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FLUCTUATION ENHANCED GAS SENSING AT MODULATED TEMPERATURE OF GAS SENSOR

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Abstract: Taguchi gas sensors are commonly used sensors to measure gas concentration. The detection method utilizes only sensor DC resistance changes for determination of various gases concentration. Unfortunately, such technique leads to false results due to cross-sensitivity of gas sensors at presence of other gases. Such adverse effects can be reduced by applying fluctuation enhanced sensing and temperature modulation of sensor which gather more information about ambient atmosphere than the DC resistance. The measurement setup of voltage fluctuations across the gas sensor as well as the selected measurement results are presented. New indicators of gas detection have been proposed. The indicators utilize fluctuations and DC resistance measurements at two different temperatures of the gas sensor.

Keywords: gas detection, gas sensors, noise

1. INTRODUCTION

The detection method in commonly used gas sensors such as Taguchi Gas Sensors (TGS) implies the measurements of the sensor DC resistance only. Sensor active layer consists of SnO_2 grains, which are heated to elevated temperature. Such layer exhibits established conductivity in dry air, which changes at presence of other gases and their different concentrations. The gas sensors are optimized to detect selected gas or group of gases. Unfortunately, selectivity of TGS gas sensors is rather poor and DC resistance changes can be induced by presence of many various gases. A good example of such measurement is detection of ammonia (NH_3) or methane (CH_4) at presence of carbon monoxide (CO). Then the DC resistance changes measurements lead to false detection because the same change could be induced by different combinations of concentrations of NH_3 and CO mixtures.

Gas adsorption-desorption processes which occur in the sensors active layer may result in temporary changes of electrical properties of porous gas sensitive layer (potential barrier fluctuations between the grains) [1]. Such changes can be observed as resistance fluctuations, which are valuable source of information about ambient atmosphere of gas sensor. This information can be utilized for improving gas sensor sensitivity and selectivity by proposing more effective detection methods. The fluctuation enhanced sensing (FES) method allows detection and distinction between various gases (e.g. ammonia and hydrogen) using only a single gas sensor [2-4].

Taguchi gas sensors depend strongly on their working conditions, such as temperature of gas sensitive layer. This phenomenon is used for improving selectivity and sensitivity of gas detection by modulating sensor temperature [5-6]. This method combined with the FES method is considered in the paper and shows that ammonia or methane concentration can be established even at presence of additional gas – CO. The measurement setup, applied for data acquisition and temperature modulation is presented, together with a proposed detection parameter which is a combination of DC resistance and noise measurements.

2. MEASUREMENT SETUP

Low frequency voltage fluctuations across the gas sensors are usually characterized by their power spectral density $S(f)$ that means application of FFT algorithm [7]. Thus, the data acquisition system should not measure DC resistance only but has to amplify and record voltage fluctuations.

In this exploratory study we present measurement results of voltage fluctuations observed across a gas sensor placed into a gas chamber. The gas sensor was located in ambient atmosphere of gases mixture with established concentration.

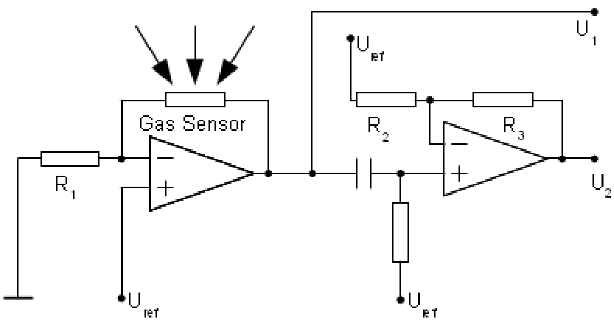

Fig. 1 Measurement setup used for recording voltage fluctuations across the gas sensor and its temperature modulations.

The electronic circuit used to polarize the gas sensor presents figure 1. The sensor current is determined by the resistance R_1 which was equal 100 kΩ. The reference voltage U_{ref} was set to 1.25 V and the gain K of voltage fluctuations was set to 500 V/V by proper selection of resistors R_2 and R_3.

