Semiconductor Physics, Quantum Electronics & Optoelectronics, 2011. V. 14, N 3. P. 330-333.

PACS 07.07.Df

Sensors for fire gas detectors

V.R. Kozubovsky, V.V. Kormosh, I.P. Alyakshev, N.H. Lishchenko
Uzhgorod National University

Abstract. Considered in this paper are the possibilities to reduce energy consumption in semiconductor gas sensors with the purpose of their application in multichannel fire gas detectors and gas alarms with an independent power supply.

Keywords: gas sensor, carbon monoxide, adsorption sensing element.

Manuscript received 20.09.10; revised manuscript received 16.08.11; accepted for publication 14.09.11; published online 21.09.11.

1. Introduction

In recent years in Ukraine, a lot of attention has been focused on public protection from possible carbon monoxide (CO) poisoning. This is an extremely toxic gas without color or scent that can accumulate in closed buildings when motor engines are running, during incomplete fuel burning, or during fires and frequently has lethal outcomes.

The cause of CO accumulation during fires is its release in the early stages of fire when smouldering is prevalent. In such situations, temperatures and optical density (smoke formation) inside the building do not rise significantly, and the traditional means of fire detection (heat and smoke detectors) do not yet trigger. Therefore, there is an obvious need to develop a fire gas alarm based on traditional electrochemical and electrochemical-semiconducting gas sensing element (adsorption sensing element – ASE) [1].

ASE operates through electrochemical reactions taking place on the surface of the semiconductor doped with a catalyst (for example, in the case of CO, catalyst Pd: $Pd + O_2 \xrightarrow{400\,°C} PdO$; $PdO + CO \xrightarrow{110\,°C} Pd + CO_2$). As a result, its conductivity changes due to saturation of the surface of the material with gas of acceptor or donor type (oxidizer or reducer).

Among the advantages of such elements are high sensitivity (to the tenths of ppm); linear dependence of the output signal in a wide range of gas concentrations; long life; resistance to aggressive gases and considerable overloads in terms of the concentration; stability; fast response; and low price. However, this type of a sensor has a significant deficiency: its high power consumption (around 100-200 mW) thereby making it an unlikely candidate for use in gas and fire alarms with an independent power supply. It also dramatically increases energy consumption for fire receiving-controlling devices which supply power to the alarms.

Considering these factors, the energy efficient ASE CO developed by our team specifically for this class of devices is of great relevance. It is designed to convert the concentration of carbon monoxide in the air into an electrical signal in devices with an independent power supply that have a dual purpose – to analyze gas pollution according to the EN 50194 [2] and to prevent fires in accordance with EN 54 [3], ISO 7240 [4].

We have achieved the reduced energy consumption in our ASE as follows:

a) reduction of the size of sensing layer and substrate with a heater;
b) fine tuning of the duration of the cycles of gas components desorption (when ASE is warmed up) and adsorption (when ASE is cooled down).

As far as size reduction of the ASE is concerned, it is clear that the smaller the mass of the sensing element, the lower the power consumption by the sensor needed to warm it up to a certain temperature. Fig. 1 shows maximum power consumption by the sensor in standard operating mode – thermal cleaning mode 10 s (heating temperature 450 °C) and measuring mode 18 s (CO control temperature 100 °C). The values reflect when the sensing element is applied directly to the heater (TGS 3870), when the size of the dielectric substrate with a thick-film heater is 1.5×1.5×0.3 mm ($ASE-16$), when the size of the dielectric substrate with the thick-film heater is 2.0×0.5×0.3 mm ($ASE-01$), and when a film dielectric substrate with a vacuum-evaporated heater is used (experimental substrate). It is obvious that the optimal solution is the film dielectric substrate with vacuum-evaporated heater. However, the transition to this type of substrates means a complete overhaul of current technology for ASE production, which is unlikely to appeal to ASE manufacturers in the nearest future.

An easier choice for the manufacturing industry would be fine tuning the ASE operation parameters.

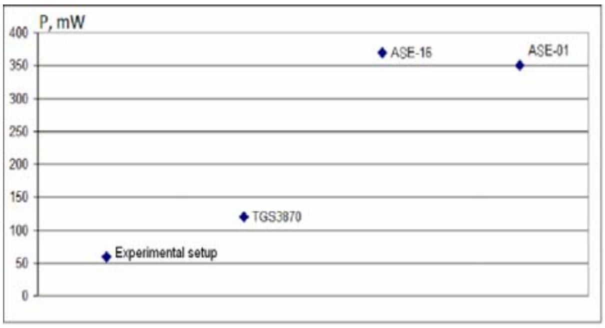

Fig. 1. Maximum power consumption by sensors with various heating designs for the sensing element.

