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INVESTIGATION OF VOLT-AMPERE CHARACTERISTICS OF A GAS-SENSITIVE SENSOR BASED ON TIN DIOXIDE

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The volt-ampere characteristics of the sensitive elements of gas sensors are investigated and plotted in coordinates corresponding to various mechanisms of the transfer current. It has been established that the prevailing mechanism of current transfer in the section from 0 to 6 V is Om's law, in the interval (3 - 6) V the Mott's law is fulfilled, and at higher voltages deviations from these laws are observed. It is determined that the laws of Om and Mot confirm the mechanism of the flow of currents limited by the space charge.
Key words: *Tin dioxide; Sensor; Heterojunction; Gas sensing; Sensitive element*
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INTRODUCTION

Currently, microelectronic gas sensors are widely used for environmental monitoring, ventilation and air conditioning systems, household devices, and the automotive industry [1,2]. They are also employed to determine the maximum permissible concentrations of hazardous gases in mining, chemical, and metallurgical industries [3,4]. Among a wide range of metal oxide semiconductors, tin dioxide is considered the most promising sensing material [5]. Gas-sensitive resistive-type sensors are manufactured using tin dioxide, which detect the presence of gases in the air by measuring changes in resistance between contacts.

The miniaturization of gas sensors, while maintaining operational voltages, increases the electric field in the gap between contacts. This stimulates the migration of ion-adsorbed gas particles across the active layer surface, influencing the overall characteristics of gas-sensitive devices and enabling gas analysis and recognition [6,7].

Research into the electrophysical characteristics of metal-oxide-semiconductor structures typically involves measuring their volt-farad characteristics (often at high frequencies) for dielectric oxide layers and their volt-ampere characteristics (IVC) under direct current for oxide layers with relatively high conductivity. This study presents experimental results on the current transport mechanism in heterojunctions based on SnO_2/Si.

EXPERIMENTAL METHOD

The results of the study of current flow mechanisms in SnO_2 films based on the investigation of the current-voltage characteristics of test structures are presented. The object of the study is the sensitive element of a gas sensor. The crystal of the gas sensor, measuring 1×1 mm^2, contains the following elements: on an oxidized silicon substrate, a heater and contacts for the sensitive layer in the form of an intersecting pin structure, made based on Ti-Pt, and two gas-sensitive elements based on tin dioxide, doped with 1 at. % silicon [8]. The resistance of the heater is -29.8 Ohms. The sensitive elements have resistances of 4.2 and 4.6 MOhms, respectively.

For the research, the following equipment was used: two power sources (DC Power Supply HY 3005), three multimeters (MASTECHMY64), and a measuring stand [9-10]. The current through the gas-sensitive element is controlled by the voltage drop across the standard load resistance connected in series with the gas-sensitive element. The voltage applied to the sensitive element ranged from 0 to 30 V with a step of 1 V. As the voltage on the sensitive element increased, the current through the sensitive element also increased. The current values on the sensitive element ranged from 0 to 4.5 mA.

RESULTS AND DISCUSSION

Figure 1 shows the volt-ampere characteristic of the gas sensor's sensitive element, measured at room temperature in the voltage range from 0 to 31 V. It was found that with a change in voltage from 1 to 31 V, the current changes from 0 to 4.19 mA. From Figure 1, it can be seen that the volt-ampere characteristic of the sensitive element can be conditionally divided into 3 sections, each with a different slope: section 1 from 0 to 6 V, section 2 from 6 to 17 V, section 3 from 17 to 31 V.

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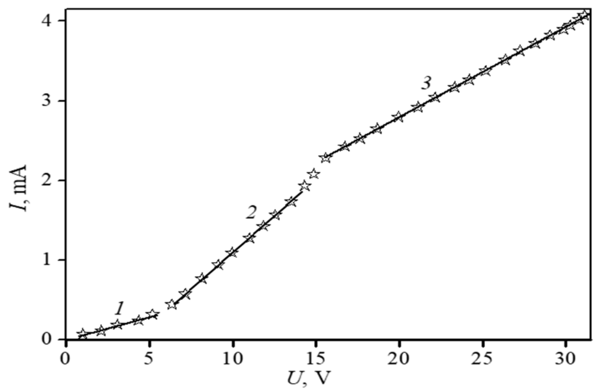

Figure 1. Volt-ampere characteristic of the gas sensor's sensitive element, measured at room temperature in the voltage range (0 - 31) V.

To evaluate the current conduction mechanisms, the volt-ampere characteristics were transformed into the following coordinates: I/U = F(U) - Ohm's law [11,12], $I/U^{1/2} = F(U^{1/2})$ - Poole-Frenkel mechanism [13-15], $I/U^2 = F(U^2)$ - Mott's law[16] (Fig. 2-4).

In the voltage range of (0 - 6) V (Fig. 2), rectification of the volt-ampere characteristic in the coordinates I/U = F(U) occurs, which means that Ohm's law is satisfied.

The construction of the $I/U^{1/2} = F(U^{1/2})$ coordinate corresponds to the Poole-Frenkel mechanism (Fig. 3). The current-voltage characteristic constructed in these coordinates linearly increases over the entire voltage range, and therefore the Poole-Frenkel mechanism does not work in this case.