The DC voltage component across the sensor U_1 and amplified AC voltage component U_2 were connected to the input of the 24-bites AD converters to record the data. The frequency range where the $1/f$ noise component dominates usually up to tens of kHz.

The measurement setup was controlled by a microcontroller which was responsible for handling the applied precise AD converters and communication with PC where the further data processing was performed. The sensor heather was managed by a DA converter available in the applied microcontroller to execute simultaneously measurements and to change voltage across the sensor heater. Such approach allows real-time fluctuations measurements at modulated heather voltages to change sensor temperature. The system was controlled by the developed virtual instrument in LabVIEW environment. This approach allows collecting measurement data in PC for further processing.

DC resistance and its fluctuations were observed in investigated commercial gas sensor, type TGS 2600 (fig. 3). The selected sensor is characterized by high sensitivity to low concentrations of gaseous air contaminants, such as carbon monoxide which exists in cigarette smoke [8].

Fig. 2. The applied gas sensor, type TGS 2600.

3. EXPERIMENTAL RESULTS

All measurements were carried out in the same way. The measurement cycle lasted six minutes at the atmosphere of selected gas concentration (mixture of CH_4, CO, NH_3). Both the DC resistance and its fluctuations were recorded. Within the first two minutes the heather voltage was fixed to 5 V and after that dropped abruptly to lower value of 4.7 V. After the next four minutes the heather voltage was restored again to 5 V. To assure stationarity of the measured random signal the recording begun after a delay of two minutes from a change of the heather voltage. Figure 3 plots the normalized sensor DC resistance during heather voltage changes, in ambient atmosphere of synthetic air and in ambient atmosphere of 30 ppm CO. These results show that two minutes after changing sensor heating the DC resistance stabilizes and its fluctuation component can be assumed as a stationary random signal.

The estimated power spectra exhibited $1/f$ noise in the low-frequency range, at least up to 14 kHz which is similar to results observed at presence of ammonia, hydrogen sulphide measurements [4] or essential oils scents [9]. Figure 4 shows the estimated power spectrum of voltage fluctuations across the sensor at ambient atmosphere of ammonia and carbon monoxide mixture or methane and carbon monoxide mixture. We observe small difference of noise intensity induced by different sensor temperature and more significant change of the $1/f$ noise component dependence on frequency at changes of the sensor ambient atmosphere.

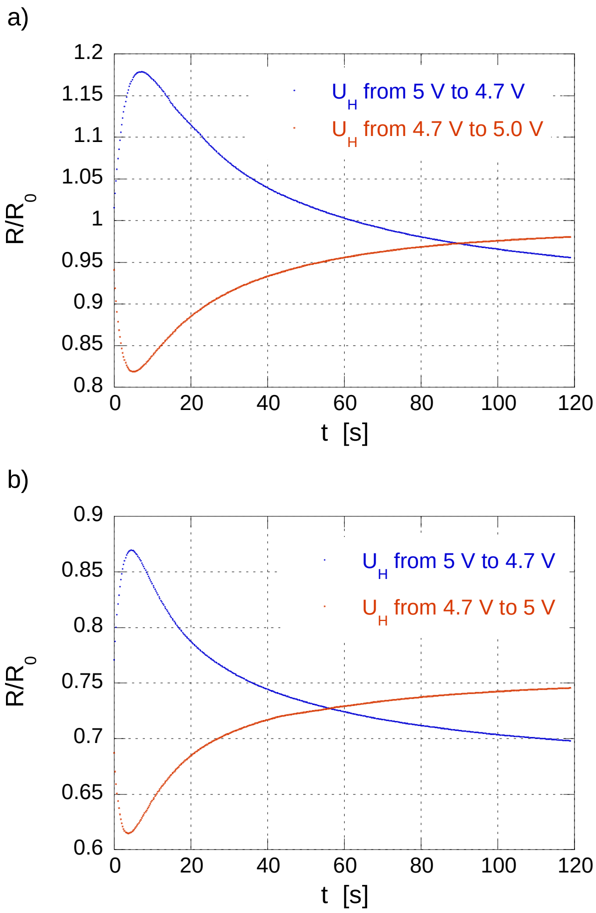

Fig. 3. The DC resistance changes of TGS gas sensor, type TGS 2600, observed during heater voltage U_H changes and normalized to the sensor DC resistance measured at: a) ambient atmosphere of synthetic air only, b) atmosphere of 30 ppm CO.

