Applying catalytic sensor in non-volatile wireless sensor networks

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Abstract

Fundamental solutions were developed and energy-saving parameters of a catalytic sensor operation were chosen for using a catalytic sensor in non-volatile wireless sensor networks. Energy-saving mode is based on cyclic method, where every cycle includes short current pulse and the pause between pulses does not exceed regulated by normative documents "response time" for sensors working in continuous mode. To reduce current pulse duration, heating and measuring processes are combined. Two-staged pulse shape was chosen for this, the first stage accelerates heating, the second one is measuring, where we reduce sensor supply voltage and heating temperature, form transient cooling of the sensing element, then measure cooling rate, which is proportional to measured concentration of flammable gas in the air.

Introduction

The advantages of wireless sensor networks, that don't need cable routing for power and data transfer, are attractive for developers of the systems for monitoring explosiveness of atmosphere that could contain methane and/or other flammable gases and vapors. Such monitoring objects are industrial premises and spaces (i.e. minings), and also dwellings where natural gas is used as fuel.

Catalytic sensors are widespread among the existing devices for detecting combustible gases due to, mostly, very simple technology of sensing elements manufacture that doesn't need unique equipment.

A catalytic sensor is characterized by the simplicity of design solutions. It has small weight and size, high output signal and an ability to sense only flammable gases and vapors what is very valuable for explosimetry, when evaluation of flammable gases mix is required. Cross-sensitivity to non-flammabe gases is absent at all.

A catalytic sensor is also characterized by a relatively low power consumption, which eliminates problems with intrinsically safe circuits. Diffusion supply of the analyzed gas mixture implemented in the sensor design does not require boosters, and the overlap of the diffusion flux by the ceramic gas filter provides explosion protection and defense against dust and wind.

The preference of using catalytic sensors in wireless sensor networks is dictated not only of the listed advantages, but also because of their lower market cost compared with other known combustible gas sensors (semiconductor, optical).

An important indicator of a particular type sensor in a wireless sensor network is its power consumption that should be minimized.

The aim of the research is the choice of the characteristics of pulsed power of sensing elements (SE) of the catalytic sensor that operates in a cyclic mode, providing the minimum pulse width that is sufficient to heat up a SE to operating temperature and perform measurements.

Results and discussions

As the object of study a commercially available catalytic sensor manufactured by “NTC IGD” (Russia) (Fig. 1).

Power consumption at the static (continuous) mode – 70 mW, current – 50 mA, voltage 1.4 V, the sensitivity is 15 mV /% CH4, the response time is less than 15 seconds.

Selection and evaluation of the pulse characteristics was carried out on the stand, a block diagram is shown on Fig. 2.

As a result of the research of the different variants of the pulsed power providing short-term heating operation and the response time of the measured parameter (concentration of methane) it was established that that the most energy-efficient mode is a two-staged pulse combining heating and measurement of the signal from sensor with forcing the heating in the first step pulse, and in the second step - measuring, while cooling process, the changes of heat proportional to the concentration of CH_4 in a controlled atmosphere. Two-staged pulse with different pause values between pulses is shown on fig. 3.

Functions of formation of the current pulses with exact duration and amplitude, the synchronization processes are carried out by the microprocessor 6 (Fig.1) with 10-bit DAC (digital-to-analog convertor) and 12-bit ADC (analog-to-digital convertor). Since the DAC has low output power, the final formation of the current pulse occurs in the pulse generator unit, which has high-speed characteristics allowing it to not distort the time and amplitude boundaries of the current pulse.

The first pulse stage with stabilized voltage, increased with respect to its working value of 2-2.5 times, speeds up the heating process and the sensor provides sensor heating for ~ 80 ms to a temperature higher than working voltage by 100°C.

The second pulse stage is generated on reaching regulated sensor overheating in the first stage by the abrupt decrease in the supply voltage to the value corresponding to the sensor temperature enough to work in the diffusion area of oxidation of fuel gas to the catalytically active surface of SE. Measuring the concentration of combustible gas is produced during the transient cooling of sensor.

The differential signal proportional to the concentration of combustible gas is formed in the block 5, as the difference between the readings of the two fixed time points of the transient thermal cooling of the sensor element.