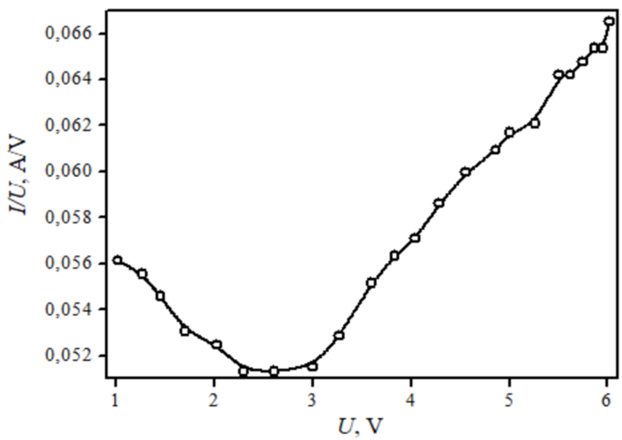

Figure 2. Volt-ampere characteristic of the sensitive element (SE1) of the gas sensor in the I/U = F(U) coordinates within the voltage range of (0 - 6) V

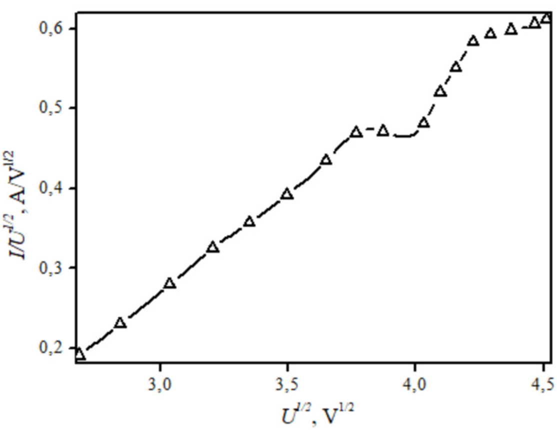

Figure 3. Volt-ampere characteristic of the sensitive element (SE1) of a gas sensor, plotted in the coordinates $I/U^{1/2} = F(U^{1/2})$ within the voltage range of (6 - 20) V

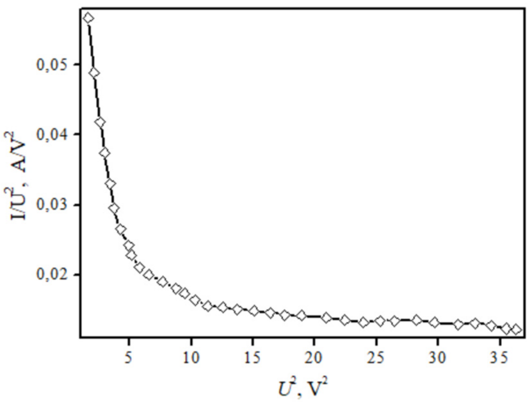

Figure 4. Volt-ampere characteristic of the sensitive element (SE1) of the gas sensor, measured at room temperature, in the coordinates $I/U^2=F(U^2)$ in the voltage range (0-6)

In the voltage range of (3-6) V or (9-30) V (Fig. 4), rectification of the volt-ampere characteristic in the coordinates $I/U^2 = F(U^2)$ occurs, which means that Ohm's law is satisfied. With further increase in voltage in the coordinates $I/U^2 = F(U^2)$, the function shows an increasing trend and no leveling off is observed.

It is known that the main physical mechanisms of charge carrier transport in semiconductors are: currents obeying Ohm's law; currents limited by space charge; currents determined by barrier (Schottky) emission; the volume mechanism of Poole-Frenkel - enhanced by the electric field ionization of impurity centers; electron tunneling through thin layers of insulators and semiconductors; hopping conductivity through impurities in semiconductors [17-19]. The traditional analysis of current transport mechanisms in solids is based on the measurement of static volt-ampere characteristics [20]. In the low voltage mode, while the average concentration of free charge carriers is approximately equal to the equilibrium concentration, Ohm's law will be observed. Its characteristic feature is the linearity of the VAC structure, the dependence of $j = \sigma E$ or $I = U/R$ and its rectification in the coordinates $I/U = f(U)$. At higher voltages, the volt-ampere characteristic begins to obey the quadratic law of Mott and the VAC structure rectifies in the coordinates $I/U^2=F(U^2)$. The linearity of the VAC in the coordinates $I/U^{1/2}=F(U^{1/2})$ is characteristic of the Poole-Frenkel effect. Obviously, there may be conditions when both two or more charge transport mechanisms can act simultaneously.

CONCLUSIONS

The voltammetric characteristics of gas sensor sensitive elements were investigated and plotted in coordinates corresponding to different mechanisms of charge transfer. It was established that the predominant charge transfer mechanism in the range of 0 to 6 V follows Ohm's law, while in the range of 3 to 6 V, Mott's law applies. Therefore, in the voltage range from 0 to 6 V, the simultaneous manifestation of Ohm's and Mott's laws confirms a current flow mechanism limited by space charge. At higher voltages, deviations from these laws were observed.

The results obtained can be applied in gas sensing technology to determine the operating temperature of sensors, facilitating the recognition of gas types.

Conflict of Interests

The authors declare that they have no conflict of interests

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ДОСЛІДЖЕННЯ ВОЛЬТ-АМПЕРНИХ ХАРАКТЕРИСТИК ГАЗОЧУТЛИВОГО СЕНСОРА НА ОСНОВІ ДІОКСИДУ ОЛОВА

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Досліджено та побудовано вольт-амперні характеристики чутливих елементів газових сенсорів у координатах, що відповідають різним механізмам перенесення струму. Встановлено, що переважаючим механізмом передачі струму на ділянці від 0 до 6 В є закон Ома, в інтервалі (3-6) В виконується закон Мотта, а при більш високих напругах спостерігаються відхилення від цих законів. Визначено, що закони Ом і Мот підтверджують механізм протікання струмів, обмежених просторовим зарядом.

Ключові слова: *діоксид олова; датчик; гетероперехід; датчик газу; чутливий елемент*