Taguchi sensors under temperature modulation

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Abstract: Semiconductor gas sensors are widely used in gas-analyzing applications for various gas species determination due to their low cost and possibility to detect number of different gases. However, one of the main problems with such sensors is their lack of selectivity. To overcome this issue different approaches can be used. One of them is the operation with sensor temperature modulation combined with dedicated data processing methods. In this paper, a measurement stand for semiconductor gas sensors with temperature modulation is presented. Proposed approach allows measurement with "On – Off" technique and periodic square, sinusoidal and triangle heating voltage. Exemplary results of Taguchi type gas sensor in the presence of synthetic air are shown. Influence of the temperature modulation on the parameters of the sensors were investigated.

1. Introduction

Increasing the air pollution entails a need to monitor the composition of the air. That requires development and implementation of a simple and cheap gas sensing devices. There are available commercial measuring instruments allowing the analysis of air contaminants that are accurate and precise, such as chromatographs. The disadvantage of such instruments, which determine barrier to their widespread use, is their high price and an expensive operation. There is the lack of devices which are characterized by both low price and good measurement properties. Due to the fact that semiconductor gas sensors are characterized by low cost, long life and small size, they can be used for determining various gas species. However, metal oxide gas sensors have some disadvantages too such as lack of sensitivity and stability. Many methods have been used in the past to overcome these problems including certain strategies in material science (doping, catalyst, filters), signal processing algorithms for the feature extractions or using sensors working in array (*Temperature modulation in semiconductor gas sensing. Sensors and Actuators B*, 1999).

Both, sensitivity characteristics of semiconductor gas sensor (*Some basic aspects of semiconductor gas sensors.*, 1989)and the kinetics of adsorption reactions on the

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surface of the sensing surface of the sensor (*General characteristics of thermally cycled tin oxide gas sensors*, 1989), are affected by the operating temperature. Due to that fact, one of the methods to improve gas sensors properties can be temperature modulation. Oscillating heater voltage can increase the number of measured information, which can be used to improve selectivity and sensitivity. Another advantage that can arise from the sensor operating temperature change is that the sensor surface can be cleaned from the partially adsorbed contaminants, by increasing the heater temperature above its recommended working temperature. Changing the operating temperature of the metal oxide sensor also leads to characteristic patterns of sensor response. Different response patterns can provide new response features. It is well known, that by mathematical analysis these features can be extracted and provide the improvement of selectivity of a semiconductor gas sensor.

However, when applying varying voltage to the sensor we have no information about the exact value of the heater temperature, since the temperature is related to the heater resistance. Therefore, there is a need to acquire the resistance, along with the value of the applied voltage. Usually, in temperature modulation, the shape of the heating voltage is in a form of a periodic waveform. Although, the voltage of the heater is changing exactly in a form of imposed waveform, the current shape is distorted and shifted in phase. The quantity of the distortion of the shape and value of the phase shift of the current depends on the frequency of the excitation voltage.

In this paper a measurement system for semiconductor gas sensors is presented. Proposed stand allows applying periodic square, sinusoidal and triangle heating voltage to the sensor. Both, heater current and excitation voltage are measured and acquired. The value of the resistance of the sensor using 4-wire technique is also measured and acquired. Two gas sensors TGS-2602 and TGS-826 under a sinusoidal excitation voltage at different frequencies have been investigated. Test data for selected gas sensors in presence of synthetic air are shown. Sensing element and the heater of the sensors signals were analyzed during modulation.

2. Experimental

2.1. Semiconductor gas sensors

Taguchi type gas sensors, manufactured by Figaro Engineering Inc. are actually one of the most frequently used groups of sensors in gas detection throughout the world. Two different semiconductor gas sensors have been investigated in the proposed measurement system TGS-826 and TGS-2602.

Semiconductor sensors consists of a gas sensitive layer, a substrate and a heater. Tin oxide (SnO_2) is usually used as a sensing layer, due to its fast response time. Sensing layer is usually deposited on a tube or plate, which is made of material with very good thermal conductivity.

The main features of the TGS-826 is high sensitivity and quick response to low concentrations of ammonia. Its sensing element has low conductivity in clean air.In the TGS-826, the coil resistance wires are placed inside the tube, which function as a heater of a sensor. Features of TGS-2602 is high sensitivity to low concentrations of odours gases i. a. ammonia or H_2S (Inc, 2013*a*) . The TGS-2602 has sensing element consisting of a metal oxide semiconductor layer which is formed on a substrate of

Tab. 1: Specifications of TGS-2602 and TGS-826.

