PROJECT III.1A MECHANICAL AND CHEMICAL SENSORS

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Objectives

- 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.

Funding

Hellenic National Strategic Reference Framework (ESPA) 2007-2013, Contract no. MICRO2- 45, S. Chatzandroulis

MAIN RESULTS IN 2011:

In 2011, our main activities were focused on the following tasks:
A. Polymer based chemical sensor arrays
B. Capacitive Type Sensors

A: Polymer based chemical sensor arrays

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Chemoresistors and chemocapacitors have been successfully applied in a wide range of diverse applications with high sensitivity and detection limit, offering the advantage of very low power consumption and output signal acquisition-digitization. In order such a system to be suitable for real life applications it should be able to be fabricated with microfabrication technologies to form low-cost with high repeatability arrays, and be able to quantify the concentration of the analyte of interest in the presence of humidity. Furthermore the system footprint should be very small to allow for installation at any point in the area under monitoring and be compatible with the commercially available electronics for wireless control and data transmission (e.g. ZigBee protocol).

A promising approach in this direction is the development of a hybrid gas sensing module consisting of (a) polymer coated capacitive sensor array and (b) low power control and read-out electronics. In the present work, a compact gas sensing module comprised of 8-chemcapacitors and all the necessary commercially available electronics for control and data acquisition through PC is introduced, fig. 1. The chemocapacitor array is fabricated with standard microelectronics/ micromachining processes allowing for the realization of IDEs with critical dimension of 2μm and the formation of a well for controlled deposition of the polymeric solutions. The control and read-out electronics sub-module consists of an analog multiplexer for the sequential measurement of the chemcapacitors array elements, a capacitance to 24-bit converter and a USB to I^2C interface, fig. 2. The total size of the module is $10cm^2$ and could be further decreased by 50% through the

use of smaller package for the chemocapacitor array. The module is connected with a PC through a standard USB cable, that provides the necessary power for the operation of all electronic components. The electronic sub-module developed, presents a noise of ~0.2fF that leads to limit of detection for p-xylene to be ~30ppm and for toluene ~90ppm (200ppm is the Permissible Exposure Limit for Industry). The packaging of chemocapacitor array into a standard package allows for the use of the electronics sub-module in numerous applications where capacitors are used. Furthermore by employing the two channels available on AD7746 converter, further improvement of the limit of detections is expected.

In fig. 3 the dynamic responses of two chemocapacitors for small concentration of pure volatile organic compounds (toluene and xylene), as well as in the presence of 35% humidity are illustrated. The VOC removal lowers the capacitance, indicating the potential detection of such concentrations at real environment. By applying standard PCA algorithms over the responses of the chemocapacitors array, fig. 4, the detection of minute concentrations of those two analytes is illustrated.

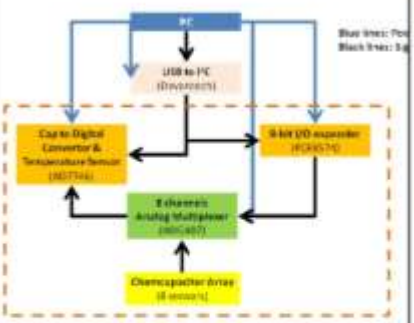

Fig. 1: *Block diagram of the gas sensing module and electronic interface with the PC for the data acquisition and data processing. For wireless data transmission, the USB to I^2C chip will be replaced by a wireless module.*

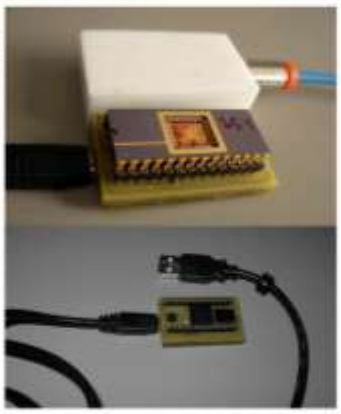

Fig. 2: *Photos from the gas sensing module: (top image) 8-sensor array and electronics and chamber, (bottom image) the read-out and control electronics sub-module.*