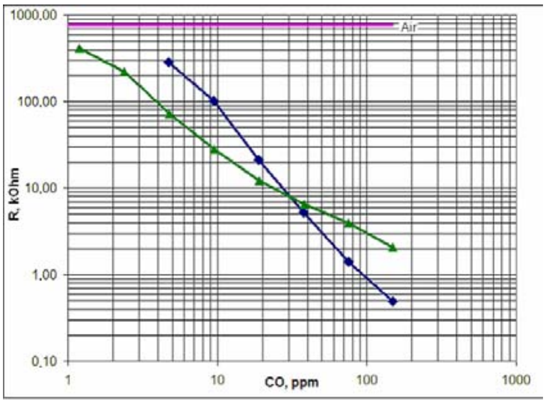

Fig. 2. Concentration dependence of the ASE-16 sensing element resistance R in the standard mode 10-18 s (▲) and with period 1.5-30 s (■).

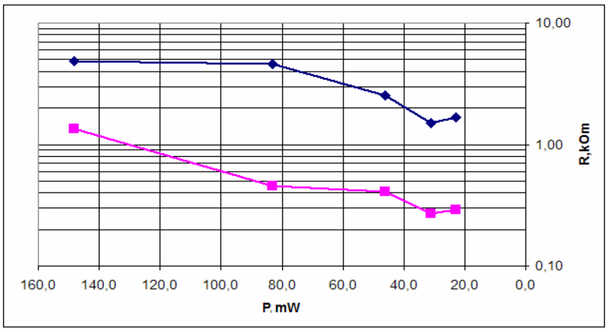

Fig. 3. Dependence of the ASE resistance R to CO on average power consumption (depending on the cool-down time) with the thermal cleaning duration of 1.5 s at the CO concentration: 50 ppm (♦), 150 ppm (■).

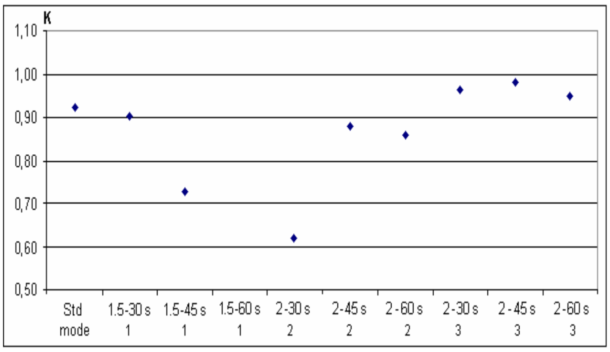

Fig. 4. Dependence of the influence of relative humidity on ASE signal at the CO concentration 50 ppm (relative units) in various operation modes of the ASE power supply circuit and information read-out circuit; $K = R_{100}/R_{40}$.

First of all, to decrease energy consumption, it is possible to use a pulse voltage to power the heater. Indeed, when using the pulse voltage to power ASE, the heat dissipation on passive elements of the control circuit is decreased. Energy savings make up to about 30%.

Second, it is possible to minimize the ASE warm-up period (450 °C) and maximize the period when it is cooled down to the temperature of 100 °C and below. It is clear that the sensor's responsiveness to CO increases as the duration of the cooling cycle goes up (see Fig. 2).

As far as power consumption is concerned, of course it goes down when the cool-down period increases and the warm-up period decreases. In this case, ASE's sensitivity (change of its resistance) to CO initially increases and then plateaus at a certain level (see Fig. 3).

However, when the cooling period is prolonged, there is a greater influence of humidity on the sensor's resistance and, therefore, on its output signal (condensation takes place on the sensor surface). Fig. 4 shows how humidity affects the sensor in different operation modes (1.00 – humidity influence is zero) at a direct voltage power supply of sensitive layer (mode 1 – see Table). It is obvious that the 1.5 to 30 s and 2 to 45 s modes are acceptable as humidity influence is at 10%.

To reduce the effect of humidity on fire alarm readings, it is also possible to use pulse power supply for the information read-out circuit. Fig. 4 shows humidity influence $K = R_{100}/R_{40}$ under different operation modes of the ASE power supply circuit and information read-out circuit, here R_{100} is the resistance at 100% of relative humidity and R_{40} is the resistance at 40% of relative humidity.

