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Gas selectivity enhancement by *sampling-and-hold* method in resistive gas sensors

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ABSTRACT

Commercial resistive gas sensors exhibit various sensitivity to numerous gases when working at different elevated temperatures. That effect is due to a change in velocity of adsorption and desorption processes which can be modulated by temperature. Thus, to reach better selectivity of gas detection, we propose to apply a known method (called the *sampling-and-hold* method) of cooling down the gas sensor in the presence of the investigated gas, and the fluctuation enhanced sensing. The adsorbed gas molecules were captured in the porous gas sensing layer and then slowly released by heating up. We observed a significant (greater than one order) change of the normalized low-frequency resistance noise during the process of slow heating up. That change was characteristic for different investigated gases. Moreover, the resistance noise reached its minimum at the temperature characteristic for the adsorbed gas. This effect can be explained by differences in the activation energy of the adsorbed gas molecules. The observed results are very promising for improving gas detection by determining the position of minimal noise intensity and can be utilized in practice.

1. Introduction

Resistive gas sensors are popular commercial sensors applied in numerous gas detection systems [1–4]. They are reliable and can work even a few years without almost any maintenance. The main driving force of improving their use is their low selectivity and sensitivity, often limiting their application to signaling a threshold crossing of the selected gas concentration. The simplest method of improving their selectivity is a temperature modulation of the gas sensing layer [5]. An improvement in gas detection can be also reached by adding some impurities activating adsorption–desorption processes [6]. These methods were investigated in various gas sensing layers [3,7].

Another proposed method utilizes low frequency resistance fluctuations (1/*f*-like noise) across the gas sensing layer and is called the fluctuation enhanced sensing (FES) [8–10]. That method assures much better gas sensor sensitivity due to generation of a low frequency noise by random processes, responsible for fluctuations of the potential barrier between grains and related to adsorption–desorption processes, as observed in other grainy materials [11]. We estimated the power spectral density of generated resistance fluctuations by observing voltage fluctuations across the gas sensor biased by the DC voltage [12]. The intensity and slope of estimated power spectral density can be utilized to improve gas sensor sensitivity. Such a method was applied in practice to determine intensity of essential oil scents in aromatherapy [13].

The FES increases selectivity of gas detection as well (e.g. detection of gas mixture components by a single gas sensor [10]), but further progress is still required. That method was modified by utilizing the low frequency noise measurement after cooling down the sensor at the atmosphere of detected gas [14]. The method is called the *sampling-and-hold* FES method. The output pattern of that method is the spectrum measured at a low temperature when molecules of the detected gas are kept inside the porous gas sensing layer (adsorbed to its grains) and influence the 1/*f*-like noise intensity by changing the potential barrier between the grains and its fluctuations [15]. The method was applied in numerous experimental studies and the published results confirmed its usefulness in the gas sensing area [16,17].

Consequently, we propose a modification of the *sampling-and-hold* FES method to shed light on differences in adsorption–desorption processes of various gases by applying an altered measurement procedure. The proposed modification combines the known *sampling-and-hold* FES method with activation of adsorption–desorption processes by a change of the sensor

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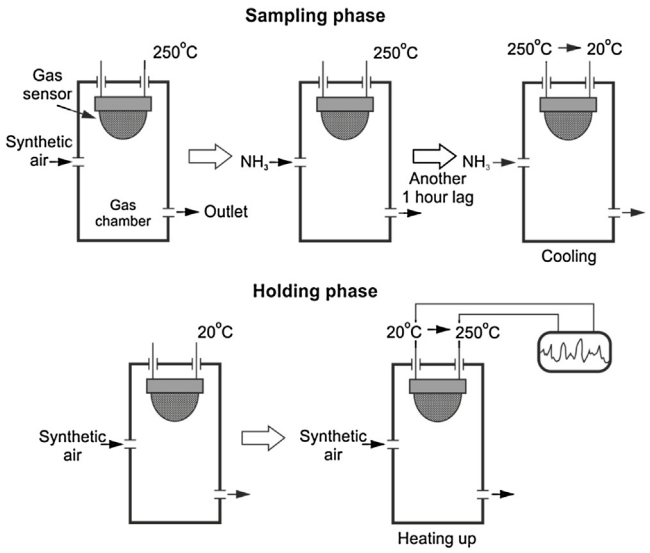

Fig. 1. Illustration of the *sampling-and-hold* FES method.

temperature. The gas molecules adsorbed to grains of the gas sensing layer require an energy sufficient to induce desorption. The presence of adsorbed gas molecules changes the potential barrier between grains and modifies the 1/*f*-like noise intensity. We can suppose that increasing temperature should change the low frequency noise by intensification of desorption processes and continuous release of the captured gas molecules to the moment when the gas molecules evaporate completely into the ambient atmosphere. When that process occurs, the gas sensing layer temperature should be characteristic for the adsorbed gas because it depends on its activation energy. Such an effect should certainly improve gas detection by adding this information as the input data for various detection algorithms [18,19].

