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Plug-and-Play Electronic Unit for MOS and Thermocatalytic Gas Sensors †

Alexey Vasiliev [1,2,*], Sergey Merzlikin [2], Ilia Shakhnovich [2], Andrey Sokolov [2], Oleg Shulgin [2] and Pavel Agafonov [2]

1 NRC Kurchatov Institute, Moscow, Russia
2 LLC RIIIT, Moscow, Russia; Merzlikin.S@ostec-group.ru (S.M.); shakhnovich.i@ostec-group.ru (I.S.); sok44@yandex.ru (A.S.); Shulgin.O@ostec-group.ru (O.S.); agafonov.p@ostec-group.ru (P.A.)
* Correspondence: A-A-Vasiliev@yandex.ru; Tel.: +7-903-194-9551
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Abstract: The electronic plug-and-play electronic unit for controlling the semiconductor and thermocatalytic sensors is described. This is a controller with standard UART interface, which maintain preset working temperature of the sensor, measures resistance of the sensing layer, makes linearization of the sensitivity curve, compensates ambient humidity. In the case of thermocatalytic sensor, it measures power necessary to heat sensing and reference elements of the sensor, and the difference in these two values of power is proportional to the gas concentration. The digital output signal contains information about gas concentration, working parameters of the sensor, sensor type, enabling plug-and-play operation mode.

Keywords: plug-and-play electronic unit; semiconductor and thermocatalytical gas sensor; controller

1. Introduction and Motivation

Mass application of metaloxide semiconductror (MOS) and thermocatalytic (TC) gas sensors is recently restricted by individual calibration of electronic units with these devices. This problem becomes more complicated in the case of distributed safety and security networks were the sensors need periodic recalibration during their operation.

In this work we developed the smart sensor units permitting the stabilization of temperature of sensing layer, data acquisition, calibration of the sensor, supplying information about type of sensor, target gas, standard interfacing of the unit and other possibilities necessary to provide plug-and-play regime of gas sensor operation. The size of easy replaceable "smart" unit is of 25 (diameter) × 25 mm. The pre-calibrated units are suitable for "hot" substitution in a network under operation.

2. Results and Discussion

The goal of this work was the development of small sensor unit with very simple and robust connector for MOS and TC sensors. The device (Figure 1) has to meet the following main requirements:

- stabilization of heating element temperature with accuracy ±0.5 K, with a dynamic range from 120 to 500 °C;
- prevention from sensor overheating (not more than 500 °C);
- PWM frequency for temperature stabilization ≥1000 Hz;
- calibration of heating element in automatic mode (by measuring heater resistance—platinum wire or thick film—under normal conditions);

- measurement of semiconductor sensing layer conductivity in a dynamic range of 3 orders of magnitude with accuracy of 0.5% of maximum value;
- linearization, calibration and humidity compensation of sensor gas response;
- connection with external devices using standard, for example UART, interface.

The additional requirement was to minimize the relaxation time, when pre-set working temperature changes. It's necessary for identification of several target gases during one measuring cycle or for working in low power consumption mode (for example, one measurement per 10 s).

We developed a sensor unit that meets all these requirements (Figure 1). The unit in this picture is marked by arrow, it consists of two board 25 mm in diameter: the first one contains controller, humidity sensor, the second one is a communication board with electrical connector designed to assure explosion protection of the unit. As a result, the unit is suitable for "hot" replacement even at presence of explosive gases.

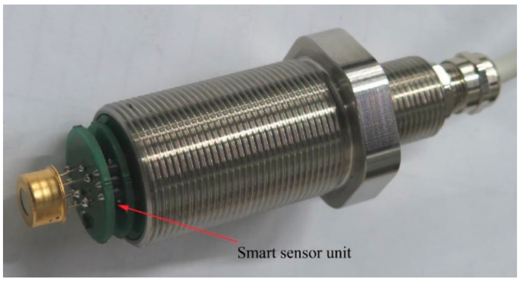

Figure 1. Measuring head based on smart sensor unit developed for the controlling of MEMS semiconductor sensors. Hot-replaceable smart sensor is marked by arrow. The substitution of this pre-calibrated part enables the utilization of different types of gas sensors (semiconductor, thermocatalitic, and others) with the same instrument.