Fig. 4 shows a process of heat dispassion on transient from 100 to 200 ms. The lower curve reflects the process of cooling of the sensor at 0% CH_4, following by curve that describes cooling at 1.01% CH_4, and the top curve – at 2.5% CH_4.

It is experimentally established that the greatest difference in the rate of cooling is observed in the initial stage of the transition process.

So, for the tested sensor with weight and size parameters (determining diameter d = 0.3 mm, mass m = 0.0008 g), accelerated heating time was 80 ms, registered duration of cooling – 100 ms, the total time of the transition – 200 ms.

To evaluate the heat dissipation dependence on the entire measurement range from 0 to 2.5% v/v CH_4, signals on heat transfer were measured for concentrations 0%, 0.17%, 0.45%, 1.01%, 1.5%, 2.5% v/v CH_4. The dependence of the signal on CH_4 concentration is shown on Fig. 5, where the calibration curve is slightly different from the linear dependence. Power consumption in the two-stage pulse duration of 200 ms was, in the first stage for 80 ms the current pulse changed from 0.3 A to 0.07 A = 0.014 A*s; in the second stage for 100 ms currentpulse – 0.07 A to 0.05 A = 0.006 A*s. Total consumption for 1 year at a selected shape and pulse duration and pause time equal to 30 will be 5.3 A/h.

As an independent power supply of the sensor it is possible to use a removable battery chemical elements or solar cell incorporated with the buffer battery.

Experimental results

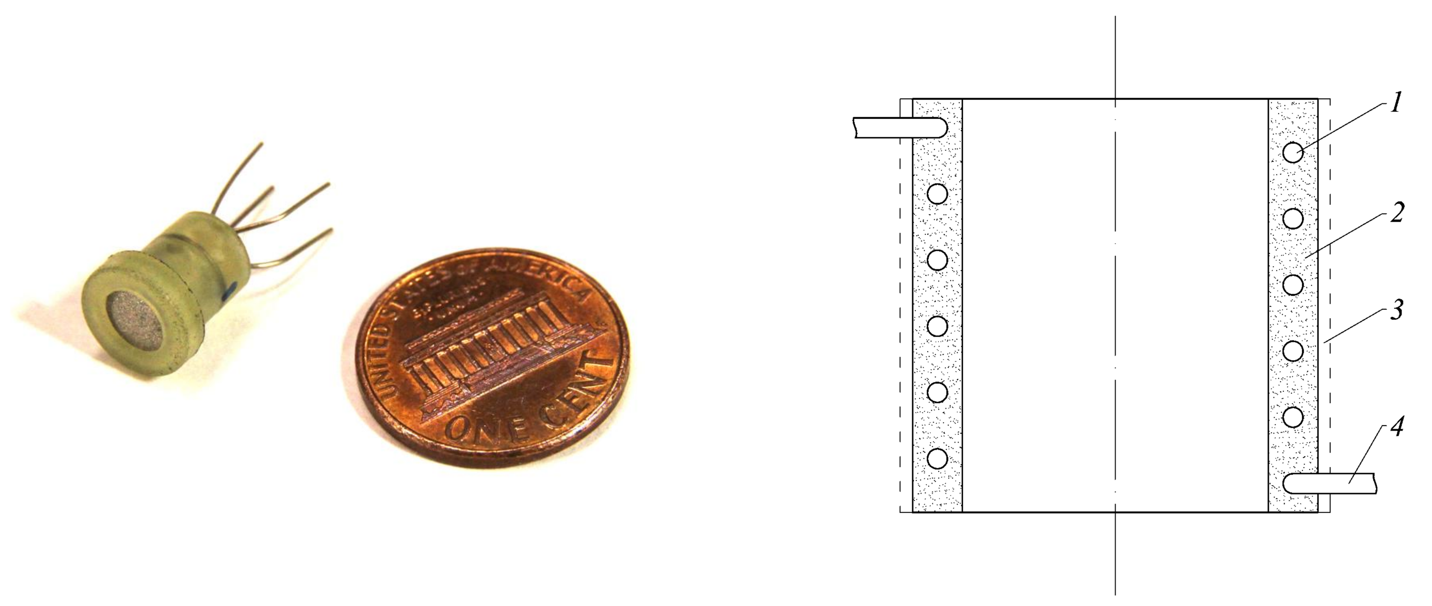

Fig.1. Sensor view and scheme. 1 – platinum wire, 2 – carrier (Al_2O_3), 3 – catalyst, 4 – leads