The experimental research involved two power supply modes for the information read-out circuit at the pulse voltage: mode 2 – the circuit received short pulses lasting $\tau = 10$ ms with the amplitude 5 V and period $T = 1$ s; and mode 3 – the circuit received a short single pulse lasting $\tau = 10$ ms with the amplitude 5 V at the end of each period. As shown in Fig. 4, humidity influence in the single-pulse information read-out mode is significantly lower, and the sensor power supply mode 3: 2-60 s (thermal cleaning time is 2 s, cooling period is 60 s, and single-pulse read-out at the end of the period is 62 s) is completely acceptable. In this case, the ASE power supply circuit does not require more than 20 mV.

The results of our research for various power supply modes are summarized in Table.

Table. The impact of relative humidity on different parameters of sensor ASE-16.

Operation mode	Relative humidity, %	Voltage for various CO concentrations, V		Resistance at different CO concentrations, kOhm		Relative sensitivity (relative units)	Effect of humidity on the signal for various CO concentrations, (relative units)	
		50ppm	150ppm	50ppm	150ppm	R_{150}/R_{50}	$K_{50} = R_{100}/R_{40}$	$K_{150} = R_{100}/R_{40}$
Stand. mode	100	2.84	2.19	12.0	7.1	0.59	0.92	0.95
	40	2.94	2.25	13.0	7.4	0.57	1.00	1.00
Mode 1: 1.5-30 s	100	1.9	1.35	5.6	3.4	0.60	0.90	0.92
	40	2.02	1.43	6.2	3.6	0.59	1.00	1.00
Mode 1: 1.5-45 s	100	1.84	1.21	5.3	2.9	0.55	0.73	0.77
	40	2.22	1.46	7.3	3.8	0.52	1.00	1.00
Mode 1: 1.5-60 s	100	2.75	1.5	11.1	3.9	0.35	1.49	1.10
	40	2.25	1.4	7.4	3.5	0.48	1.00	1.00
Mode 2: 2-30 s	100	2.04	0.86	6.3	1.9	0.30	0.96	0.74
	40	2.09	1.1	6.5	2.6	0.39	1.00	1.00
Mode 2: 2-45 s	100	1.72	0.84	4.8	1.8	0.39	0.88	0.96
	40	1.87	0.87	5.4	1.9	0.35	1.00	1.00
Mode 2: 2-60 s	100	1.38	0.72	3.5	1.5	0.44	0.86	0.87
	40	1.54	0.81	4.1	1.8	0.43	1.00	1.00
Mode 3: 2-30 s	100	**1.8**	**0.9**	5.1	2.0	0.39	0.97	1.00
	40	**1.84**	**0.9**	5.3	2.0	0.38	1.00	1.00
Mode 3: 2-45 s	100	**1.72**	**0.82**	4.8	1.8	0.37	0.98	0.97
	40	**1.74**	**0.84**	4.9	1.8	0.38	1.00	1.00
Mode 3: 2-60 s	100	**2.09**	**0.9**	6.5	2.0	0.31	0.95	0.97
	40	**2.15**	**0.92**	6.9	2.1	0.30	1.00	1.00

Reduction in power consumption by the fire gas alarm can also be achieved through the microcontroller's hibernation operation mode, which in active mode, too, consumes a considerable amount of energy.

We designed a system concept for multisensor fire detectors with a gas-sensing fire detector and heat detector. Fig. 5 shows the example of its operation. The sensor works in cyclical regime – thermal cleaning mode 2-3 s (heating temperature 450 °C) and cooling mode 28 s. The measurements are made in the end of cooling mode (*Rh*). The terminal of microcontroller converts them to the high-voltage state except times of the measurement (about 1 ms). Thermal cleaning begins with pre-heating (pulse of heating with 50% filling and control of heaters resistance over 0.5-1 s). Pre-heating is completed when the heater reaches the resistance value 1.5 Rh_0 (Rh_0 is the resistance value in the cold mode). Then heating by a total voltage occurs within the time 2 s. The heater resistance is controlled by a pulse from microcontroller exit *P* through the resistor *R*3. The heater voltage is read off by an analog-digital converter.

The signal from sensitive layer is taken under different loading. Layer integrity is verified by using the resistor *R*2 and changing the concentration – by using *R*4.

All-in-all, it is possible to build an ASE CO-based fire gas alarm with low energy consumption, and there are virtually no technical difficulties in achieving this. The problem lies in the absence of current reference data for this type of devices. In addition, the fire gas alarm that measures the CO concentration (or that of another gas) is, in essence, an instrument of measuring technology and as such a subject to metrological control (i.e., conducting State approval tests, adding to the National Registry of the means of measuring technology, conducting State control tests, verification of the devices after manufacturing and throughout operation). In other words, to develop normative documentation and launch a full-scale production of this type of devices, there needs to be a coordinated effort between two departments (plus the manufacturer of course) – the State Standard and the State Fire Safety departments, which is hard to achieve.