4. GAS DETECTION METHODS

The main aim of the performed measurements is to detect ammonia or methane at presence of carbon monoxide as the crossing gas. Figure 5 shows measurements results of sensor DC resistance R at various ambient atmospheres, referenced to the sensor DC resistance at ambient atmosphere of synthetic air. It is clear that there is any possibility of distinguishing between a pure ammonia and a mixture of relatively small concentration of ammonia (4 ppm) and carbon monoxide (25 ppm) as the crossing gas (fig. 5a).

An even greater difficulty can be met for the assessment of methane concentration in presence of carbon monoxide (fig. 6b), where the resistance value is very similar in both cases. Therefore we propose new indicators which will take into account the sensor DC resistance together with voltage fluctuations intensity measured at different sensor temperatures.

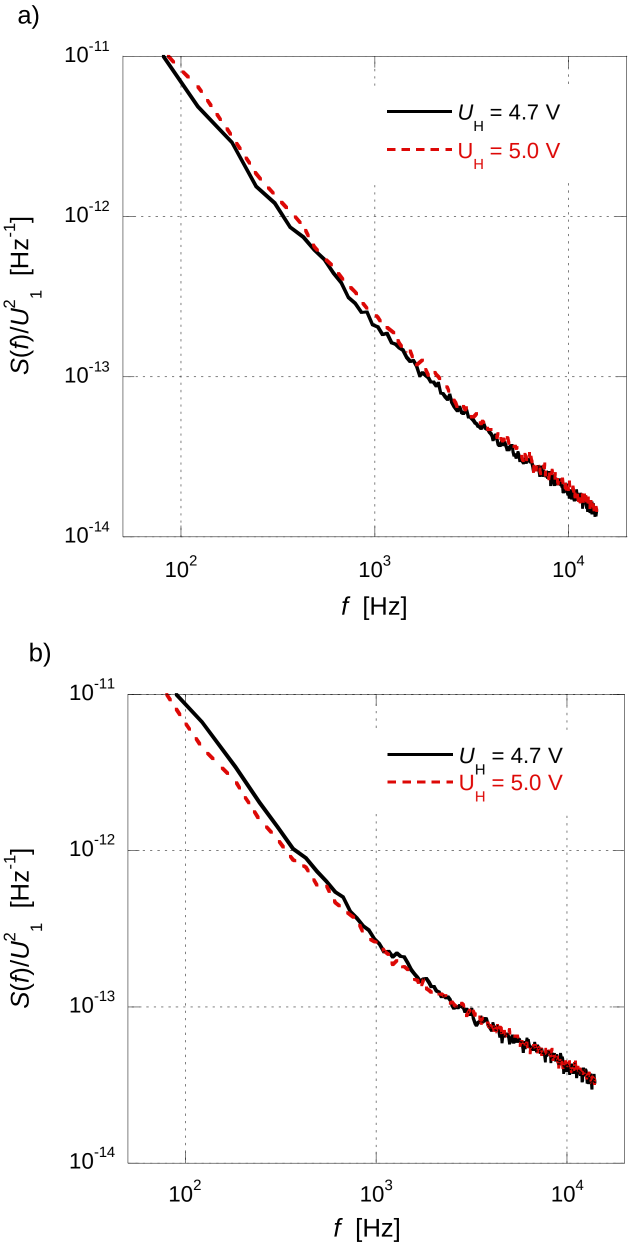

Fig. 4. Power spectrum density $S(f)$ of voltage fluctuations across the gas sensor TGS 2600 normalized to its DC polarizing voltage at ambient atmosphere: a) 12 ppm of NH_3 and 25 ppm of CO, b) 12 ppm of CH_4 and 25 ppm of CO at different heater voltage U_H.

