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Highly Sensitive Hydrogen Sensor Based on ZnO/MWCNTs Nanocomposite Material

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Summary:
The development of a flexible hydrogen sensor based on ZnO/MWCNTs (Multi-Walled Carbon Nanotubes) is presented in this work. The sensor was prepared by an electron-beam deposition method, when gas sensitive ZnO/MWCNTs thin film was deposited onto a flexible polyimide substrate. The produced sensor demonstrated excellent gas sensing characteristics to hydrogen at 150°C operating temperature, where the resistance of the sensor decreased more than 100 times in the presence of 25 ppm of hydrogen demonstrating the linear dependence of the sensor response on hydrogen concentration. The obtained results proved that ZnO/MWCNTs based flexible structure may become an excellent material for hydrogen monitoring devices.

Keywords: Gas sensor, hydrogen, flexible sensor, carbon nanotube, zinc oxide.

Introduction

Hydrogen is widely used in various fields of human activity and the need for its application continues to increase year by year becoming one of the promising alternatives to traditional energy sources. Consequently, the highly flammable nature of hydrogen and its explosive characteristics under certain conditions increase the interest in hydrogen sensors in all areas where hydrogen technologies are used [1].

Resistive gas sensors based on metal oxide semiconductors are attractive in their simple structure, high response, low cost, availability of the electric signal, low power consumption, and high reliability [2]. However, metal oxide semiconductor gas sensors have poor electron conductivity and a small surface area which worsens their sensing properties. The presence of MWCNTs in main metal oxide materials improves the gas sensing properties of the sensors, decreases the operating temperature (even to room temperature), and gives stability to the sensors [3].

Compared with non-flexible sensors, flexible ones are more conducive to applications in wearable electronics, they are lightweight and have low cost and low power consumption. Due to their high flexibility and small sizes, these sensors can be easily integrated into the surfaces of any flexible objects [1, 4].

In this work, a new nanocomposite ZnO/MWCNTs material is proposed, which is distinguished by a relatively high response to hydrogen and low operating temperature.

Experimental

The ZnO/MWCNTs (Nanoshel-UK Ltd., UK, with 99% purity) based sensing layer was deposited on a polyimide flexible substrate with 130 µm thickness (Zhongcheng Insulating Material Ltd., China) on which were pre-deposited gold interdigitated electrodes (Fig. 1).

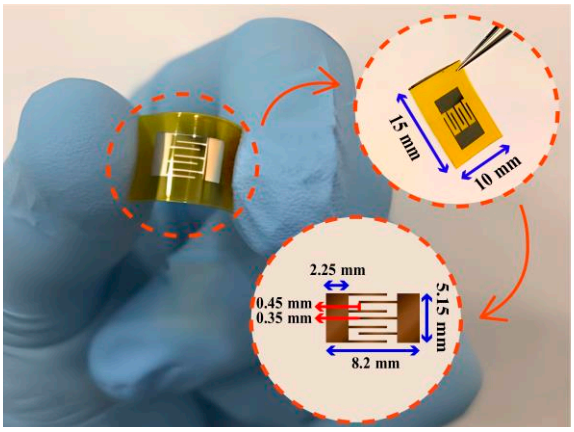

Fig. 1. Actual photo of the flexible hydrogen sensor.

The electron-beam deposition process of ZnO/MWCNTs material was conducted under the following conditions: 40 mA anode current, 0.4 kV anode voltage, 100 °C substrate temperature, 75 mm distance between the target and substrate, 3×10^{-3} Pa base pressure,

5×10^{-1} Pa deposition pressure and 15 minutes duration of sputtering using pre-prepared ZnO/MWCNTs target. Then, palladium catalytic particles were sputtered on the active surface of the ZnO/MWCNTs material by an ion-beam sputtering method.

Results

Gas sensing properties of the ZnO/MWCNTs material were studied in the air and in the presence of hydrogen by laboratory-designed (automated) gas sensor testing setup. The response of the sensor is defined as the resistance ratio of the sensor in the air and in the atmosphere of the target gas, respectively (R_a/R_g, where R_a and R_g are the resistance of the sensor in the air and in the presence of target gas, respectively). The sensing characteristics of the sensor were investigated in the temperature range of 25–250°C (Fig.2).

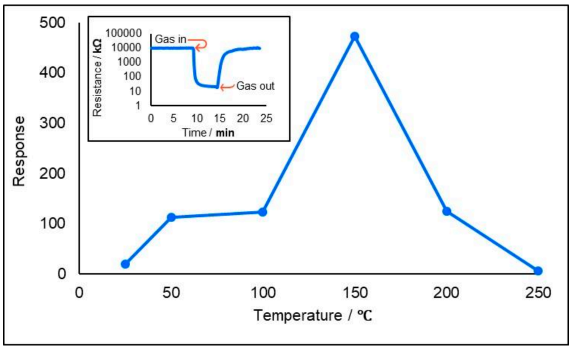

Fig. 2. Dependence of the ZnO/MWCNTs sensor response on temperature in the presence of 100 ppm hydrogen and the dynamic change in the sensor resistance at 150°C (inside of the picture).

As Fig. 2 shows, the sensor demonstrated the best response to 100 ppm at 150°C temperature where its resistance changed more than 472 times and response and recovery times were 15 s and 4.5 s minutes, respectively. The ZnO/MWCNTs structure showed a response to 100 ppm hydrogen even at room temperature, where its resistance changed about 20 times during 18 minutes and recovered after 5 hours.

The dynamic response curves under the influence of different concentrations of hydrogen at 150°C temperature as well as the dependence of sensor response on hydrogen concentration are shown in Fig. 3. The ZnO/MWCNTs flexible gas sensor reacted to 25 ppm hydrogen at the operating temperature with a response value of 100. It is important to mention that sensor response changed linearly toward hydrogen concentration which allows for estimating different concentrations of hydrogen in real environments.

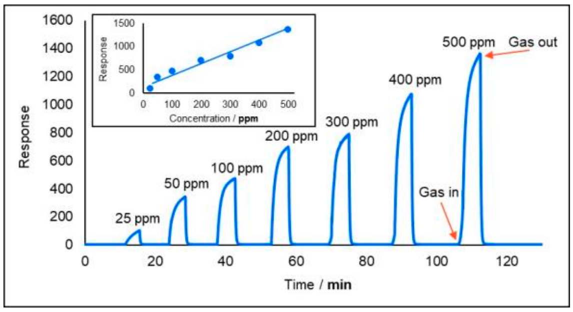

Fig. 3. Dynamic response curves of the ZnO/MWCNTs sensor for different concentrations of hydrogen and the dependence of the response on hydrogen concentration at the operating temperature (inside of the picture).

Conclusion

In summary, the fabricated ZnO/MWCNTs based flexible sensor showed a high response (~100) to 25 ppm hydrogen at 150°C operating temperature. Besides, the sensor demonstrated the linear response dependence on hydrogen concentration toward 25-500 ppm at that temperature. The ZnO/MWCNTs structure also exhibited good sensitivity toward 100 ppm hydrogen even at room temperature.

Acknowledgment

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