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Electrical properties of ZnO/Au and ZnO/SnO_2 nanorod arrays when exposed to UV irradiation with controlled intensity

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Abstract. Arrays of zinc oxide (ZnO) nanorods were synthesized on quartz substrates by the hydrothermal method. The nanorods were grown mainly in a vertical orientation, had a length of 500–800 nm and an average cross-sectional size of 40–80 nm. Gold nanoclusters with average sizes of 9 ± 1 nm and 4 ± 0.5 nm and tin with average sizes of 30 ± 5 nm and 15 ± 3 nm were formed on top of the ZnO nanorods. Annealing was carried out at 300 °C for 2 hours with the formation of arrays of ZnO/SnO_2 nanorods. For the manufacture of resistive sensor elements, V/Ni contact metallization was applied on top of the samples. The study of the electrophysical characteristics of the ZnO/Au and ZnO/SnO_2 nanorods arrays showed that exposure to UV radiation of different intensity leads to a change in the electrical resistance of the sensor structure, and also affects the time of establishing the readings of the obtained samples.

Keywords: ZnO, nanorods, electrophysical properties, ultraviolet irradiation

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Материалы конференции
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Электрофизические свойства массивов ZnO/Au и ZnO/SnO_2 наностержней при воздействии УФ-излучения с регулируемой интенсивностью

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Аннотация. Массивы наностержней оксида цинка (ZnO) были синтезированы на кварцевых подложках гидротермальным методом. Наностержни были выращены преимущественно вертикальной ориентации, имели длину 800–500 нм и средний размер поперечного сечения 80–40 нм. Поверх наностержней ZnO формировались нанокластеры золота со средними размерами 9 ± 1 нм and 4 ± 0.5 нм и олова со средними размерами 30 ± 5 нм и 15 ± 3 нм. Отжиг проводился при 300 °C в течение 2 ч с образованием массивов ZnO/SnO_2 наностержней. Для изготовления резистивных сенсорных элементов поверх образцов была нанесена V/Ni контактная металлизация.

Исследование электрофизических характеристик массивов ZnO/Au и ZnO/SnO_2 наностержней показало, что воздействие УФ-излучения разной интенсивности приводит к изменению электрического сопротивления сенсорной структуры, а также влияет на время установления показаний полученных образцов.

Ключевые слова: ZnO, наностержни, электрофизические свойства, ультрафиолетовое облучение

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Introduction

Zinc oxide (ZnO) is a promising metal oxide that is widely used as a sensitive layer in chemoresistive sensors [1]. One of the ways to increase the selectivity of semiconductor oxides is to modify their surface with metal nanoparticles and metal oxides, for example Au and SnO_2. It is known that when UV radiation is applied to gas-sensitive materials, the higher the radiation intensity, the higher the response [2]. However, the impact of radiation with an intensity above 500 μW/cm^2 on gas molecules can lead to the destruction of molecules [3]. At the same time, when measuring the gas-sensitive properties of the materials under study with simultaneous exposure to gas and UV radiation, it is necessary to know the time of establishing equilibrium between and recombination of charge carriers (photo-response time). Studies of the electrophysical characteristics of ZnO/Au and ZnO/SnO_2 nanorods arrays under the influence of UV radiation with adjustable intensity in the range from 55 to 133 μW/cm^2 have not yet been conducted. These studies are the purpose of this work.

Materials and Methods

Arrays of ZnO nanorods were synthesized by the hydrothermal method on quartz substrates. The obtained samples had mainly nanorods with a length of 500-800 nm and an average cross-sectional size of 40-80 nm. Gold nanoclusters with average sizes of 9 ± 1 nm (ZnO/Au sample (1)) and 4 ± 0.5 nm (ZnO/Au sample (2)) were formed on top of ZnO nanorods by vacuum thermal evaporation. A similar number of samples were obtained by tin spraying. For tin, the calculated nanocluster sizes were 30 ± 5 nm (sample ZnO/SnO_2 (1)) and 15 ± 3 nm (sample ZnO/SnO_2 (2)). For the final formation and stabilization of the electrophysical characteristics of ZnO/Au and ZnO/SnO_2 nanostructures, annealing was performed at a temperature of 300 °C for 2 hours [4]. Further, for the manufacture of sensor elements on top of nanorods, V/Ni contact metallization with a metal layer thickness of 0.2 microns was formed by thermal vacuum evaporation.