We propose to use a non-dimensional indicator I which is a product of summing up the multiplied normalized power spectral density $S(f)/U^2$ by responding frequency f:

$$I = \sum_i S(f_i) \cdot f_i / U^2. \qquad (1)$$

This parameter describes intensity of the measured fluctuations and is sensitive to any disturbances from the $1/f$ type noise dependence.

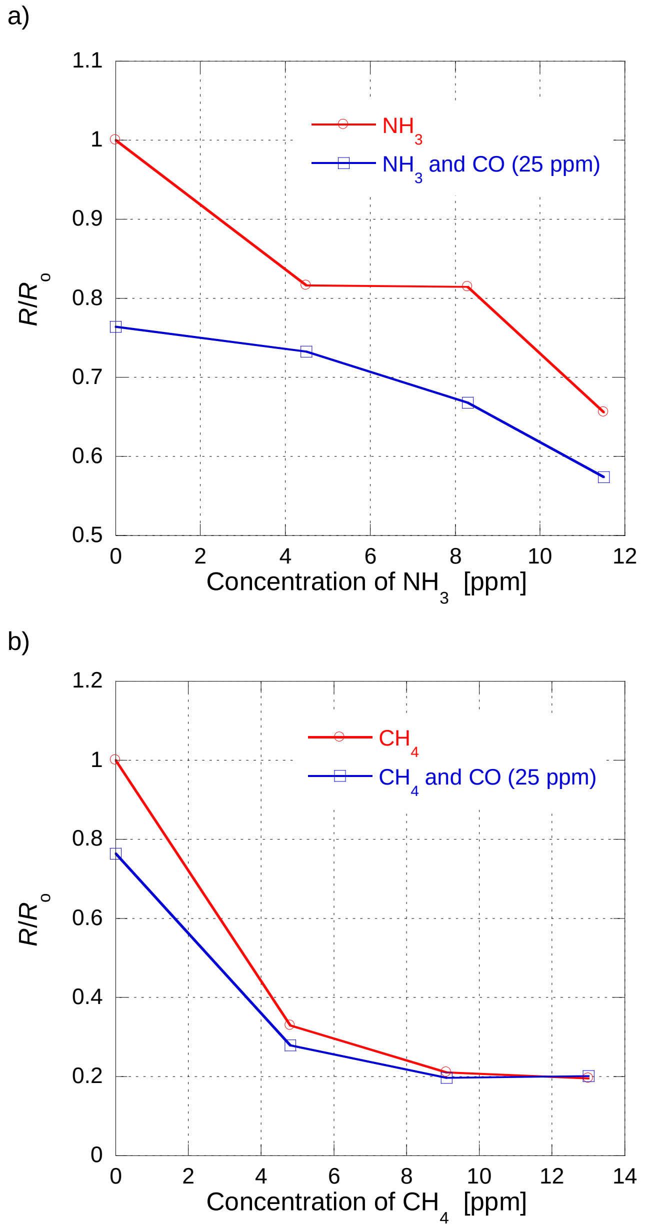

Fig. 5. The relative DC resistance of the sensor TGS 2600 at different ambient atmospheres of: a) ammonia, b) methane at presence of carbon monoxide crossing gas.

The parameter I can be combined together with the sensor DC resistance measured at different heater voltages to get a final indicator which is sensitive to presence of cross gases and can improve gas sensitivity and selectivity. Thus, we propose two parameters P_A and P_B as a linear combination of the mentioned values to evaluate a non-dimensional indicator:

$$P_A = \frac{R_2}{R_0} \cdot \frac{I_2}{I_0} \cdot \frac{R_3}{R_0} \cdot \frac{I_3}{I_0} \qquad (2)$$

$$P_B = \frac{R_2}{R_3} \cdot \frac{I_2}{I_3} \qquad (3)$$

where:

R_2 – sensor DC resistance for the heater voltage when changed from 5 V to 4.7 V,

R_3 – sensor DC resistance for the heater voltage when changed from 4.7 V to 5 V,

R_0 – sensor DC resistance in ambient atmosphere of synthetic air and the heater voltage 5 V,

I_2 – parameter I for the heater voltage 4.7 V,

I_3 - parameter I for the heater voltage 5 V,

I_0 –parameter I for the sensor in ambient atmosphere of synthetic air and for the heater voltage 5 V.