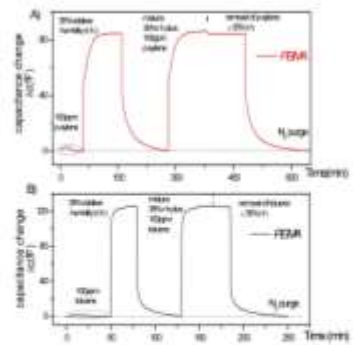

Fig. 3: *Dynamic responses of: (top graph) PBMA coated sensor upon exposure at 100ppm of p-xylene in the presence of humidity and (bottom graph) PEMA coated sensor upon exposure at 100ppm of toluene in the presence of humidity.*

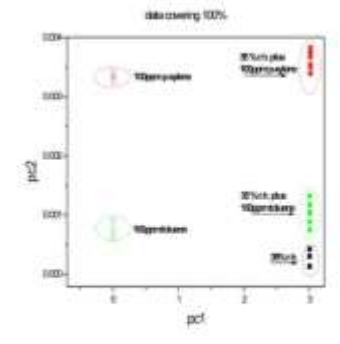

Fig. 4: *Principal Component Analysis (PCA) of the sensor equilibrium responses upon exposure at low concentrations of pure p-xylene and toluene and in the presence of humidity.*

**For more information please contact Dr. I. Raptis (e-mail:*raptis@imel.demokritos.gr*)*

B. Capacitive Type Sensors*

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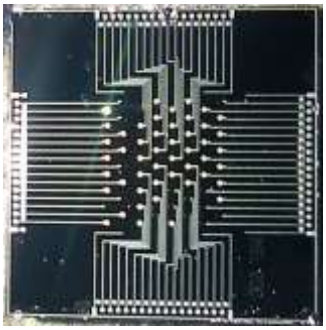
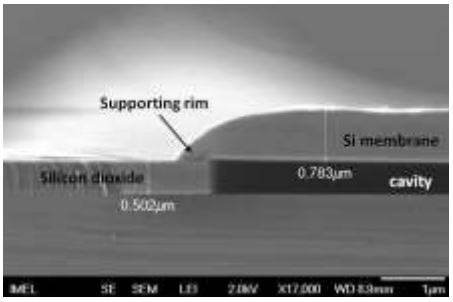
Micromechanical Capacitive DNA Sensor Arrays

A micromechanical capacitive biosensor array has been developed using a novel fabrication process. Each biosensor in the array consists of a flexible membrane and a fixed electrode implemented on the substrate. Probe molecules are immobilized on the membrane surface and the surface stress variations during biological interactions force the membrane to deflect and effectively change the capacitance between the flexible membrane and the fixed substrate. The array consists of 60 sensors and thus is suitable for parallel sensing. The process is characterized by the self-alignment of the sensitive flexible membranes and the use of silicon fusion bonding to fabricate the complete device.


(a)



(b)

Fig. 5: *(a) Microphotograph of a fully processed biosensor array and (b) SEM view of the circular membranes.*

To test the array performance 15mer synthesized thiol-modified oligonucleotide probes and corresponding targets were used. In order to immobilize the probes on the arrays, the latter were first functionalized with 3-glycidoxypropyl-tri-methoxy silane (GOPTS). Selective spotting of the probes on each membrane was then performed using the Laser Induced Forward Transfer (LIFT) technique. First experimental results indicate that the sensors are able to detect the hybridization of 10μM synthesized 15mer oligos (Fig. 6).

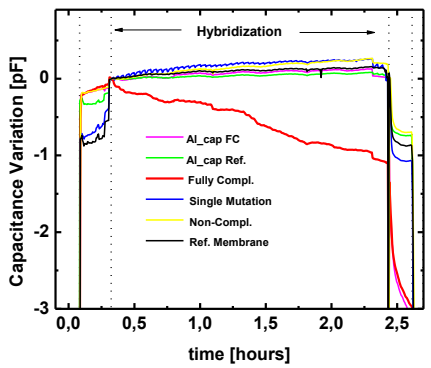


Fig. 6: *The average response of several sensing elements during DNA hybridization of the 15mer model oligos*

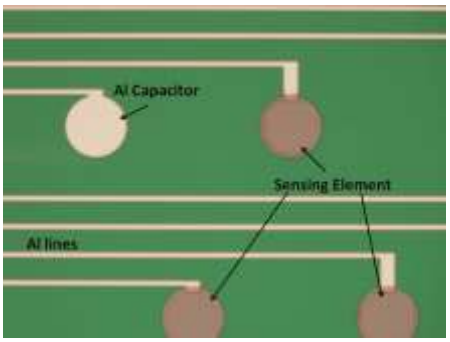


Fig. 7: *Image of part of the sensor array consisting of membranes (sensing elements) and an Al capacitor.*