The unit consists of microcontroller, two operation amplifiers and one transistor as a keying element. Supplied voltage is of 3.2 V, current without sensor is around 30 mA. The heating is provided by Pulse-Wide Modulation (PWM) with frequency of 1 kHz, range of on-off time ratio is 400–7600. This means that power supplied to the heater of semiconductor or thermocatalytic sensor can be controlled and measures with very high precision of 1/8000 s, 0.0125%. It is enough to keep temperature of sensing structure from 120 to 500 °C, if resistance of heater is below 80 Ohm at 20 °C.

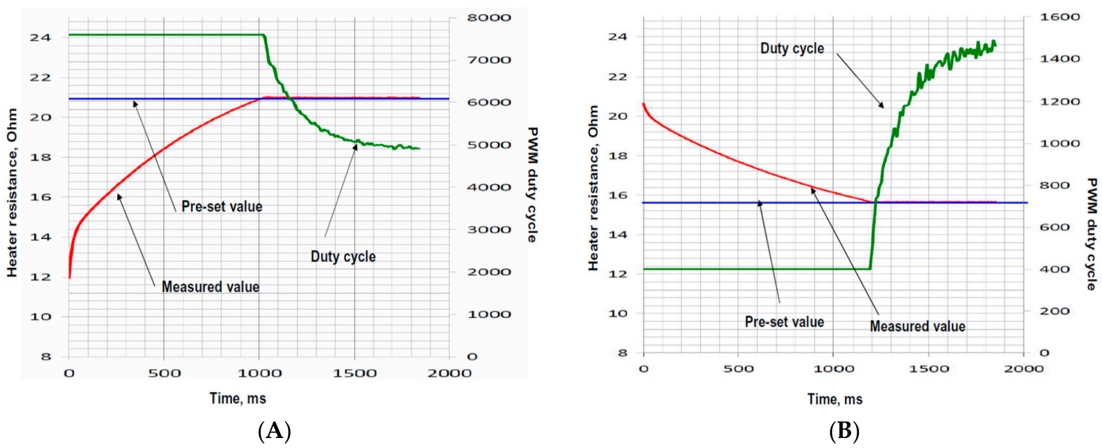

Figure 2. (**A**) Heating process of thick film gas sensor. Pre-set resistance corresponds to working temperature of 450 °C. 100% duty cycle of PWM corresponds to 8000 value at the right axis. τ_{90} of the heating process is of ~0.8 s; (**B**) Cooling process of thick film gas sensor. Pre-set resistance corresponds to working temperature of ~200 °C. 100% duty cycle of PWM corresponds to 8000 value at the right axis. τ_{90} of is ~1 s.

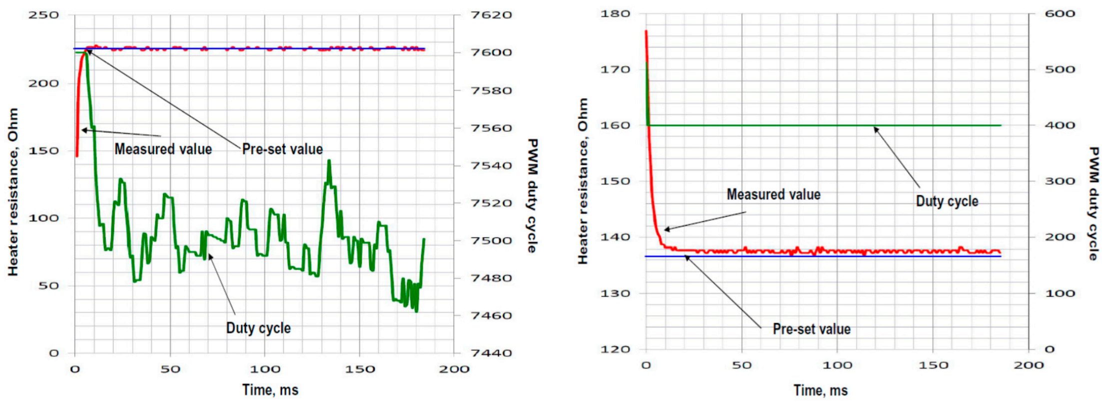

Figure 3. (**A**) Heating process of MEMS gas sensor. Pre-set resistance corresponds to working temperature of 350 °C. 100% duty cycle of PWM corresponds to 8000 value at the right axis. τ_{90} of the heating process is of ~8 ms; (**B**) Cooling process of MEMS gas sensor. Pre-set resistance corresponds to working temperature of 350 °C. 100% duty cycle of PWM corresponds to 8000 value at the right axis. τ_{90} is of ~8 ms.