Results and Discussion

Studies of the electrophysical properties of the obtained samples were carried out on a hardware and software measuring complex that allows measurements of the electrophysical characteristics of sensory structures, including when exposed to UV radiation [5]. Previously, we estimated the relaxation time constant of photoconductivity (τ) when exposed to UV radiation with a wavelength of 400 nm and a radiation intensity of 133 μW/cm^2 [4]. The time constant values were similar for the ZnO/SnO_2(1) and ZnO/SnO_2(2) samples and ranged from 8 to 12 s. For the samples

ZnO/Au(1) and ZnO/Au(2), the time constant values were close to 10 and 8 s. Large values of τ correspond to large values of E_a and φ_b. This indicates the influence of the activation energy of the conductivity and the potential barrier of the ZnO nanostructure on the current transfer mechanism. The data obtained also indicate that it is necessary to wait more than 3 minutes to stabilize the resistance of the gas sensor after turning on the UV radiation.

In this work, additional studies were carried out in which the samples were irradiated with UV radiation from an LED with a wavelength of 400 nm with an adjustable radiation intensity from 55 to 133 μW/cm². Fig. 1 shows the dependences of the resistance (R) of the studied samples on the time of exposure to UV radiation of different intensities. The photoconductivity was estimated as a change in the resistance of the sample of the Ri nanorods over time after 0 s. The resistance values were normalized by the resistance R_0. The measurements were carried out before the curves were flattened.

