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Hybrid integration of microfabricated chemocapacitor arrays with miniaturized read-out electronics towards low-power gas sensing module

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Abstract

A hybrid gas sensing module consisting of an array of 8 polymer coated capacitive sensors and low power read-out electronics is introduced. The chemocapacitor array is fabricated with standard microelectronics/micromachining processes allowing for the realization of planar InterDigitated Electrodes (IDEs). The read-out electronics sub-module consists of an analog multiplexer for the sequential measurement of the sensor array elements, a capacitance to 24-bit converter and a USB to I^2C interface. The compact hybrid module has been successfully applied in the detection of sub-100ppm concentrations of p-xylene and toluene. The responses to various humidity levels have been also evaluated.

Keywords: gas sensing, chemcapacitor, polymer, volatile organic compounds

1. Introduction

Research in the field of detection of various chemical species is intensive during the last two decades and several transduction principles have been proposed and explored. Typical examples of the mostly used sensors are: sensors based on metal oxides [1], acoustic waves [2], cantilever resonance [3], resistance changes-chemresistors [4] or capacitive changes- chemocapacitors [5, 6]. In several of these approaches have very good results in terms of sensitivity and selectivity have been obtained but two

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particular categories, chemresistors and chemocapacitors, have attracted considerable research interest. Both sensor types can be fabricated with conventional microelectronic-micromachining processes, they operate at ambient temperature offering low power consumption, and they have been successfully applied in a wide range of diverse applications with high sensitivity and detection limit.

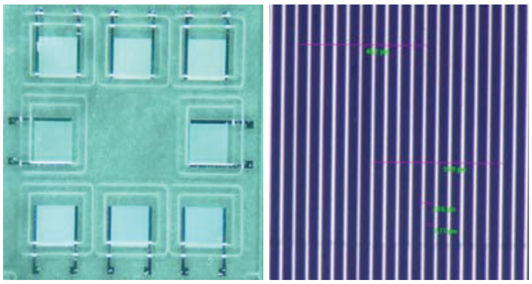
Capacitive sensing devices with polymeric films as sensing layers have already found applications in the detection of volatile organic compounds and humidity. The detection mechanism has been studied previously, e.g. [7], and rely on a combination of swelling and change of dielectric permittivity of the sensitive polymeric material due to vapour sorption.

The capacitive devices for gas sensing applications are based on three electrode layouts: (i) by anchored top and fixed bottom electrodes with a polymeric film, the sensing film, in between [8]. The top electrode has openings for fast interaction of the analyte with the polymeric film. (ii) Planar InterDigitated Electrodes (IDEs) [9] where the polymeric film covers the electrodes. This configuration is the most popular one mainly because of the easy fabrication. However in this case half of the electric field lines pass through the sensitive polymeric film and therefore the sensitivity is reduced and (iii) Vertical IDEs [10] with the polymeric film covering the space between the electrodes. The sensitivity is increased compared to Planar IDEs however the diffusion is slower and fabrication is more changeling.

In the present work we deal with the development and evaluation of a low cost miniaturized device consisting of a capacitive sensor array hybrid integrated, with the appropriate read-out electronics providing low power control and facile data acquisition and processing, that can be used for detection of several Volatile Organic Compounds (VOCs).

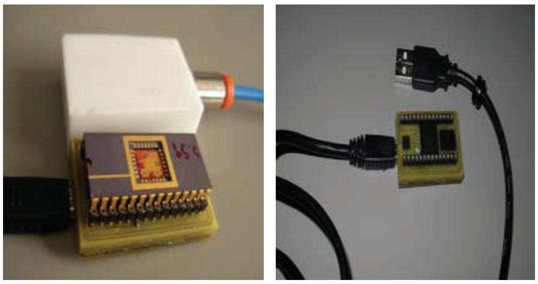
2. Experimental

The chemocapacitor array is fabricated with standard microelectronic/micromachining processes allowing for the realization of IDEs [9] with critical dimensions of 2μm and the formatting of a well of a thick epoxy- based resist layer (~ 50μm) around every IDE (Fig 1). This way we achieve controllable repeatable deposition of the polymeric film that acts as the sensing layer, on the IDEs without deterioration of the sensing response. Each chip has an area of 7 x 7mm^2 and consists of 8 IDCs, each one of them with 1 mm^2 sensing area. For the targeted application, the detection of VOCs in low concentrations at the presence of humidity, three hydrophilic (PHEMA, PVP, PEI) and five hydrophobic (PBMA, PEMA, PHS, divinyl terminated [P(DMS-co-DPhS)], dihydroxy terminated [P(DMS-co-DPhS)]) polymers were deposited by drop-casting over the pre-defined, by thick epoxy walls, IDE areas.



