Cyclical Heating to Reduce Consumption of SnO_2 Sensors for Alcohol Monitoring

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Abstract— **In this work, we study the response of a Tin Dioxide (SnO_2) sensor under ethanol exposure to enable alcohol monitoring under a number of different power conditions (continuous and cyclical heating) in order to investigate the impact of reduced system level power consumption on sensor sensitivity. The sensitive thin layer of SnO_2 with a thickness of 50nm was deposited by a magnetron reactive sputtering technique. The power consumption of the SnO_2 sensor when continuously heated was 53mW (280°C). In the case of a cyclical heating operating mode, power consumption was 13mW when a frequency of 16mHz was used. The division of power consumption by four results in a slight decrease in the sensitivity of the sensor of about 25%.**

Keywords-ethanol monitoring; cyclical heating; low power consumption; SnO_2 gas sensor.

I. INTRODUCTION

Research in the field of metal oxide chemo-resistive gas sensors (MOX Sensors) has been a growing area of interest for biomedical applications, such as the detection of Volatile Organic Compounds (VOC) released by the human body. For the monitoring of alcohol vapor emitted by transdermal perspiration after alcohol consumption [1], SnO_2 metal oxide sensors are often used. Tin dioxide is one of the most sensitive layers which can be used for gas detection due to its high sensitivity and stability [2]. Thus, in the case of transdermal alcohol monitoring, the main criterion to be considered when developing a mobile/battery-operated sensor is the greatest sensitivity attainable with the minimum heater power consumption conditions which allow it to be incorporated into the power-constrained mobile component.

A MOX sensor requires two voltage inputs, the heater voltage and the sensor bias voltage. The heater voltage allows the semiconductor to be maintained at a specific temperature in order to enable gas detection. A sensor bias voltage is applied to allow the measurement of the sensor response to gas exposure. One critical aspect to be considered when working with a metal oxide semiconductor gas sensor is the power consumption required for the heating element, which is in the order of 70mW or more on average. In the case of continuous monitoring using power-constrained sensors, it is important to decrease heater consumption so that they can be incorporated in microsystems such as a wristband, patch and armband, or watch (this requires a power consumption in the order of 5mW). One possible solution is to use cyclical heating, which means switching the heater on and off, thus minimizing the active period of energy consumption so as to save power [3]. Given the high value of sensitive layer resistance, the power of the sensitive layer is negligible compared with that of the heater. In order to monitor the transdermal ethanol emission of the skin, we compare the responses of the sensor in both cases, i.e. continuous heating and cyclical heating. The SnO_2 sensors were exposed to ethanol vapor with various concentrations ranging from 1ppm to 100ppm.

The rest of the paper is structured as follows.

In Section 2, we describe the MOX sensor device, the measuring bench and the parameters of cyclical heating. In Section 3, we present the sensor responses in each case of heating conditions and we offer a brief discussion. The paper concludes with Section IV.

II. EXPERIMENTAL

A. Gas sensor

Tin dioxide is an n-type wide-band-gap (3.6eV) metal oxide semiconductor, with a wide range of applications for various types of oxidizing or reductive gas/vapor detection. Figure 1 shows the sensitive thin layers of SnO_2 with a thickness of 50nm which were deposited by reactive radio frequency (RF) magnetron sputtering on transducers patented by the AMU-IM2NP laboratory [4]. The transducers are designed to have three sensors and two heaters. In this study we will present only the response of the central sensor.

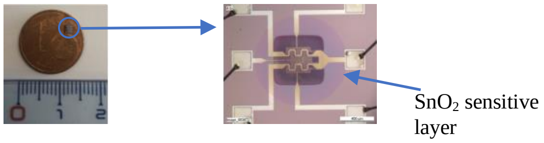

Figure 1. AMU-IM2NP ethanol sensor based on SnO_2

The films were deposited at a pressure of 22µbar with a mixture of Ar/O_2 for the sputtering process and annealed at 500°C for a duration of 12h in dry air in order to improve the sensitive layer detection properties.

