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Fabrication and Characterization of CO_2 Sensor Using ZnO<In> Nanograins

M. Aleksanyan, G. Shahkhatuni, Z. Simonyan, G. Shahnazaryan, R. Papovyan, D. Kananov,
A. Grigoryan, G. Gevorgyan, G. Stepanyan, A. Sayunts
Center of Semiconductor Devices and Nanotechnologies, Yerevan State University, 1 Alex Manoogian, 0025, Yerevan, Armenia,
Corresponding Author's e-mail address: sayuntsartak@ysu.am

Summary:

This work presents the development of a CO_2 gas sensor based on ZnO+0.5 at.% In_2O_3. The sensor, with a thickness of 40 nm, was prepared using the high-frequency magnetron sputtering method. The produced thin film exhibited excellent gas sensing characteristics towards CO_2 at an operating temperature of 265°C. In the presence of 5000 ppm of CO_2, the sensor demonstrated a decrease in resistance of approximately 2.3 times, indicating a linear dependence of the sensor response on gas concentration.

Keywords: Gas sensor, carbon dioxide, zinc oxide, greenhouse gases, nanograins

Title

As climate change becomes an urgent global issue, managing greenhouse gases, particularly carbon dioxide (CO_2), is crucial to mitigating its harmful environmental effects. The rise in CO_2 levels, primarily driven by industrial activities and the burning of fossil fuels, significantly contributes to global warming [1]. This increase in CO_2 accelerates shifts in weather patterns, the melting of polar ice caps, and the loss of biodiversity. Gas sensors play a vital role in monitoring CO_2 levels, a critical aspect of protecting human health, optimizing industrial processes, and addressing environmental challenges [2]. A key aspect of tackling these challenges is the creation of reliable and affordable gas sensors that can effectively detect and monitor CO_2 concentrations across different settings. Current sensors typically rely on resistive-type detection, where exposure to CO_2 causes measurable changes in the physical properties of the sensing material, such as resistance [3]. Ongoing advancements in sensor technology are enhancing the precision, high response, and cost-effectiveness of detection systems. These innovations enable the creation of real-time, highly accurate monitoring solutions that provide greater dependability while reducing maintenance expenses. As the demand for such devices grows, they are being incorporated into a wide range of applications, including workplace safety, residential automation, and environmental surveillance [4].

Metal oxide-based chemiresistive sensors offer a multitude of advantages, including straightforward fabrication, cost-effectiveness, adaptability, reliability, eco-friendliness, and compatibility with contemporary nano and micro systems. Zinc oxide (ZnO) is a chemiresistive material that is widely used for the detection of a wide range of gases, including CO_2 and methane, as well as ammonia and other volatile organic compounds (VOCs) [2]. Its high sensitivity makes it an ideal material for a variety of applications, including environmental monitoring and industrial safety [2].

Experimental

In order to prepare the chemoresistive sensor for CO_2 detection, the ZnO+0.5 at.% In_2O_3 polycrystalline target was synthesized in advance by means of the solid-phase reaction method. The zinc oxide and indium oxide (In_2O_3) nanopowders were previously weighed and thoroughly mixed until a homogeneous mixture was achieved. The resulting mixture was pressed into a tablet with a diameter of 50 mm and a thickness of 4 mm. The sample was subjected to annealing at temperatures between 800-1200°C for a period of 20 hours. Consequently, as a result of the solid-phase reaction, a ceramic target was formed, which served as a source of magnetron sputtering. Subsequently, nanograins were sputtered from the obtained target using the high-frequency magnetron sputtering method, condensing on a dielectric substrate. During the deposition process, the generator power was 70 W, the deposition duration was 20 minutes, and the temperature of the substrate was 200 °C. Then, palladium catalytic nanoparticles were deposited on the surface of the resulting nanostructured film to improve the sensor performance. In the final stage of the production process, the sensor was subjected to thermal heating at 300 °C for four hours. Fig. 1 illustrates the scanning electron microscopy (SEM) image of the ZnO+0.5 at.% In_2O_3 thin film, which has a thickness of approximately 40 nm (measured by the Alpha-Step D-300 ,KLA Tencor, Milpitas, CA, USA profiler). It is obvious from the SEM image that average grain size in the film is within the range of 20–40 nm.

