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Environmental monitoring with a multisensor platform on polyimide foil

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ABSTRACT

A multisensor platform on plastic foil for environmental monitoring has been produced and its gas sensing performance, investigated. It is an array of conductometric metal-oxide (MOX) and capacitive polymer gas sensors integrated with a resistive platinum thermometer on a polyimide sheet substrate. The feasibility of simultaneous measurement of oxidizing and reducing gases, volatile organic compounds (VOCs), humidity and temperature has been demonstrated. MOX signals comparable with those of the devices realized on ceramic substrates have been obtained. Due to its structure, the platform is very versatile and, by using different sensor configurations and sensing materials, it allows the detection of a broad spectrum of gaseous analytes over wide concentration ranges. From the raw signals, temperature and humidity-corrected gas responses have been inferred which have been used for the calibration of the platform sensors. All the integrated devices were stable and gave reproducible signals for more than two months of operation, even when the MOXs ran continuously at 300 °C. The performed investigation proved the device concept viability and the reliability of its practical implementation.

1. Introduction

The development of autonomous sensing systems gained significant interest within the last years due to the decreasing power consumption of the electronic components and the spread of wireless communication. At present it is a clear trend to integrate new components and expand the features of the older ones in order to make the whole assembly *smarter*. Monitoring environmental parameters may find relevance in several domains, such as human comfort and health, ambient pollution reduction or perishable goods preservation.

The measuring of various parameters – temperature, relative humidity, gas concentration or pressure – with a single chip has already been proven on silicon substrates [1–4]. For example Li et al. [5] presented several types of transducers – calorimetric, capacitive, gravimetric, resistive – for gas sensing. Also, the use of plastic foil for sensors and actuators has been reported in the literature of the last years. Among other, anemometer [6], bolometer [7], thermometer [8–10], and metal-oxide [11,12] or capacitive gas sensors [13,14] have been produced on polyimide (PI) foils.

Here, a multisensor platform for environmental monitoring on one polyimide substrate that integrates conductometric metal-oxide (MOX) and polymeric capacitive gas sensors as well as a Pt thermometer is presented.

In comparison with the investigations/implementations of different types of sensors on flexible substrates reported earlier by our group of authors, that is, the design, fabrication, and characterization of metal-oxide gas sensors [12,15], and capacitive sensor arrays [14], the multisensor platform addressed by this contribution represents a significant conceptual and technological advance. That is due to a higher degree of integration and, mainly, to the successful combination of different transducers, different types of sensing materials and different technologies. Moreover, the possibility to correct the temperature and humidity parasitic substrate contributions to the sensor responses allows achieving the same sensing potential as in the case of the Si-based platforms [3].

2. Experimental

2.1. Platform concept, structure and design

The demonstrator configuration of the hybrid multisensor platform (6 mm × 6 mm) is presented in Fig. 1. It combines three different sensor types on the same polymeric substrate: two metal-oxide and two capacitive gas sensing structures as well as a resistive thermometer. Depending on the concrete application needs, other configurations, with higher complexity, are feasible. The main

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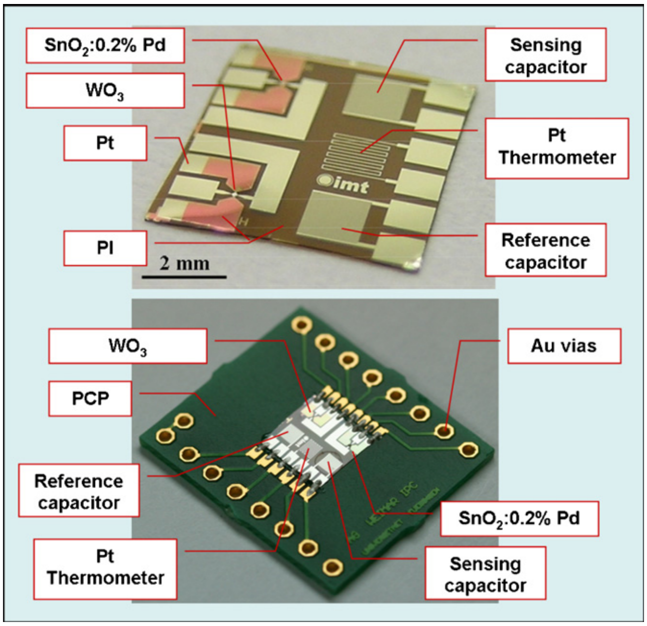

Fig. 1. Optical micrograph of the multisensor platform fabricated on polyimide foil (up) and the device packaged on a PCB for its characterization (down).

advantages of combining sensors with different transducing principles are:

- the possibility to sense gas mixtures containing different components spread over different ranges of concentrations
- the possibility to correct the temperature influence on the sensor responses and calibration curves
- the possibility to remove, in principle, the cross sensitivities by using extended arrays
- the possibility to make predictions concerning the gas composition through multivariate data analysis

The cross section of the demonstrator platform is displayed in Fig. 2. It enables the understanding of different sensor structures and their geometric parameters:

- The MOX conductometric sensors are based on Pt interdigitated transducers with an active area of 100 μm × 100 μm, and an aspect ratio of 164. The aspect ratio indicates how many times the measured resistance of the sensing layer is reduced by the electrode configuration in respect with the standard sheet resistance of the same layer. The electrodes of the transducer are deposited over the heating Pt meander, from which they are electrically insulated by a polyimide layer (see Section 2.2).
- Each capacitive transducer covers an area of 1.4 mm × 1.4 mm and has equal electrode width and spacing (10 μm). A nominal capacitance lower than 10 pF has been targeted, which allows the direct readout of the capacitance with a commercial, high resolution, capacitance-to-digital converter.

  One capacitor – addressed from now on as "reference" capacitor – has been left uncoated, as a witness for the substrate residual response to gaseous analytes. The other one – to be addressed as "sensing" capacitor – has been covered with an appropriate polymer, providing the capacitive sensing function toward either a certain VOC or to humidity.

  Because of the additional polymer layer the capacitance of the sensing capacitor is higher than the capacitance of the reference capacitor with an amount (∼10–20%) that will be referred to as "sensing layer capacitance" (or "nominal sensing layer capacitance" if measured in dry synthetic air). The structure of the capacitive section of the multisensor platform allows differential operation [14], so that the reference capacitor signal and the nominal sensing layer capacitance can be subtracted from the sensing capacitor signal, in order to obtain the net gas response of the sensing layer, eliminating in this way the parasitic contributions of the substrate to the total capacitive response of the platform. The two, reference and sensing, capacitors differentially operated will be referred to as "differential sensor". More information related to sensor evaluation in the differential operation mode is included in Section 3.
- The resistive temperature transducer is a Pt meander realized on an area of 1.4 mm × 1.4 mm and having a targeted nominal resistance of 1 kΩ at 0 °C.

At present the platform manufacture implies a certain technological complexity due to complementary technological steps being used. The foreseen "full plastic implementations" exclusively based on printed devices will considerably simplify the production chain premising the next generation of low cost and low power gas sensing platforms.

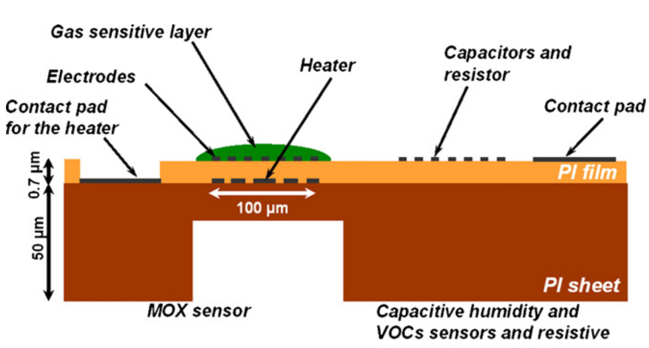

Fig. 2. Cross-sectional schematic of the multisensor platform on polyimide foil. The power consumption of the MOX sensors can be reduced by using a back-etched membrane.

2.2. Fabrication

The platform has been realized on a 50 μm thick polyimide (PI) wafer (*Upilex-50S* from *Ube Industries, Ltd*), making use of a minimal number of conventional technological steps (see Fig. 2). The conducting elements of the sensors (thermoresistor, heaters, electrodes and pads) required only two levels of platinum (130 nm) deposited by DC sputtering over an adhesion layer of titanium (20 nm) and patterned by lift-off technique. The electrical insulation between the two layers of platinum was made by a 700 nm thick polyimide film (*PI-2737* from *HD Microsystems*). To reduce the power consumption of the MOX sensors, optional 3 μm thin membranes could be formed through dry etching from the backside of the polyimide foil. The fabrication process used for the multisensor platform was the one previously developed for single metal oxide gas sensors on PI, and is fully described in reference [15]; no extra step to integrate the capacitive transducers and temperature sensor has been required.

Onto the transducers, all functional materials for gas sensing have been drop-coated. In the first step, the metal-oxide layers have been deposited: SnO_2 loaded with 0.2 wt% Pd, which will be referred to as SnO_2:0.2%Pd [16] and WO_3. They required a subsequent annealing at 400 °C to enable the stabilization of the film properties. Afterwards, the sensing capacitor has been covered with either cellulose acetate butyrate (CAB) for humidity measurement or polyetherurethane (PEUT) for VOCs detection. The polymers were allowed to naturally dry at room temperature. For laboratory