The controller is designed to work with semiconductor and thermocatalytic sensors of different types: thick film sensors (chip size of 2.5 × 0.5 × 0.1 mm, power consumption of 220 mW at 450 °C); ceramic MEMS sensors (sensor is based on 12 µm thick alumina membrane, hot area size is of 300 × 300 µm, power consumption is of 80 mW at 450 °C); thermocatalytic sensors (spiral heater is made of 10 µm wire, spiral diameter is of 100 mm, power consumption of single element is of 60 mW at 450 °C). With MOS sensing layer deposited on SiO_2/Si_3N_4 MEMS substrate (R_{heater} = 117 Ohm at 20 °C, FBK, Trento, Italy) we achieved the working temperature up to 370 °C. Thick film sensors, thermocatalytic sensors, and silicon MEMS sensors are described in [1], ceramic MEMS is presented in [2].

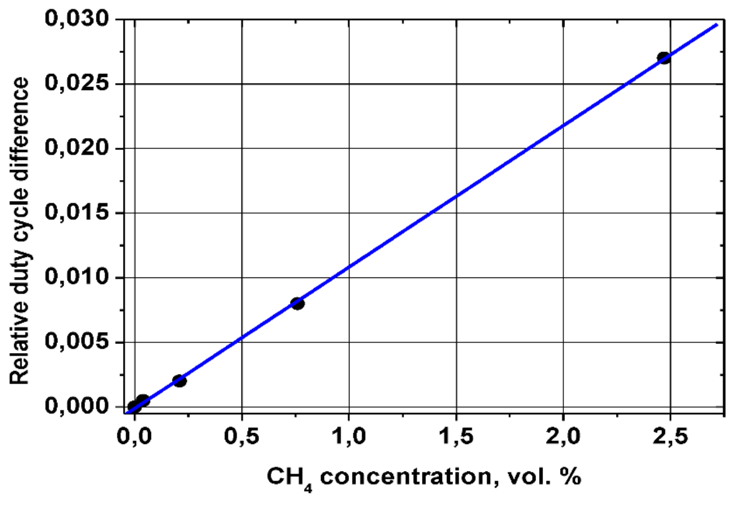

Figure 4. Response of thermocatalytic sensor to methane concentrations. Temperature of the sensing and reference elements of the sensor are stabilized independent of methane concentration in ambient air. The measured value (relative duty cycle difference) is a difference in power necessary to heat sensing and reference elements at various methane concentrations. This difference in power is measured as a difference in duty cycle of PWM temperature stabilization process.

We tested the characteristics of the units. The typical thermal response curves are presented in Figures 2 and 3. Of cause, time of relaxation defined as time necessary to reach 90% of final value of temperature (τ_{90}) depends of properties of sensor structure. We used different sensors made with various technologies. They have internal thermal characteristic time of τ_{90} ~1 ms (silicon based

MEMS), ~40 ms (ceramic MEMS), and ~1 s (thick film sensor). The results of measuring show that for all kinds of the sensors desired results were achieved (Figures 2 and 3). For example, time interval from the beginning of heating to the stable holding the target temperature of 450 °C of the sensor with τ_{90} = 1 s (thick film sensor) is ~1.2 s and <10 ms for SiO_2/Si_3N_4 MEMS sensor (intrinsic (τ_{90} ~ 1 ms). The root-mean-square (RMS) error of resistance in the holding mode is 0.005 at average resistance 20.61 Ohm (<0.03%), the RMS for sensing semiconductor structure is 0.3%.

The methane response of the thermocatalytic sensor with electronic unit assuring the measurement of heating power at stabilized temperature of the sensing and reference elements is presented in Figure 4. This approach consisting in stabilization of sensor temperature at different gas concentrations and measurement of heating power necessary to maintain this stable temperature has evident advantage compared to traditional measurement of voltage misbalance of Wheatstone bridge, because the catalyst working at stable temperature is more stable and self heating of the sensing element due to catalytic reaction can not burn out the sensor at high concentration of target gas. Indeed, the results obtained in this operation mode demonstrate perfect linearity of sensor response.

Conflicts of Interest: The authors declare no conflict of interest.

References

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