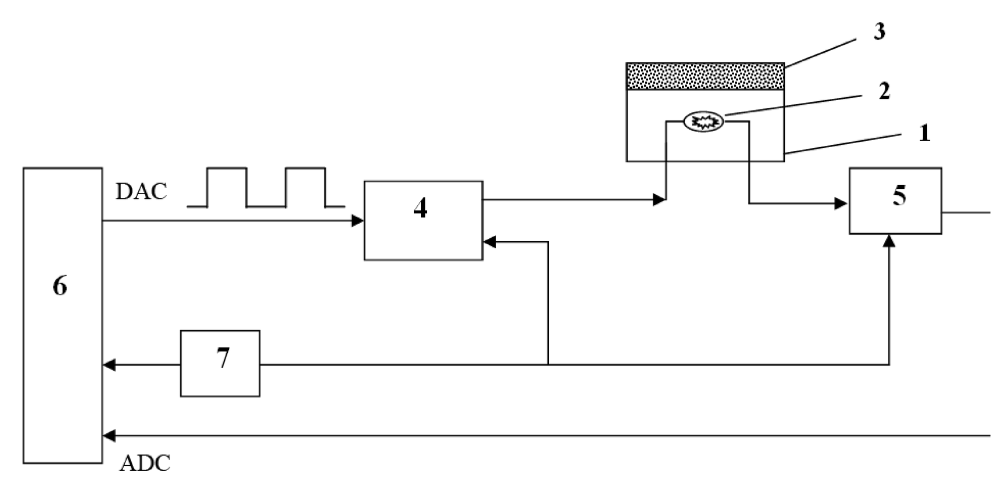

Fig.2. Stand block-diagram. 1 – reaction chamber, 2 – sensing element, 3 – gas exchange filter of a porous cermet 4 – pulse generator, 5 – measurement and display unit, 6 – microcontroller, 7 – power supply unit.

