Temperature modulated response of gas sensors array - humidity interference

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Abstract

The aim of this work is to design and test an array of metal oxide gas sensors for reliable and reproducible gas detection. Thermally modulated responses of non-specific, resistive-type metal oxide sensors to various hydrogen concentrations and humidity levels are studied. Temperature of each sensor is controlled and sinusoidal temperature profile is imposed over the temperature range of 200 – 500°C. The dynamic responses upon hydrogen exposure (0 – 3000 ppm) are recorded and studied. The time of one temperature modulation cycle varies from 5 – 10 minutes.

Keywords: gas sensor, sensor array, temperature modulation, dynamic response, thermal cycling

1. Introduction

Resistive gas sensors based on metal oxides are commonly used for detection of oxidizing and reducing gases [1]. Numerous disadvantages such as a lack of selectivity, humidity influence and cross-sensitivity limit the use of metal oxide gas sensors [1]. One of the techniques applied to improve gas sensors performance consists of transient sensor analysis [2] and modulation of sensor temperature in sensor array [3, 4]. It is well known that the gas sensitivity characteristics [5] of metal oxide sensors as well as the kinetics of adsorption reactions [6] at the surface of the sensor are affected by the operating temperature. Therefore, the modulation of the operating temperature induces a dynamic response signal characteristic for the gas mixture composition [5, 6]. In this work an array of metal oxide sensors has been
constructed with the ultimate aim to demonstrate how exploiting the cross-sensitivity and the temperature dependence of the response increases the reliability of the system based on the sensors array.

2. Experimental details

An array consisting of six different commercial metal oxide gas sensors TGS from Figaro has been designed, constructed and tested. The chosen sensors are comprised of metal oxide semiconductor layer on an alumina substrate with an integrated heater forming a miniaturized sensing chip what enables fast temperature modulation. Sensors used in the experiment with their primary specification are listed in Table 1. The constructed array of gas sensors (Fig. 1 a) operates inside a measuring chamber shown in Fig. 1 b.

Table 1. Specification of Figaro sensors used in the array.

| Sensor symbol | Primary target gases                                                      |
|---------------|-------------------------------------------------------------------------|
| TGS 2600      | gaseous air contaminants (e.g. hydrogen and carbon monoxide)            |
| TGS 2602      | odorous gases (e.g. ammonia and H₂S), VOCs (e.g. toluene)               |
| TGS 2610      | liquid petroleum and its component gases (e.g. propane and butane)      |
| TGS 2611      | high sensitivity to methane                                              |
| TGS 2612      | high sensitivity to methane, propane and butane                          |
| TGS 2620      | vapors of organic solvents as well as other volatile vapors and combustible gases |

Fig. 1. Array of six metal oxide gas sensors (a) and a chamber containing the sensor array connected to the measuring and control unit (b)

The measuring-control system designed and constructed by the authors consists of a multi-channel PID controller for fast temperature modulation of each sensor and a multi-channel resistance recording unit. Temperature of operation is derived from the changes in the resistance of sensor heater. The block diagram of the experimental setup is presented in Fig. 2.

Measurements of the gas sensor responses as a function of: gas concentration, relative humidity level and modulation of temperature have been carried out. The responses of sensors have been detected at hydrogen concentrations over the range of 0 – 3000 ppm at humidity levels of 0% Rh, 25% Rh, 50% Rh and 75% Rh. In this paper we discuss the results obtained for sinusoidal temperature modulation from 200°C to 500°C.
3. Results and discussion

A controlled sinusoidal change in the operation temperature of each sensor leads to periodic changes of the electrical resistance. The resistance changes over one temperature modulation period is normalized using the formula:

$$S_i = \frac{R_i - R_{\text{max}}}{R_{\text{max}} - R_{\text{min}}} \quad (i = 1, 2, ..., n)$$

where: $R_i$ is the sensors resistance sample, $R_{\text{max}}$ and $R_{\text{min}}$ are the maximum and the minimum resistance over one temperature modulation period consisting of $n$ samples while $S_i$ denotes the normalized response. The normalized dynamic responses and the operating temperature profiles of the sensors at different hydrogen concentrations and humidity levels are presented in Fig. 3.

Fig. 3. Dynamic response of TGS 2602 sensor to 1400 ppm of H$_2$ at 50 %Rh (a) and dynamic responses of TGS 2612 sensor to different H$_2$ concentration at 25% and 50% Rh (b) upon sinusoidal temperature modulation
The normalized responses change significantly under hydrogen exposure as shown in Fig. 3 (b), therefore detection of hydrogen can be made by the analysis of the response curve. The influence of humidity (25 – 50%) on the normalized responses is presented in Fig. 3(b). By normalization of the response the interference of humidity is reduced. This effect is especially significant in clean air (without hydrogen) when the response curves are almost identical. When hydrogen is present the interference of humidity on the response is more significant nevertheless we can conclude that it is reduced due to temperature modulation and preprocessing the dynamic response.

4. Conclusions

The results of this work indicate that by inducing a sinusoidal temperature profile the responses of metal oxide gas sensors change with gas concentration. Moreover, the shape of the normalized response curve differs slightly with interfering humidity. Further work on feature extraction, gas classification and quantitative analysis is in progress.

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