(a) (b)

Fig.1:a) Optical micrograph of an 8- IDC sensor array with a thick well around every IDE; b) optical micrograph of an IDE with measured dimensions of width and gap



(a) (b)

Fig. 2:a) Photos from the gas sensing module: 8-sensor array, electronics and chamber; b) the read-out and control electronics sub-module

The control and read-out electronics sub-module consists of commercially available integrated circuits that allow the fast and reliable measure of the sensor array with high resolution and small noise. For the scanning of the sensor array a multiplexer is used connected with a capacitance to 24-bit converter [11] and a USB to I^2C interface (Fig. 2). The total footprint of the module is $10cm^2$ and could be further reduced 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 packaging of chemocapacitor array into a standard package allows for the use of the electronics sub-module in numerous applications where capacitors are used.

3. Results

The evaluation of the sensor response was performed in a small chamber made from Teflon (~ 5 cm^3) with controlled atmospheres of humidity and low concentrations of p-xylene and toluene. The capacitance response of an analyte concentration depends on the polymer-analyte pair and the analyte vapor concentration. The capacitance responses of two IDEs coated with two different polymeric sensing layers upon exposure to low concentrations of p-xylene and toluene is illustrated (Fig. 3). For these polymer/p-xylene systems and for the examined concentration range, an almost linear increase in ΔC is observed with a slope of 0.02357fC/ppm for PBMA- coated sensor and 0.02783fC/ppm for PEMA sensor respectively. Additionally upon exposure to a range of low concentrations of toluene the respective slope values are for PBMA/toluene system 0.00622fC/ppm and for PEMA/toluene 0.00644fC/ppm.

The sensor array was studied upon exposure to different humidity levels in the 0-50% RH range. In Fig. 4 the dynamic responses of selected IDEs covered with PBMA and PEMA upon exposure to a range of different proportions of relative humidity is presented. The capacitance response is higher and reaches the equilibrium much faster in the PEMA case. Furthermore the capacitance response increases almost linearly with the relative humidity values.

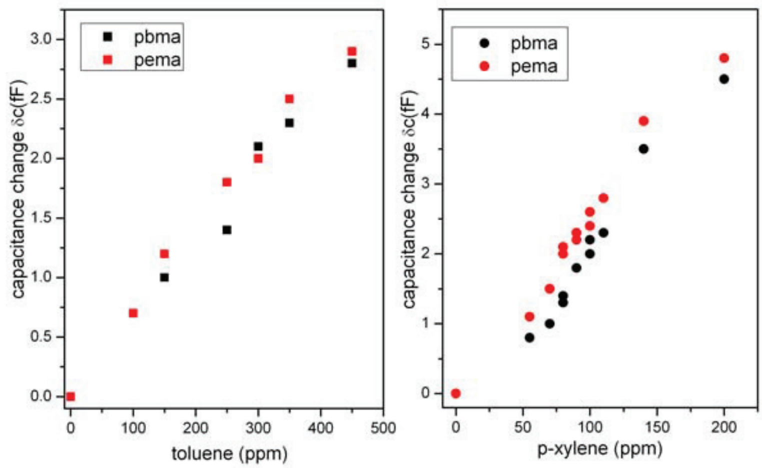


Fig.3: Capacitance responses of selected polymer- coated sensors upon exposure to a range of low concentrations of toluene and p-xylene analytes.

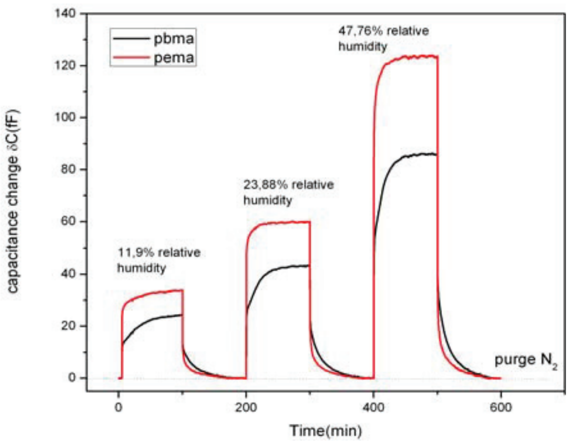


Fig. 4: Dynamic responses of: PBMA and PEMA-, coated sensors upon exposure to different humidity levels.

4. Conclusions

The results above indicate that the introduced hybrid gas sensing module, consisting of an array of 8 polymer coated capacitive sensors and low power read-out electronics, is capable for detection of low concentrations of VOCs. Therefore this sensing module can be potentially applied in real environment.

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