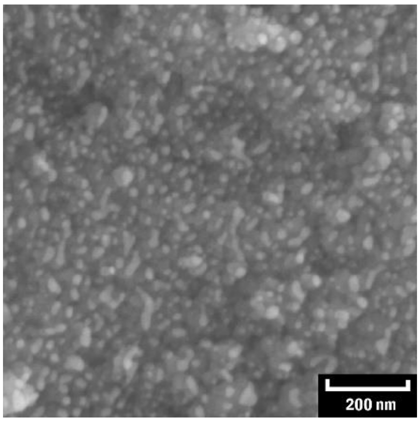

Fig. 1. SEM images of the ZnO+0.5 at.% In_2O_3 thin film with a scalebar of 200 nm.

Results

The gas sensing properties of the material were investigated using an automated gas sensor testing setup. The response of the sensor is defined as the ratio (R_a/R_g) of the sensor's resistance in air (R_a) and in the presence of the CO_2 (R_g). The sensing characteristics of the sensor were investigated over a temperature range of 25–300°C (Fig. 2).

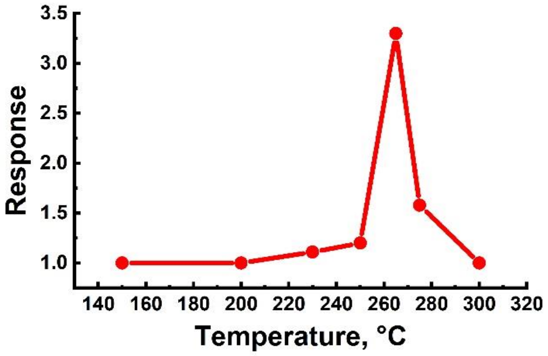

Fig. 2. Dependence of the ZnO+0.5 at.% In_2O_3 sensor response on temperature in the presence of 30000 ppm CO_2.

As Fig. 2 shows, the sensor exhibited a response to 30000 ppm of CO_2 started from 230°C and demonstrated its best result at 265°C operating temperature, where the resistance of the sensor changed approximately 3.3 times.

The dependence of sensor response on CO_2 concentration at 265°C operating temperature as well as the dynamic change in the sensor resistance under 10000 ppm of CO_2 concentration were shown in Fig. 3.

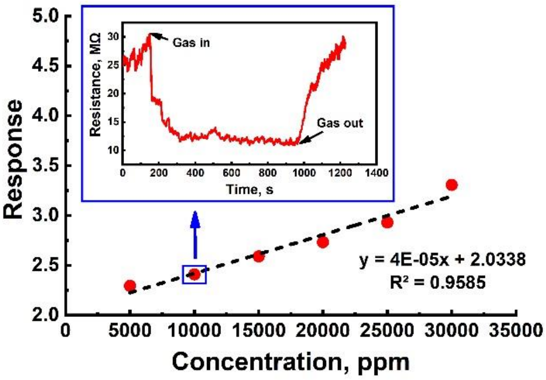

Fig. 3. Dependence of sensor response on CO_2 concentration at 265°C and the dynamic change in the sensor resistance under 10000 ppm of CO_2 concentration (inside of the picture).

It is crucial to highlight that the sensor response exhibits a linear correlation with CO_2 concentrations, enabling the estimation of varying concentrations of the target gas in authentic settings. The sensor response to the minimum CO_2 concentration (5000 ppm) was approximately 2.3, with a response and recovery times of 67 and 149 seconds, respectively.

Acknowledgment

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References

[1] A. Molina, V. Escobar-Barrios, J. Oliva, A review on hybrid and flexible CO_2 gas sensors, *Synthetic Metals* 270, 116602 (2020); doi: 10.1016/j.synthmet.2020.116602

[2] C. Zhang, K. Xu, K. Liu, J. Xu, Z. Zheng, Metal oxide resistive senso rs for carbon dioxide detection, *Coordination Chemistry Reviews* 472, 214758 (2022); doi: 10.1016/j.ccr.2022.214758

[3] M. E. DMello, N. G. Sundaram, S. B. Kalidindi, *Assembly of ZIF-67* Metal–Organic Framework over Tin Oxide Nanoparticles for Synergistic Chemiresistive CO_2 Gas Sensing, *Chemistry – A European Journal* 24, 9220-9223 (2018); doi: 10.1002/chem.201800847

[4] Y. Jian, W. Hu, Z. Zhao, P. Cheng, H. Haick, M. Yao, W. Wu, Gas Sensors Based on Chemi-Resistive Hybrid Functional Nanomaterials, *Nano-Micro Letters* 12, 71 (2020); doi: 10.1007/s40820-020-0407-5