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Analytical fluctuation enhanced sensing by resistive gas sensors

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ABSTRACT

Resistance fluctuations across polarised resistive gas sensors were studied in detail to evaluate sensor working conditions for detecting methane and ammonia at various concentrations. The 1/*f* noise component typically dominates other noise sources up to a few kHz and can be utilised to improve gas selectivity when compared with measurements of the sensor DC resistance. The Arrhenius plot was created and the activation energy for the investigated gases was evaluated. Using this method, different ambient gases can be potentially detected only by means of a single commercial Taguchi gas sensor and 1/*f* noise measurements at different temperatures of the gas sensing layer without a need of intense computations to get reliable results.

1. Introduction

Detection of various gases and evaluation of their concentration is a very important task in monitoring industrial processes as well as the surrounding atmosphere of human beings. Cheap resistive sensors (Taguchi gas sensors) are very popular and various approaches were made to improve their selectivity and sensitivity by modulating measurement conditions. Nevertheless, there is no direct method of extracting the most informative data. Some methods are based on using an array of sensors and processing the obtained signal with various detection algorithms (e.g. neural networks with self-learning procedures [1]). Therefore, the new methods should focus on assuring a low energy consumption and low cost, preserving a high gas selectivity. Hence, sophisticated signal processing may not be the only choice to improve the gas detection efficiency. Several authors, such as Kwan [2] and Kotarski [3] have dealt with that issue and proposed new methods. Kish introduced fluctuation-enhanced sensing including a mathematical description (see [4]) whereas a method consisting in the noise measurement and an analysis of the temperature dependence of electrical noise spectra was published by Solis et al. in [5]. In this experimental study we utilise their idea of fluctuation enhanced sensing to improve the gas detection at selected working conditions. Noise power spectral densities at different ambient atmospheres and temperatures of the gas sensing layers were estimated. The flicker noise (1/*f* noise) dominates the power spectral densities at a low frequency range, up to a few kHz [6,7]. Noise is generally caused by dynamic gas molecule adsorption–desorption processes on the gas sensitive layer or their diffusion inside that layer [8,9]. It is almost impossible to predict the noise intensity for individual gas sensors of various materials at different ambient atmospheres, but after a necessary calibration the observed 1/*f* noise can be used to improve the gas detection. Additionally, we can suppose that the power spectral density of 1/*f* noise is temperature-dependent in a different way than the DC resistance, and that the observed difference should depend on the ambient gas composition.

2. Experimental set-up and gas sensors under investigation

Commercially available exemplary resistive TGS 2600 and TGS 823 gas sensors (Taguchi gas sensors) were used for the detailed investigation [10]. Both sensor types are made of SnO_2 grains and are widely used to monitor the presence of combustible gases. The gas sensing layer covers a tiny pipe with a heater inside to assure a low energy consumption when the sensor is heated to operate at elevated temperatures. The TGS 823 sensor is optimised to detect vapours of organic solvents as well as carbon monoxide. The TGS 2600 sensor is sensitive to hydrogen, carbon monoxides and ethanol. The sensors were placed into a hermetically sealed glass bottle, equipped with the gas input and electrical terminals to assure necessary contacts and a power supply. The gas flow rate

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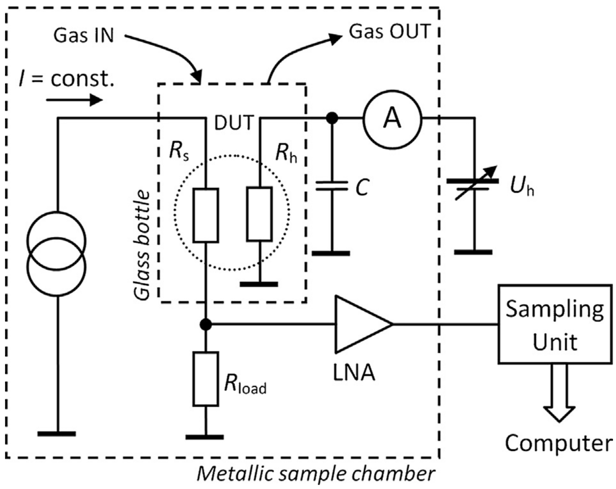

Fig. 1. The experimental setup for gas sensor DC resistance and resistance fluctuations measurements.

and composition of the gas mixture were controlled by two independent mass flow controllers: an Aalborg GFC 17 type, with a flow range up to 200 ml/min. The ambient gas atmosphere consisted of the synthetic air, up to 50 ppm NH_3 ammonium and up to 10 ppm methane. The investigated sensors were placed in a glass chamber, together with a low noise preamplifier. The glass chamber was covered by a metallic shield to avoid external electromagnetic interferences. The DC resistance measurements, as well as the heating voltage control, were done by a power supply and an external ammeter. The sensor bias current I was provided by either a custom-made (battery-based) current source or by a Keithley 6220 current source. The measurement set-up is shown in Fig. 1. The noise measurements were performed by a dedicated TiePie HS3 sampling unit and controlled by the PC software. The unit consists of ultralow noise preamplifiers (LNA, Fig. 1) characterised by a low voltage noise of about 0.9 V/$\sqrt{}$Hz at 100 Hz and the −3 dB bandwidth in the range of 0.5 Hz and 1 MHz. The voltage amplification of the preamplifier can be selected up to 1000 V/V, if necessary. The voltage fluctuations were observed across a resistor $R_{load} = 450\,\Omega$ (Fig. 1) and were recalculated to estimate the power spectral density of current fluctuations flowing through the investigated gas sensor.