The P_A indicator allows to distinguish between two cases when the ambient atmosphere contains ammonia (NH_3) only or is mixed with carbon monoxide (fig. 6). There is a clear boarder between the location of both curves groups (for $P_A \cong 0.75$).

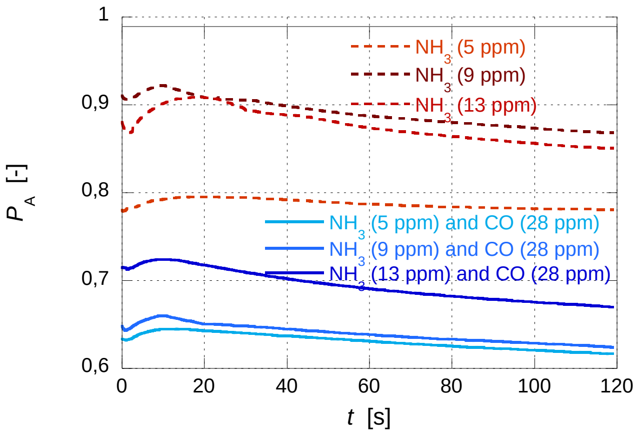

Fig. 6. Changes of the parameter P_A estimated for the gas sensor TGS 2600 at ambient atmosphere of NH_3 mixed with CO as a crossing gas.

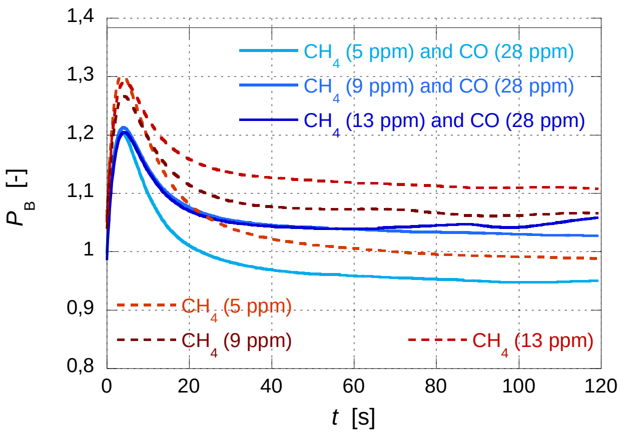

Fig. 7. Changes of the parameter P_B estimated for the gas sensor TGS 2600 at ambient atmosphere of CH_4 mixed with CO as a crossing gas.

The second proposed indicator P_B can be applied to differentiate sensor ambient atmosphere of methane (CH_4) only or the methane mixed carbon monoxide (CO). The value and position of P_B maximum can easily distinguish between both cases (fig. 7).

We suppose that the more detailed analysis of the presented curves of the indicators P_A, P_B versus measurement time (e.g. their derivatives, local maximum position and value, are under the curve) can helps to determine gas concentration but it requires additional and more detailed experimental studies.

5. CONCLUSIONS

The DC resistance and its fluctuations were observed in TGS 2600 gas sensor when the heater voltage was modulated between two selected values. The presented data confirmed that such measurements and necessary data processing can be used to reduce influence of other gases presence. The new indicators for gas detection were proposed and can improve gas detection selectivity by applying a single gas sensor. The indicators can be easily estimated without too extensive computing by a microcontroller used in the embedded devices. Thus the proposed procedure can be effectively applied for environmental monitoring and in industrial processes.

6. ACKNOWLEDGEMENTS

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