Sensor	V_H [V]	R_H [Ω]	R_S [kΩ]
TGS-826	5±0.2	30±3	20˜100 in 50ppm ammonia
TGS-2602	5±0.2	59	10˜100 in air

alumina together with an integrated heater. Basic application schema of a Figaro semiconductor gas sensor is shown in Fig.1.

The resistance decreases depending on the presence of detectable gas concentration in the air. When combustible or reducing gases are absorbed by the surface of the sensor, the concentration is determined by the change in sensor conductivity. Main specifications of TGS-2602 and TGS-826 from datasheets provided by the producer are presented in Table 1.

2.2. Measurement system

Schematic view of the proposed measurement stand for the semiconductor gas sensors with temperature modulation is presented in Fig. 2. Voltage signal applied to the sensor heater is generated using Hameg Programmable 15 MHz Arbitrary Function Generator HM8131 and a Meratronik Power Supply Amplifier Type P334. Function Generator can produce sine wave, triangle, square wave, saw-tooth, white and pink noise, or arbitrary waveform. It provides frequency range from 100 μHz to 15 MHz has low current capability, therefore it cannot be used to directly excite the sensor. Due to that fact, signal with required shape is amplified by P334 and next applied to the heater of the sensor. Power Supply Amplifier P334 provides the maximum output voltage of up to 36 V, with maximum current of 1.5 A. Measurement stand also consist

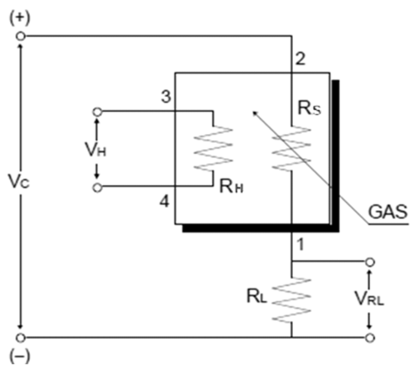


Fig. 1: Basic application circuit of a TGS gas sensor (Figaro USA Inc., n.d.)

of three Rigol DM3051 digital multimeters. The value of voltage, current of the heater and the resistance of the sensing element using four wire technique are measured by multimeters. Data from multimeters are aquired in the personal computer using RS232. Multimeters are controlled from personal computer by dedicated measurement software.

3. Measured data

Using prepared measurement platform semiconductor gas sensors TGS-2602 and TGS-826 properties have been investigated. The sinusoidal signal with amplitude of 0.5 V was superimposed on DC voltage of 4.8 V. The measurements were performed for the selected frequencies: 5 mHz, 10 mHz, 20 mHz, 40 mHz, 70 mHz and 100 mHz. For each frequency the sensors were measured in the presence of synthetic air.

Fig. 3 shows the last 200 s of the experimental results of the TGS-2602 modulated using sinusoidal voltage with frequency of 10 mHz. It was observed that during one period of measurement the resistance of the sensing element changes from 900 Ω up to 1700 Ω. The current on the heater, due to AC excitation alters of about 6 mA (from 47 mA to 54 mA). The current plot is a bit noisy but it generally speaking follow sinusoidal shape.

Both TGS-826 and TGS-2602 were measured under sinusoidal voltage signal at different frequencies. Phase shift between excitation voltage and the sensing resistance signal was observed. If the temperature of the sensing element can follow the temperature changes, then the phase shift of voltage signal applied to the sensor and the sensor resistance should ideally beequal to 180 °. It is related to the fact that the conductivity and temperature are related with Arrhenius equation (1),

$$R = A \cdot \exp\left(\frac{E}{k \cdot T}\right) \tag{1}$$

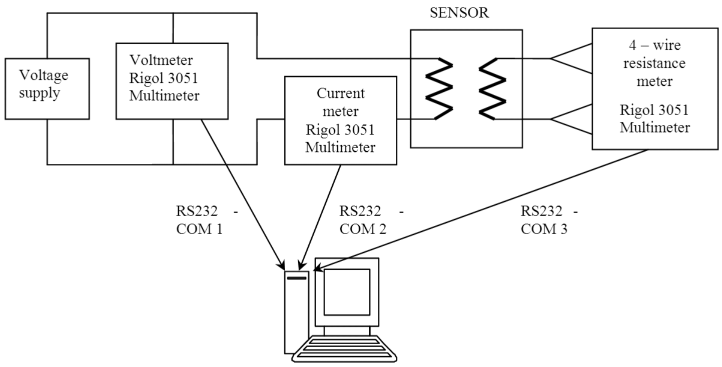


Fig. 2: Schematic view of the measurement platform for semiconductor gas sensors with temperature modulation