We have implemented serial production of energy saving ASE CO and CH_4 and also gas contamination detectors, which are simple to use, are capable of long

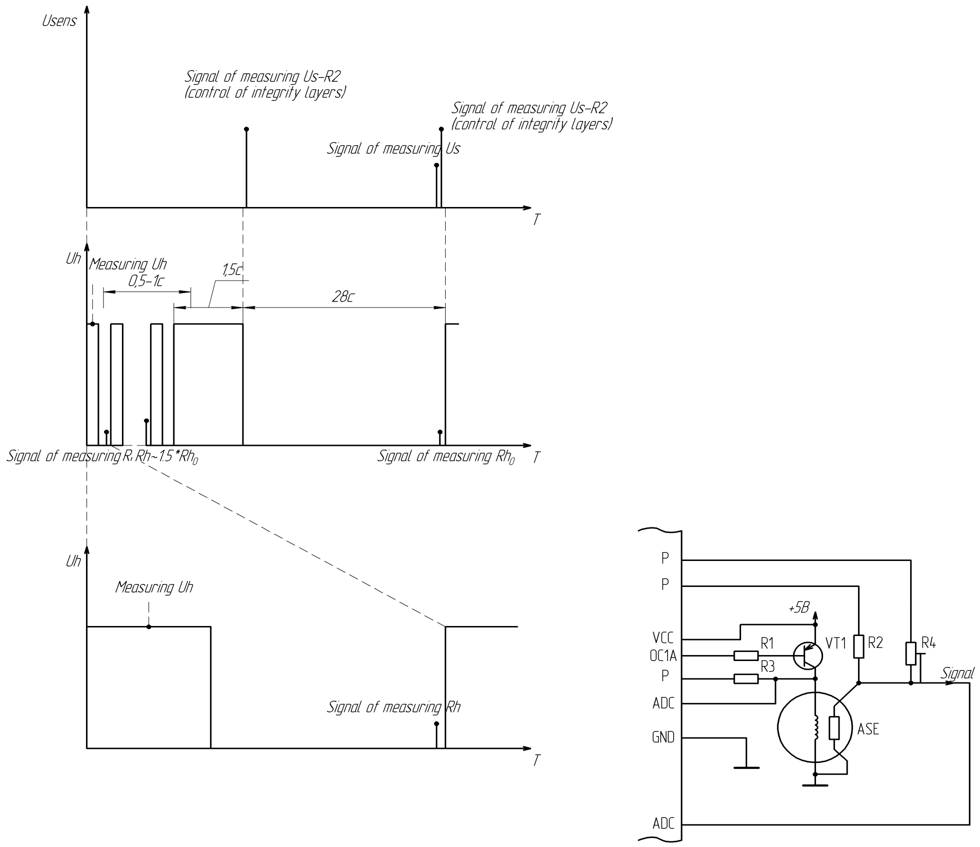

Fig. 5. The method to measure gas concentrations and operation mode.

continuous operation and long-rage signal transmission, are compact and lightweight, and are priced very competitively.

Application of these devices in systems of emergency and fire notification will allow to:

a) detect initial stages of fire;

b) prevent dangerous and emergency conditions and people poisoning.

The ASE-based carbon monoxide detector GSB – 01 – 3 developed by our team is fully compliant with the European Standard EN 50291 **Electrical apparatus for the detection of carbon monoxide in domestic premises.** Beside their direct purpose, these devices may also be used as gas-sensing fire detector in accordance with EN54 – 7 : 2004 Fire Alarm Systems. As a matter of fact, different types of smoke contain a CO concentration that by far exceeds the signal concentration in GSB – 01 – 3. Therefore, the alarm triggers even in presence of small amounts of smoke. Moreover, to compensate for temperature impacts, GSB – 01 – 3 has a thermistor controlled by the device microprocessor. This means that with minor program adjustments, GSB – 01 – 3 can also be used as a heat detector.

Presently, along with private company "Arton", we are conducting research in order to develop a multisensor fire detector that will comply with existing normative documents.

References

1. V. Kozubovsky, Using gas detectors in fire alarm systems // *Metrologiya ta prylady*, **3**(11), p. 26-29 (2008), in Ukrainian.
2. EN 50291: 1999. Electrical apparatus for the detection of carbon monoxide in domestic premises.
3. EN 54-1: 1996. Fire detection and fire alarm systems – Part 1: Introduction.
4. ISO 7240-1: 2005. Fire detection and alarm systems – Part 1: Generalities and definitions.