogiannakis, S. Chatzandroulis & C. Tsamis, Eurosensors XIX, Barcelona, Spain, Sept. 11-14, 2005(Oral)
5. "A simple process for the deposition of polymer arrays for use in chemical sensing", D. Goustouridis, M. Kitsara, S. Chatzandroulis, K. Beltsios, I.Raptis, Eurosensors XIX, Barcelona, Spain, September 11-14, 2005 (Poster)
6. "Sorption of vapors in thin polymer films studied by white light interferometry", K. Manoli, D. Goustouridis, S. Chatzandroulis, I. Raptis, M. Sanopoulou, 4^{th} Int. Conf. Instrumental Methods of Analysis (Iraklion, Greece, 10/2005) (Poster)
7. "UV irradiation as a means of engineering polymer swelling properties used in chemical sensors", D. Goustouridis, S. Chatzandroulis, I. Raptis, E.S. Valamontes, 4^{th} Int. Conf. Instrumental Methods of Analysis (Iraklion, Greece, 10/2005) (Oral)
8. "A Lithographic Polymer Process Sequence for Chemical Sensing Arrays", M. Kitsara, D. Goustouridis, S. Chatzandroulis, K. Beltsios, I. Raptis, Micro- and Nano-Engineering, MNE 2005, 19-22 September 2005, Vienna, Austria) (Oral)
9. "Capacitive Pressure Sensors And Switches Fabricated Using Strain Compensated SiGeB", S. Kolliopoulou, S. Chatzandroulis, D. Goustouridis, D. Tsoukalas, Micro- and Nano-Engineering, MNE 2005, 19-22 September 2005, Vienna, Austria) (Poster)

M. Sc. THESES

1. "Optimization of suspended microhotplates for micromechanical sensors", R.Triantafyllopoulou, SEMFE/NTUA, November 2005, Supervisor: C. Tsamis
2. "Sorption of vapors in thin polymer films studied by white light interferometry", K.Manoli, October 2005, Supervisors: I. Raptis, M. Sanopoulou
3. "Development and Characterization of Si/polymer bimorph chemical sensors", A.Batagiannis, September 2005, Supervisors: D.Goustouridis, D.Tsoukalas
4. "Reliability study of micromelectromechanical pressure sensors", I.Politis, July 2005, Supervisors S.Chatzandroulis, D.Tsoukalas.

DIPLOMA THESES

1. "Characterization and modeling of suspended microstructures for sensor applications", J. Fragakis, SEMFE/NTUA, June 2005, Supervisor: C. Tsamis
2. "Optimization of the mechanical properties of Porous Silicon for micromechanical applications", K. Anestou, SEMFE/NTUA, July 2005, Supervisor: C. Tsamis