3. Experimental results and discussion

3.1. Sensor heating and self-cleaning procedure

Resistive gas sensors are gas sensitive at elevated temperatures. Thus, the gas sensing layer has to be heated. The TGS 2600 sensor requires a nominal heating power of 210 mW which should be secured by a stable external voltage source. The sensor is very sensitive to the heater power stability because adsorption and desorption processes depend on the sensing layer temperature and can be modulated by its change. The same conclusion is valid for the TGS 823 sensor, but because of a few times higher power consumption (∼660 mW) this sensor is more stable during the investigation. The sensors were designed to operate when the heater is polarised by the voltage $U_h = 5$ V (Fig. 1) but lower U_h can be also applied to modify their gas sensing properties at a lower power P of the heater (Fig. 2). In addition, the sensors have to be cleaned up to remove gas remnants adsorbed during their shelf storage. Otherwise the current fluctuations in the gas sensors polarised by a constant current and caused by resistance fluctuations could be non-stationary. When the current noise was observed after 40 min from switching on the sensor heating, its power spectral density was still

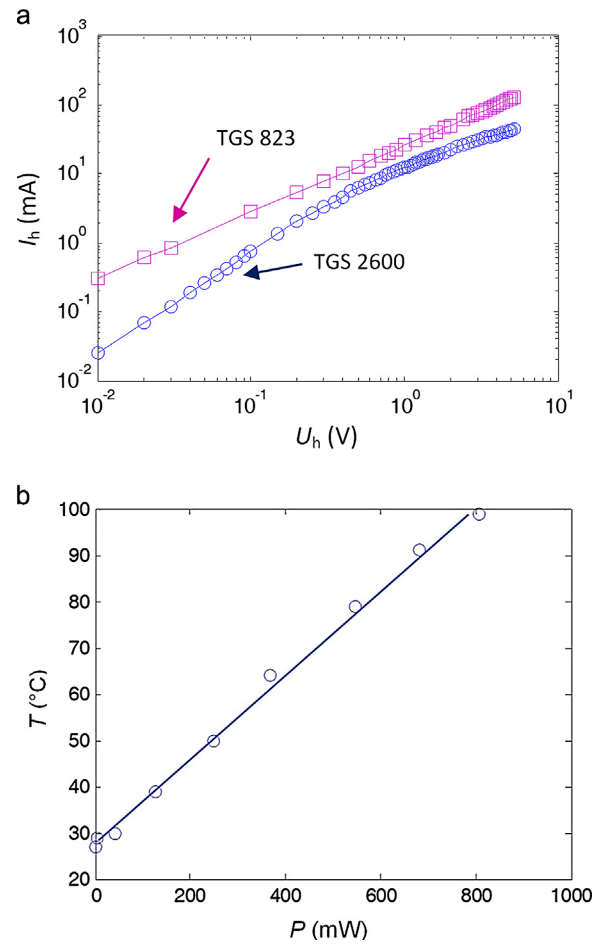

Fig. 2. The applied heaters in the investigated commercial resistive gas sensors: (a) the current-voltage I_h–U_h curves of TGS 823 and TGS 2600 sensors, (b) the gas sensing layer temperature T of TGS 823 sensor versus heater power P.

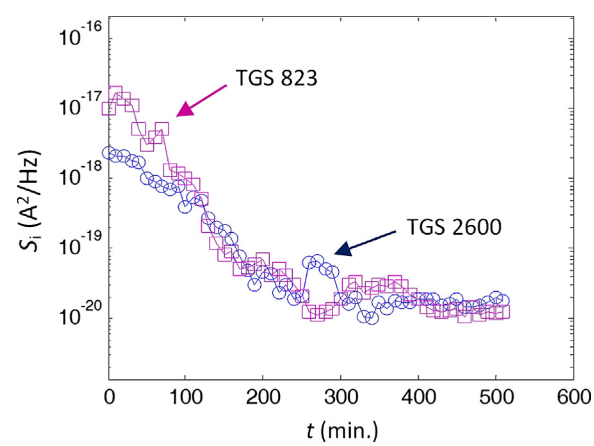

Fig. 3. Power spectral densities $S_i(f)$ of current fluctuations in the investigated TGS 823 and TGS 2600 gas sensors polarised by the DC current $I_s = 5\,\mu$A at frequency $f = 820$ Hz and ambient atmosphere of synthetic air; noise was recorded after turning on the heater voltage $U_h = 5$ V and waiting 40 min to stabilise the gas sensor temperature and measuring current noise across the sensor; the sensor stayed at ambient atmosphere of synthetic air, at a flow rate of 200 ml/min, the current power spectral density $S_i(f)$ was estimated over 128 independent spectra to reduce estimation error below 10%.

non-stationary and exhibited an excessive variation (Fig. 3) because of the cleansing process which required even 8–9 h to stabilise the gas sensor. At the same time the sensor DC resistance required only 4–5 h to be stabilised. Additionally, the DC resistance