Study of electrophysical characteristics of metal oxide sensors based on SnO_2 at given concentrations of acetone

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The stability of electrical conductivity of SnO_2-based metal-oxide gas sensors fabricated by sol-gel technology in laboratory air has been investigated. Various oxides were used as modifiers: ZnO, BaO, CuO, NiO, V_2O_5, MoO_3. Measurements of electrical conductivity of semiconductor gas sensors were also carried out when given concentrations of acetone vapor were applied to their surface.

Keywords: electrical conductivity, adsorbtion, gas sensor, stability, sensitivity.

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The study of long-term stability of the electrophysical characteristics of semiconductor metal-oxide gas sensors (MOS) designed to determine volatile organic compounds in atmospheric air is crucial for metrology. It should be noted that the use of MOS in biomedicine for rapid diagnostics of a wide range of diseases has been in the focus of recent research [1,2].

In the present study, the long-term stability of MOS readings in laboratory air at constant temperature was investigated for composite materials based on SnO_2 with ZnO, BaO, CuO, NiO, V_2O_5, and MoO_3 additives in a quantitative ratio of 1:0.035 (mass) fabricated by sol-gel technology [3,4]. A small batch (7–10 units) of gas sensors of a given composition in standard TO-8 packages was introduced into a chamber with a volume of 9 l. Certain predetermined concentrations of acetone vapor were applied to gas-sensitive elements. This volatile organic compound was chosen for the fact that acetone is both a toxic substance (its concentration in atmospheric air is monitored in certain production operations) and a biomarker of various diseases associated with liver and kidney dysfunction, poisoning, and endocrine pathologies. The conductivity of the gas-sensitive layer of the sensor's composite material was measured at a constant surface temperature, which was set by applying a common voltage to platinum heaters. Owing to the difference in resistance of the heating elements of sensors, the temperatures of their gas-sensitive layers varied slightly within the range of 400−450°C. A Hamilton microsyringe was used to introduce the specified amount of acetone into the chamber. The sample concentration inside the working chamber was calculated using the following formula:

$$C_V = \frac{V_l \rho_l RT}{MV_o P}, \qquad (1)$$

where C_V is the volume concentration of the sample substance in the chamber [ppm], V_l is the substance volume in the liquid phase [μl], ρ_l is the substance density in the liquid phase [g/cm^3], $R = 8.314\,\mathrm{m}^3 \cdot \mathrm{Pa}/(\mathrm{K} \cdot \mathrm{mol})$ is the universal gas constant, T is the temperature of laboratory air in the chamber [K], M is molar mass [g/mol], V_o is the chamber volume [m^3], and P is the atmospheric pressure [kPa].

Figure 1 illustrates the stability of the electrophysical characteristics of sensors in laboratory air under heating. According to the data presented in Fig. 1, *a*, the coefficient of variation of sensor readings over a long period of time (approximately one month) at a certain given surface temperature was less than 4%. At the same time, a significant drift of the electrophysical characteristics of sensors in air at a constant temperature is observed for the SnO_2:NiO and SnO_2:V_2O_5 compositions (Fig. 1, *b*): the variation coefficient exceeds 11%.

Figure 2 shows the concentration dependences of sensor sensitivity $S = \frac{\sigma}{\sigma_0} - 1$, where σ is the sensor conductivity at a certain concentration of acetone and σ_0 is the sensor conductivity in laboratory air. The SnO_2:CuO and SnO_2:V_2O_5 compositions are the most sensitive to acetone. A power function typical of gas adsorption models (see [5–7]) was used to approximate the concentration dependences for all the studied MOS compositions.

It can be concluded that the sensitivity of the studied sensors to acetone is generally low: it does not exceed 0.5 at acetone concentrations below 400 ppm. It should be noted that the SnO_2:CuO material with added Pt (0.15%) synthesized in the same process has a higher sensitivity at an acetone concentration of 50 ppm than the studied sample of the same composition (SnO_2:CuO) presented with significantly higher concentrations of acetone (up to 900 ppm).