2. Measurement procedure

In this experimental study we have applied the FES method at various temperatures for the commercial TGS 816 gas sensor specimens, comprising the SnO_2 gas sensing layer. We used the procedure presented in Fig. 1. The investigated sensor was cleansed by applying overheating pulses in the atmosphere of synthetic air only. Next, after one hour of keeping the sensor in the synthetic air only and at its working temperature of 250 °C, equivalent to the heating voltage of 5 V [20], the investigated gas (ammonia or ethanol) was introduced. After one additional hour the sensor was cooled down to the room temperature by decreasing its heating voltage in the ambient atmosphere of the selected gas. That stage assured adsorption of the gas molecules to the grain surface. Then, the sensor was again placed in the ambient atmosphere of synthetic air only, and was slowly heated up to its working temperature. That last phase increased the energy of the adsorbed gas molecules which were in the meantime being slowly released, and – finally – the sensor exhibited the same properties (i.e., the DC resistance, low frequency noise) as at the beginning of experiment. The sensor temperature was being raised slowly to assure stable measurement conditions of 1/*f*-like noise and to avoid any drifts.

3. Experimental results

Two TGS 816 type sensor specimens were used in the experiment. They exhibited different DC resistances in the same conditions due to some unavoidable technological differences in thickness of the applied gas sensing SnO_2 layer [20]. When the

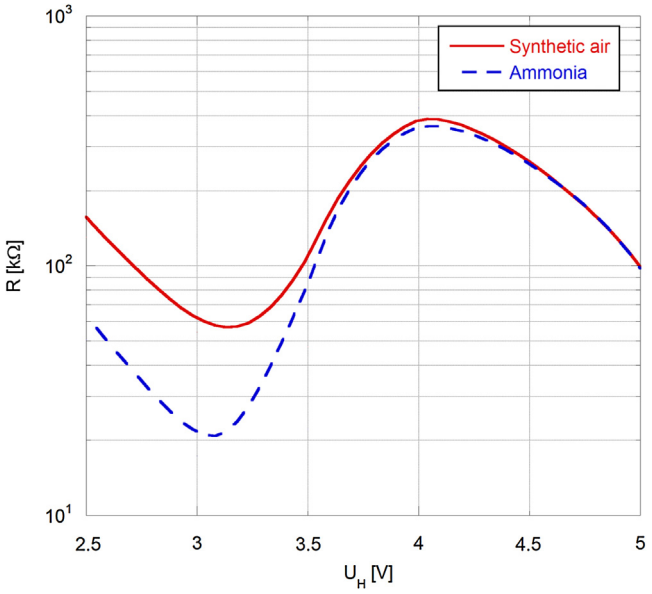

Fig. 2. Changes of TGS 816 (specimen no. 1) commercial gas sensor DC resistance *R* during heating up in the ambient atmosphere of synthetic air by increasing heating voltage U_H when the sensor was previously cooled down to room temperature in the atmosphere of synthetic air (continuous line) or ammonia 100 ppm (dashed line).

sensors were subjected to the presented *sampling-and-hold* procedure (Fig. 1) we observed that the sensor DC resistance preserves information about the exposed atmosphere. That result was observed for the investigated gases: ammonia (NH_3) (Fig. 2) and ethanol (C_2H_5OH) (Fig. 3). When the voltage U_H dropped below the nominal value of 5 V, and – proportionally to its value – so did the gas sensing layer temperature, the adsorbed gas molecules stayed within the gas sensing layer and changed the sensor DC resistance. That change depended on the applied ambient gas. The most intense changes of DC resistances – as a result of the applied *sampling-and-hold* procedure – were observed at $U_H \approx 3$ V (corresponding to the temperature of 160 °C for the gas sensing layer) and for ammonia. It means that the temperature of 160 °C is still

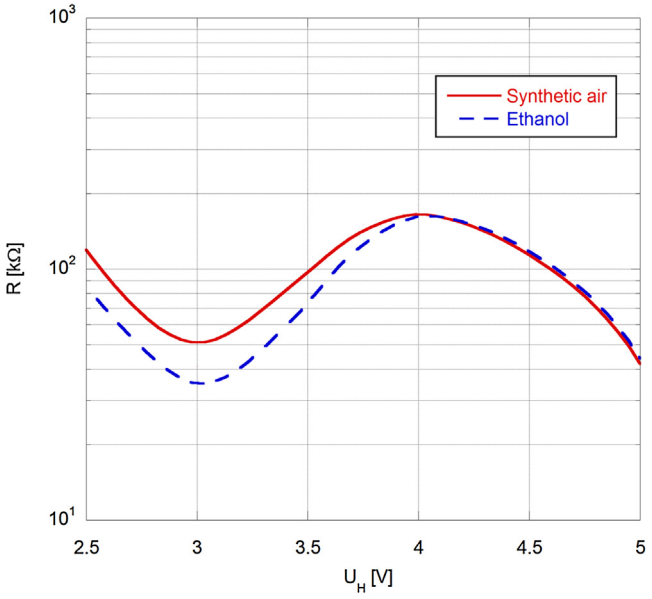

Fig. 3. Changes of TGS 816 (specimen no. 2) commercial gas sensor DC resistance *R* during heating up in the ambient atmosphere of synthetic air by increasing heating voltage U_H when the sensor was previously cooled down to room temperature in the atmosphere of synthetic air (continuous line) or ethanol 100 ppm (dashed line).