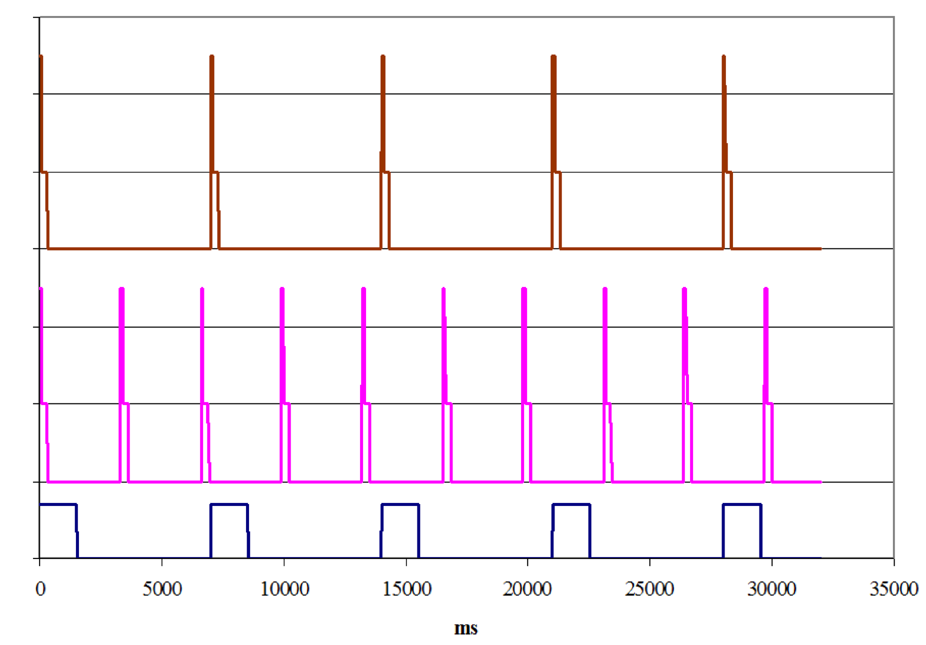

Fig. 3 Two-pulsed shape diagram

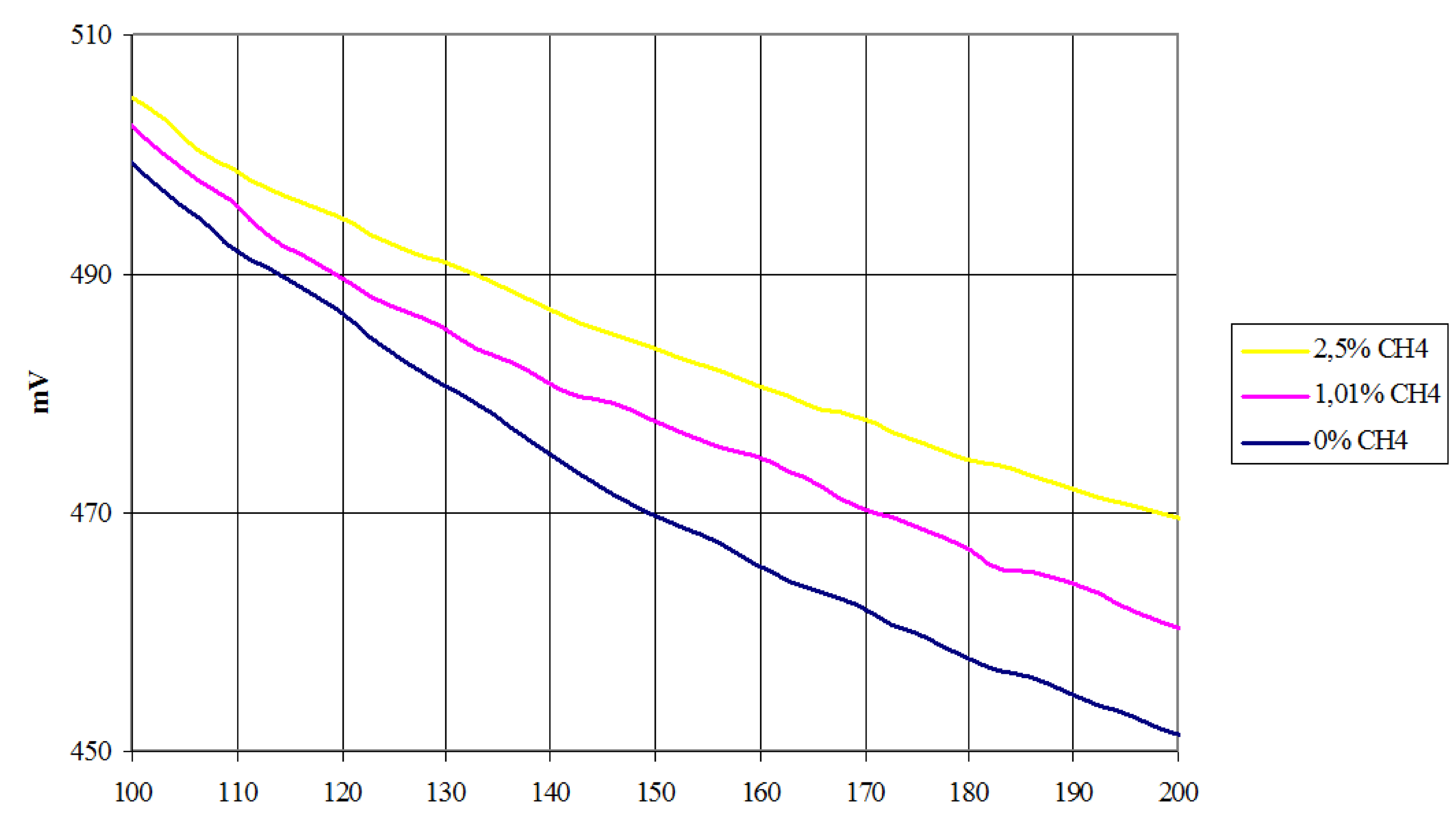

Fig. 4 Curves of sensor transient cooling in air and with different concentrations of CH_4.