Although the stability of readings of most samples in air is acceptable, the sensitivity of sensors to acetone is too low for biomedical applications, since the typical working concentration range there is 1−100 ppm. This problem may be solved by doping SnO_2 with, e.g., Pt and Pd [8–10] to

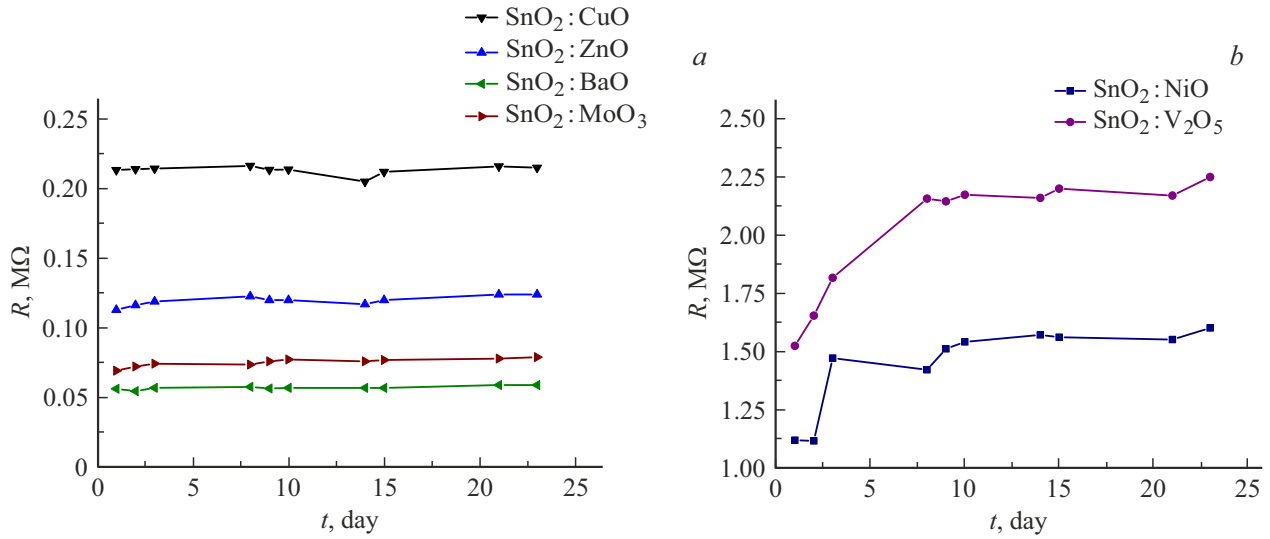

Figure 1. Stability of the electrophysical characteristics of sensors in laboratory air.

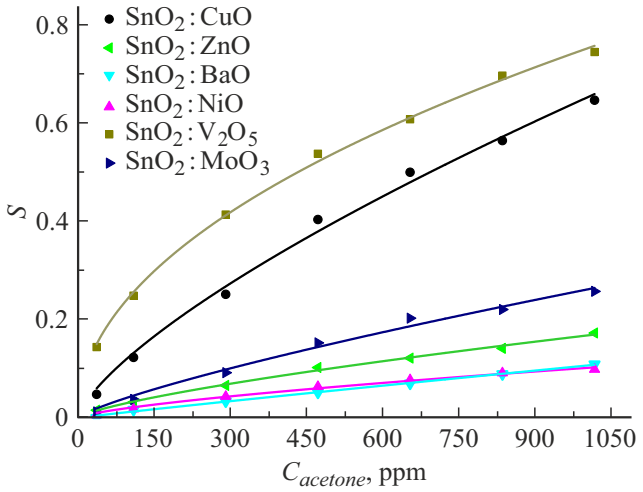

Figure 2. Concentration dependences of the sensitivity of sensors to acetone.

produce specific adsorption centers. At the same time, the SnO_2:CuO sensor examined in the present study is reliable enough to be used as an alarm for exceeding the daily average threshold limit and the short-term exposure limit.

Conflict of interest

The authors declare that they have no conflict of interest.

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