PROJECT OUTPUT IN 2011

Publications in International Journals

1. "A Chemocapacitive Sensor Array System for gas sensing applications", S.Dimopoulos, M.Kitsara, D.Goustouridis, S.Chatzandroulis. I.Raptis Sensor Lett. 9 577(2011)
2. "Disposable lithographically fabricated bismuth microelectrode arrays for stripping voltammetric detection of trace metals", Ch.Kokkinos, A.Economou, I.Raptis, Th.Speliotis, Electrochem. Comm. 13 391(2011)
3. "Performance simulation, realization and evaluation of capacitive sensor arrays for the real time detection of volatile organic compounds", P.Oikonomou, G.P.Patsis, A.Botsialas, K.Manoli, D.Goustouridis, N.A.Pantazis, A.Kavadias, E.Valamontes, Th.Ganetsos, M.Sanopoulou, I.Raptis, Microelectron. Eng. 88 2359 (2011)
4. "Capacitive Microsystems for Biological Sensing", V. Tsouti, C. Boutopoulos, I. Zergioti, S. Chatzandroulis., Biosensors and Bioelectronics, vol. 27 (1), pp. 1-11 (2011)
5. "A Reconfigurable, Multi-Channel Capacitive Sensor Array Interface", E. D. Kyriakis-Bitzaros, N. A. Stathopoulos, S. Pavlos, D. Goustouridis and S.Chatzandroulis, IEEE Transactions on Instrumentation & Measurement, vol. 60 (9), art. no. 5765495, pp. 3214-3221

Publications in International Conference Proceedings

1. "Hybrid integration of microfabricated chemcapacitor arrays with miniaturized read-out electronics towards low-power gas sensing module", P.Oikonomou, A.Botsialas, G.Patsis, K.Manoli, D.Goustouridis, E.Valamontes, N.Pantazis, M.Sanopoulou, I.Raptis, EuroSensors 2011 (Athens, Greece, 09/2011)
2. "Disposable microfabricated bismuth microelectrode arrays for trace metal analysis by stripping voltammetry", Ch.Kokkinos, A.Economou, I.Raptis, Th.Speliotis, EuroSensors 2011 (Athens, Greece, 09/2011)
3. "Chemocapacitance response simulation through polymer swelling and capacitor modeling", P.Oikonomou, A.Salapatas, K.Manoli, K.Misiakos, D.Goustouridis, E.Valamontes, M.Sanopoulou, I.Raptis, G.P.Patsis EuroSensors 2011 (Athens, Greece, 09/2011)
4. "Direct laser printing of oligonucleotides for the fabrication of a label-free biosensor", M. Chatzipetrou, G. Tsekenis, V. Tsouti, S. Chatzandroulis, D. Thanos, I.Zergioti, Proc. Eurosensors XXV, September 4-7, 2011, Athens, Greece, Procedia Engineering 25 (2011) 851 – 855
5. "Self-Aligned Process for the Development of Surface Stress Capacitive Biosensor Arrays", V. Tsouti, M. Filippidou, C. Boutopoulos, P. Broutas, I. Zergioti, S. Chatzandroulis, Proc. Eurosensors XXV, September 4-7, 2011, Athens, Greece, Procedia Engineering 25 (2011) 835 – 838

Conference Presentations

1. "Oligonucleotide deposition through Laser Induced Forward Transfer on functionalized LTO surfaces, Gold surfaces and capacitive sensors", M. Chatzipetrou, G. Tsekenis, S. Chatzandoulis, V. Tsouti, G. Thireos, I. Zergioti, EMRS 2011, 9-13 May, 2011
2. "Laser Induced Forward Transfer of thiol modified oligonucleotides on GOPTS functionalized capacitive sensors", M. Chatzipetrou, G. Tsekenis, V. Tsouti, S. Chatzandoulis, D. Thanos, I.Zergioti, Conference on Laser Ablation COLA 2011, Playa del Carmen México, 13-19 November, 2011.