ISBN: 978-1-61208-621-7

B. Measuring bench

An innovative sensor system calibration was developed in collaboration with the OMICRON Company (http://www.omicron-technologies.com). This platform for sensor characterization generates ethanol and acetone vapor (acetone is one of the most important interference VOCs for the detection of alcohol in perspiration). Ethanol vapor is generated by heating tubes with concentrations ranging from 20ppb to 150ppm for a flow rate of 250ml/min with dry air as the gas vector. Ethanol vapor is carried in a test chamber with a volume of 1.86ml, where the sensor is polarized by means of a Keithley source meter for data acquisition and the heater power is modulated to provide the operating temperature. The sensor response is defined as Ra/Rg, where Ra is the sensor resistance measured in air and Rg is the sensor resistance measured under ethanol exposure.

When the concentration of alcohol in the blood after alcohol consumption reaches 0.5g/l (2 standard glasses of alcoholic beverage), its equivalent in the breath is 139ppm and lower concentrations varying between 1 and 100ppm may be expected on the surface of the skin. We therefore varied the ethanol concentration from 1ppm to 100ppm every 2 minutes of exposure in our application.

C. Cyclical heating

MOX sensors involve high working temperatures (220°C-300°C) in order to detect gaseous species. This is because temperature provides the sensitive layer with the activation energy required for adsorption between the gaseous species and the surface of the oxide. Temperature also influences the gas desorption. Figure 2 illustrates the sensor response as a function of the heater voltage supply for 50ppm of ethanol. 2V is the heater polarization which corresponds to the optimal heating temperature for the best response. Below this value, the response decreases.

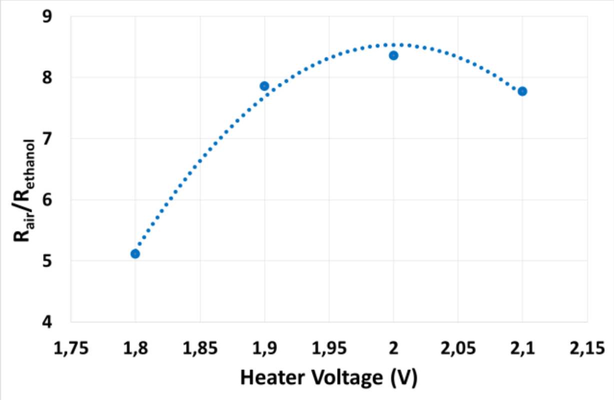

Figure 2. Ethanol sensor response according to the heater voltage

A frequency of cyclical heating was studied previously to determine the optimum active time of a heating element. Figure 3 illustrates an example of a sensor response according to different heater activation times (6s, 10s, 15s, and 20s) under different ethanol concentrations.

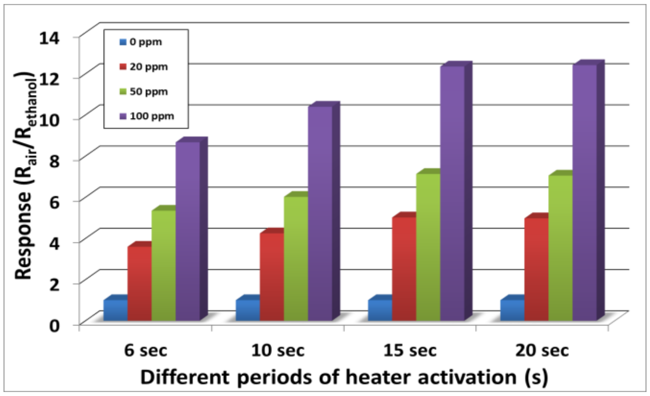

Figure 3. Cyclical frequency study

Figure 3 shows that, for a heater activation of 15s, the response of the sensor stabilizes and the sensitive layer almost reaches the optimal temperature for the detection process.

Before applying the voltage for the cyclical temperature, we used an oscilloscope to visualize the output voltage modulation. Figure 4 shows an example of cyclical heating which was considered.

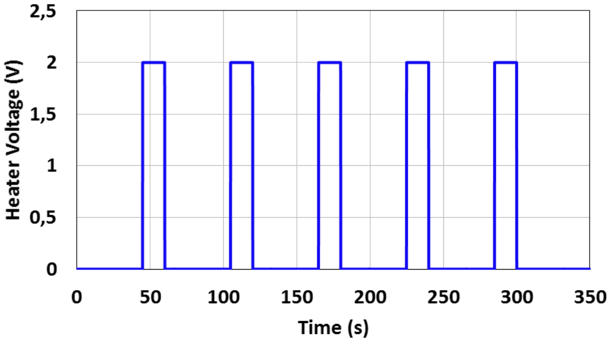

Figure 4. Cyclical heating applied to SnO_2 sensor (2V~53mW/280°C)

During a period of 60s (1min), the heater is switched off for 45s, and on for 15s. This is repeated throughout the measurement. The period of this cyclical heating is 60s, its frequency is 16mHz and the cyclical ratio is 0.25.