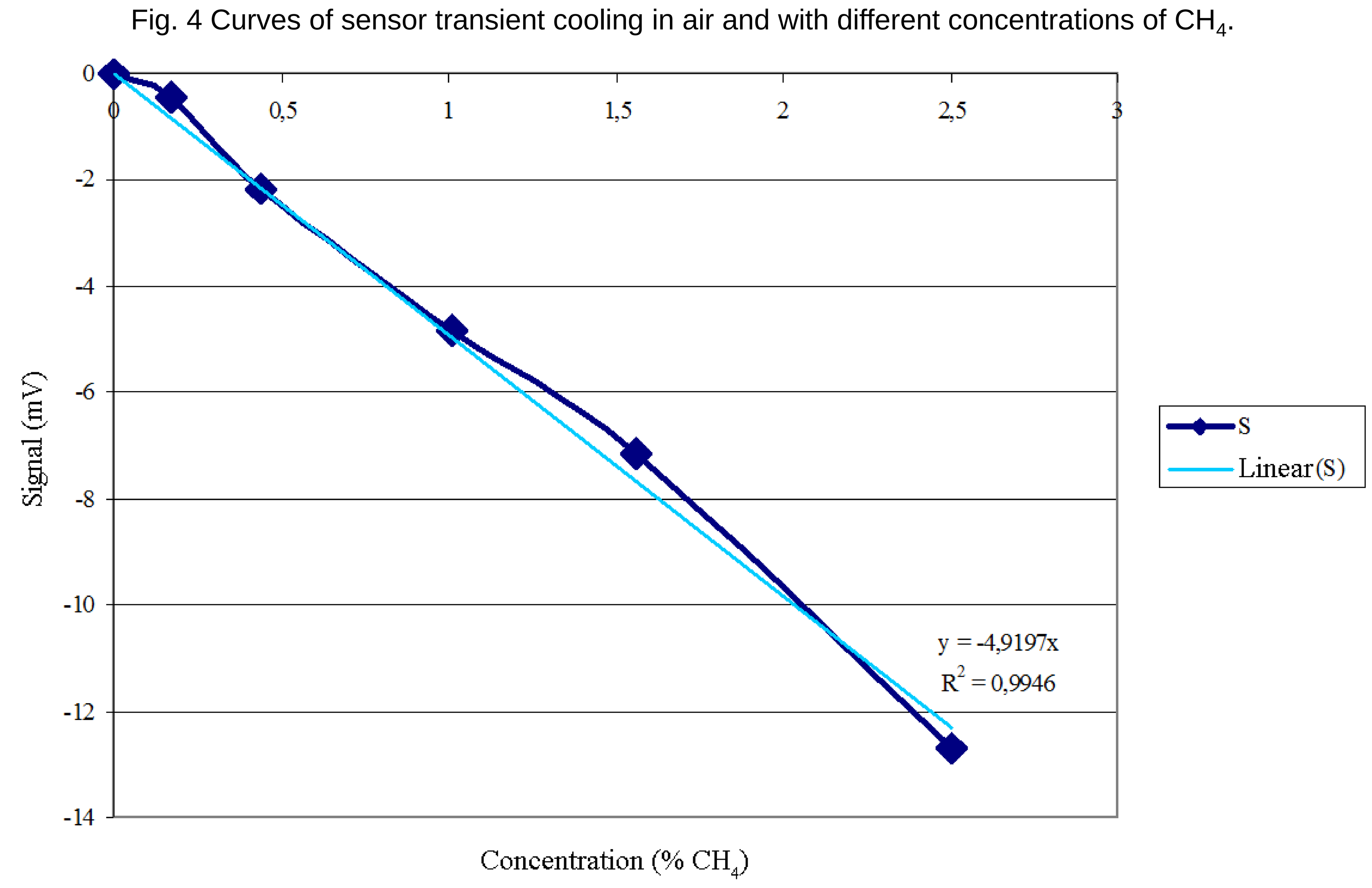

Fig. 5 Calibration curve $S_{(mV)} = f(\%CH_4)$

Conclusions

Explored way of forming a two-staged pulse current providing boosted heating of the sensor in the first stage and measuring the output signal using the fast and thus energy-saving cooling effect was evaluated on commercially available sensor manufactured using bulk technology, which is not in spirit of the age. Recently there have been publications on the development of sensors using planar and MEMS technology, using new materials, the main advantage of which – small weight and size parameters and low power consumption. We believe that we investigated a method of forming a two-stage pulse current that can be used in newly developed sensors and will further reduce power consumption.

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