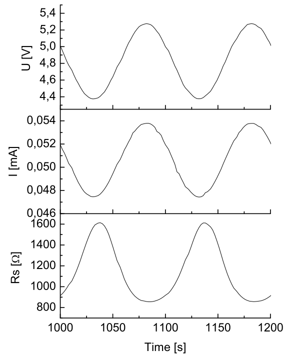


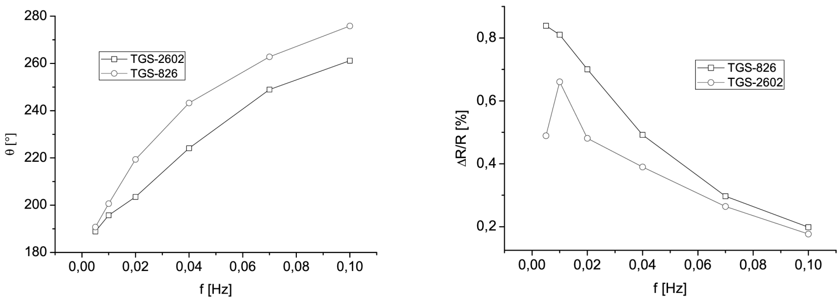
Fig. 3: Current (I) and voltage (U) of the heater, and the resistance of the sensing element (Rs) of TGS2602 under sinusoidal voltage with a frequency of 10 mHz

where R is the resistance, A is the material constant related to the energies required to form and move the charge carriers responsible for electrical conduction, E is the energy of activation, k is the Boltzmann constant and T is the temperature.

In Fig. 4 a difference between maximums of the resistance signal of the sensing element and applied voltage signal is presented. For the lowest frequency of 5 mHz, the shift is almost the same for both sensors and is equal about 190 °.Difference between sensing resistance and applied voltage signals, indicates that the temperature of the sensing element does not follow the change of the temperature of the heater. It can be seen that the shift is increasing faster for the TGS-826 than it is in the case of the TGS-2602. This is due to the fact that dimensions of the sensing element in the TGS-826 are larger than in the TGS-2602. It was observed that the shift, in case of both sensors is increasing as the frequency is increasing. For example, in case of TGS-2602 and frequency of 40 mHz, the shift was of 225 °.

As previously mentioned the temperature of the sensing element is smaller than the temperature of the heater. This can also be seen as a decreasing amplitude of the sensing resistance with the increase of frequency. Too high frequency of the excitation signal that modulates the temperature of the sensor, can reduce the range of temperatures of the sensing element. That may reduce the selectivity of the sensor to specific gases. Due, to that fact the change of the resistance (temperature) of the sensors under different frequencies of the heating voltage was investigated.

In Fig. 4b the ratio $\Delta R/R$ (where ΔR and R are the peak to peak and mean value of the sensing resistance, respectively) of two investigated semiconductor gas sensors under different frequencies of the excitation voltage signal is presented. It was observed the magnitude of changes of the signal is decreasing along with the increase of the frequency. For higher frequencies, the relative change of the resistance signal of both sensors is almost equal.



(a) (b)

Fig. 4: Difference between maximums of heater excitation voltage and the resistance of the sensing element of TGS-2602 and TGS-826 (a), change of the resistance of the sensing element of TGS-2602 and TGS-826 under different frequencies of the excitation voltage signal (b)

4. Conclusions

Two Taguchi type semiconductor gas sensors, TGS2602 and TGS826 had been investigated using prepared measurement system. Sinusoidal voltage signal with variable frequency was applied to the heater of each sensor in the presence of synthetic air. Sensing element and the heater of the sensors signals were analyzed during modulation.It was observed that modulation of the gas sensor can be performed using different frequencies, but the fact that increasing frequency entails the reduce of the range of working temperatures of the sensor, has to be taken into account.Future work will be devoted to investigate other waveform types of excitation signal.

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