III. RESULTS AND DISCUSSION

The SnO_2 sensor shows a good sensitivity to ethanol, mainly for low concentrations and a slight saturation of around 70ppm. This slight saturation occurs when the coverage rate of the adsorption sites decreases. Figure 5 shows the variation of sensor resistance in the case of continuous heating (53mW).

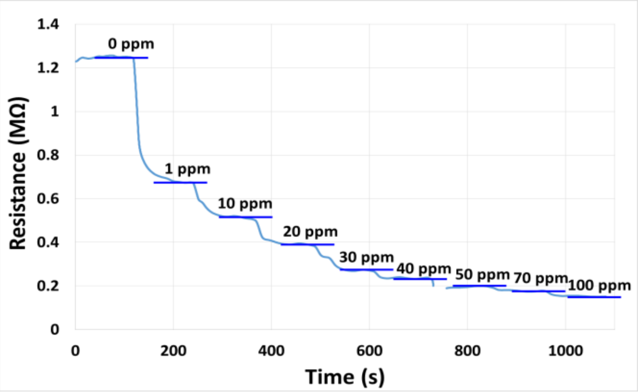

Figure 5. SnO_2 sensor reponse under different ethanol concentrations: continuous heating

Figure 6 shows the variation of sensor resistance in the cyclical heating mode (13mW). The power reduction (by a factor of 4) causes a slight decrease in sensor responses, as shown in Figure 7. In fact, in the case of continuous heating the sensor operates at 280°C and 53mW. With cyclical heating, the heating time is decreased and thus power consumption too, without any reduction of the operating temperature (280°C) during the detection process.

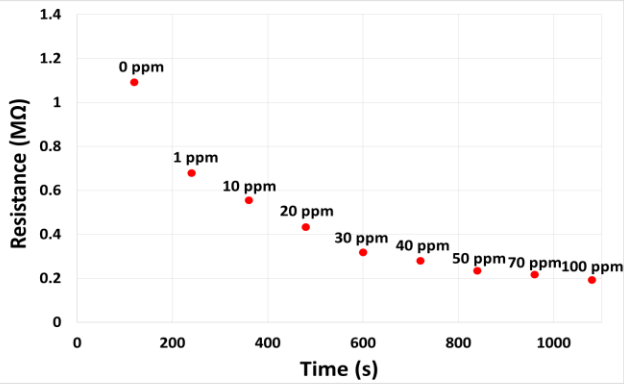

Figure 6. SnO_2 sensor reponse under different ethanol concentrations: cyclical heating

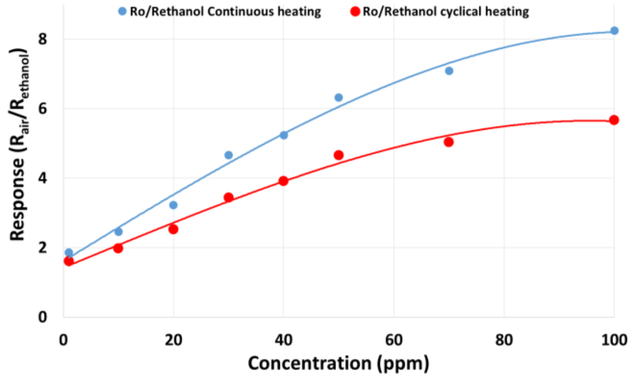

Figure 7. Comparison of SnO_2 responses with continuous heating (53mW) and cyclical heating (13mW)

However, even if cyclical heating allows a reduction of power consuption of 75%, it is important to note that pulse mode heating can also reduce slightly the sensor response.

IV. CONCLUSION

This paper describes the efficiency of cyclical heating in the gas/vapor detection process. This method allows a reduction of power consumption in the integrated gas detection microsystems. Thanks to this heating modulation and to the short response time of the microsensors, energy consumption can be further reduced with only a slight decrease in the response.

V. REFERENCES

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