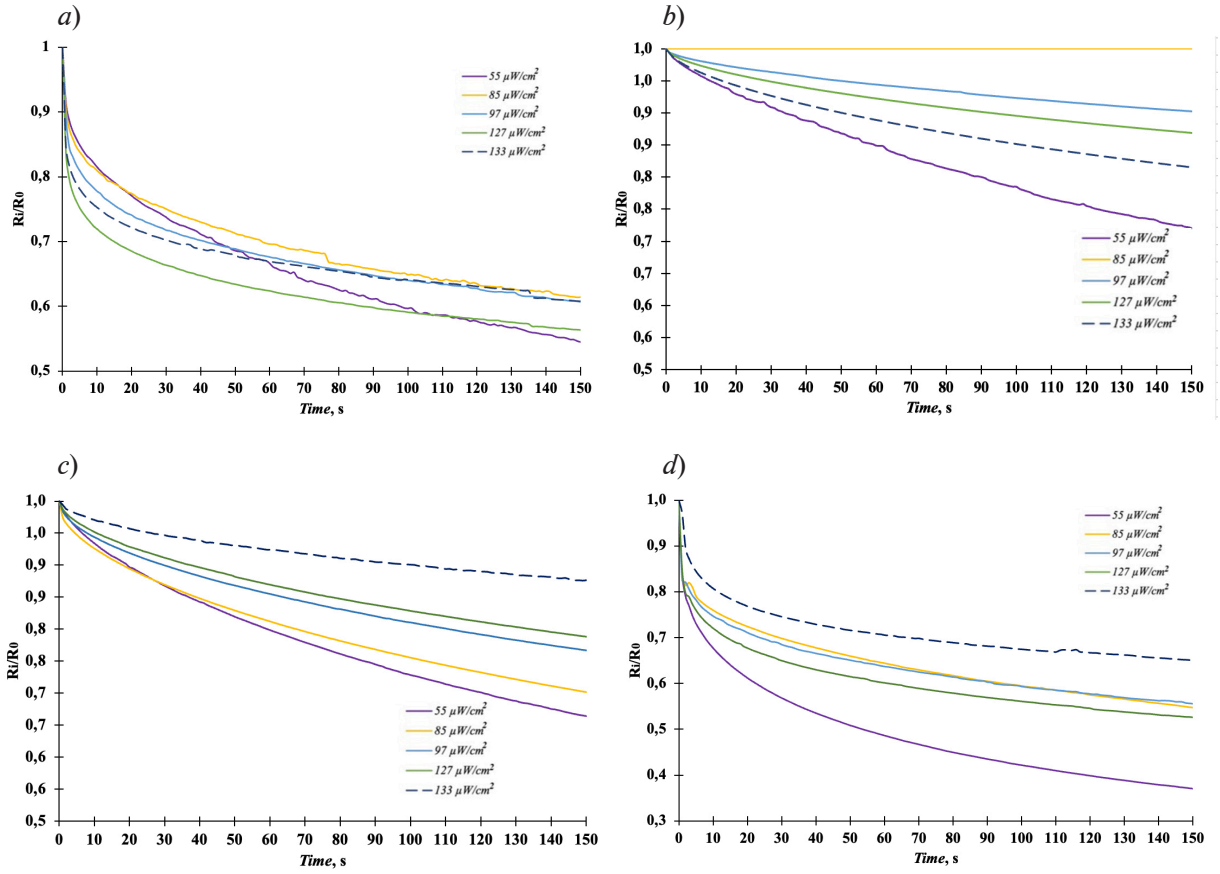

Fig. 1. Dependence of the resistance of samples ZnO/SnO_2(1) (*a*), ZnO/SnO_2(2) (*b*), ZnO/Au(1) (*c*), ZnO/Au(2) (*d*) on the time of exposure to UV radiation with an adjustable intensity of 55 μW/cm² (purple lines), 85 μW/cm² (yellow lines), 97 μW/cm² (blue lines), 127 μW/cm² (green lines), 133 μW/cm² (blue lines)

Studies have shown that when exposed to ZnO/Au and ZnO/SnO_2 samples of UV nanorods, their electrical conductivity increases due to the generation of photoexcited charge carriers. This leads to an activated state of the surface due to an increase in the concentration of free electrons. The estimation of the photo response time was carried out by the time 90% of the maximum change of signal value was reached. The photo-response times for the sample when exposed to UV radiation with an intensity of 55, 85, 97, 127 and 133 μW/cm² are calculated in Table 1.

It can be seen from the data in Table 1 that the onset of balance between the generation of charge carriers by UV radiation and their recombination occurs faster in samples with large tin nanoclusters and smaller gold nanoclusters.

Table 1

Sample	Photo response time (s) when exposed to UV radiation with adjustable intensity				
	55 μW/cm^2	85 μW/cm^2	97 μW/cm^2	127 μW/cm^2	133 μW/cm^2
ZnO/SnO_2(1)	123	96	92	77	87
ZnO/SnO_2(2)	125	141	126	124	124
ZnO/Au(1)	122	122	120	121	122
ZnO/Au(2)	91	102	92	86	84

Conclusion

The conducted studies have shown that an increase in the intensity of UV radiation from 55 to 133 μW/cm^2 causes an increase in the electrical conductivity of the studied samples. The onset of equilibrium between the generation of charge carriers by UV radiation and their recombination occurs faster in samples with large tin nanoclusters and smaller gold nanoclusters. The ZnO/SnO_2(1) sample with an average tin nanocluster size of 30 ± 5 nm has the shortest photo-response time.

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REFERENCES

1. **Que M., Lin C., Sun J., et al.,** Progress in ZnO nanosensors. Sensors. 21 (16) (2021) 5502.

2. **Chinh N.D., Hien T.T., Do Van L., et al.,** Adsorption/desorption kinetics of nitric oxide on zinc oxide nano film sensor enhanced by light irradiation and gold-nanoparticles decoration. Sens. Actuators B Chem. 281 (2019) 262–272.

3. **Chizhov A.S., Rumyantseva M.N., Gaskov A.M.,** Light Activation of Nanocrystalline Metal Oxides for Gas Sensing: Principles, Achievements, Challenges. Nanomaterials. 11 (4) (2021) 892.

4. **Ivanisheva A.P., Sysoev V.V., Abdullin Kh. A., et al.,** The Application of Combined Visible and Ultraviolet Irradiation to Improve the Functional Characteristics of Gas Sensors Based on ZnO/SnO_2 and ZnO/Au Nanorods. Chemosensors 11 (3) (2023) 200.

5**. Gulyaeva I.A., Ivanisheva A.P., Volkova M.G., et al.,** Investigation of electrophysical, photo- and gas-sensitive properties of ZnO–SnO_2 sol–gel films J. Adv. Dielect. (14) (1) (2024) 2245002.

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