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A novel flexible room-temperature NO_2 sensor based on WO_3 integrated with white LED lamps

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Abstract

Miniaturized, portable and flexible WO_3 sensors illuminated by commercially available white LED lamps for ppb-level NO_2 detection at room temperature were successfully fabricated. The gold electrodes and LED lamps were integrated on the transparent substrates, in which the electrodes were deposited on the front side and the lamps were fixed at the back side. The hierarchical hollow WO_3 microspheres were solution-processed, and screen-printed on the substrate. The prepared sensor exhibits excellent response to ppb-level NO_2 in the range of 100-700 ppb, the sensitivity is as high as 13.3 even for 100 ppb NO_2. The repeatability tests show that the sensor has a good repeatable performance. In addition, in contrast with the traditional room-temperature semiconductor gas sensors which are strongly influenced by humidity, the prepared sensor is less sensitive to humidity.

Key words: flexible, WO_3, light illumination, room temperature, integration.

Introduction

Traditional semiconductor gas sensors work at high temperatures in the range of several hundred degrees to accelerate the surface kinetics. High operating temperatures lead to many problems, like high power consumption, thermally induced grain growth. Upon exposure to flammable and explosive atmosphere, it may trigger an explosion or fire. Besides, it requires heating elements and temperature resistant substrates like ceramics increasing the design and fabrication costs. Therefore, it is necessary to decrease the working temperature as low as possible. If the sensor could work at room temperature, even flexible plastic substrates can be utilized.

However, semiconductor gas sensors exhibit very poor sensing response to the target gases at room temperature, including low sensitivity, long response and recovery times, and strong humidity dependence. Another external energy source is needed to stimulate the sensing process instead of heating. Previous studies show that light irradiation is a feasible alternative to achieve this goal [1].

In addition, the material morphology also plays an important role in the sensing properties, which can adjust the specific surface area. It should be improved to increase surface adsorption sites and surface reactivity. Furthermore, porous structure is applied to increase the gas diffusion rate and pathways. So a special morphology should be designed to further enhance the sensing characteristics.

Results and discussion

Fig.1 shows the FE-SEM image of the as-synthesized WO_3 powder. It exhibits a morphology of highly porous and hierarchical hollow microspheres constituted of tiny nanoplatelets. Hierarchical and hollow structures are ideal structures for gas sensor applications. Hierarchical structures can effectively prevent the aggregation of nanomaterials, greatly increasing the specific surface area. The thin, permeable and hollow shell is highly favorable for gas diffusion. The hierarchical hollow microspheres can effectively combine these advantages, and thus drastically improve the sensing performance.

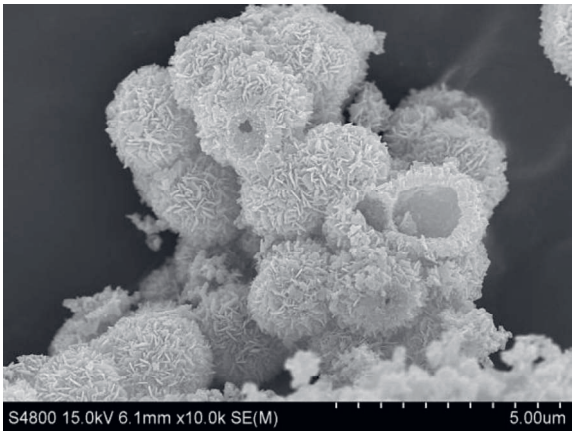

Fig. 1. FE-SEM images of the solution-processed WO_3 powder.

Flexible substrates were home-made according to the procedures below: a negative drawing of the electrodes was printed on the PET foils with a laser printer (HP color laser Jet CP1515). A gold layer (200 nm) was then deposited on the printed substrates by sputtering (Leica EM SCD 500, 10^{-2} mbar air). The electrodes were revealed by a lift off in an acetone bath removing the ink. Afterwards, the WO_3 powder was screen-printed on the front side of the substrate, and commercially available white LED lamp was installed on the back side.

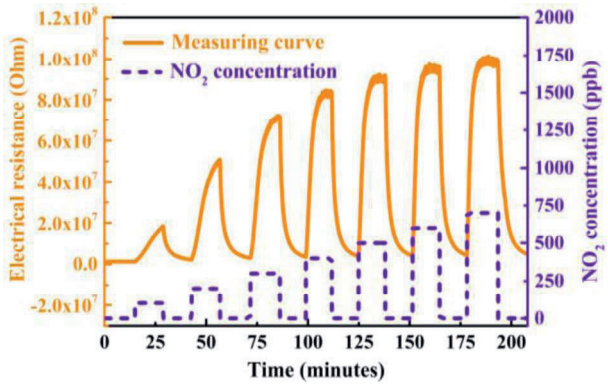

Fig. 2. Sensor response of the prepared sensor as a function of NO_2 concentration.

Fig.2 illustrates the sensing response of the prepared sensor towards 100-700 ppb NO_2. It is obvious that the fabricated sensor exhibits an excellent response to ppb-level NO_2. The detection limit is very low, and the sensor response is 13.3 even for 100 ppb NO_2, moreover, the response and recovery times are ca. 1.5 min and 3 min, respectively. The sensing property of the sensor is comparable to those working at high temperatures.

Fig.3 shows the repeatability test of the sensor towards 400 ppb NO_2 at room temperature. The result demonstrates that the prepared sensor possess a good repeatability.

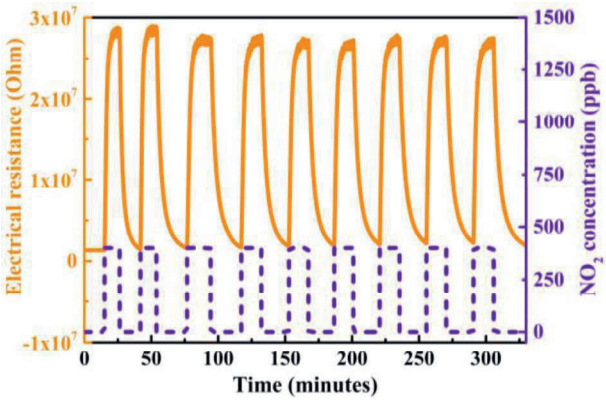

Fig. 3. Repeated tests of the prepared sensor towards 400 ppb NO_2.

For high temperature gas sensors, humidity becomes less problematic. In contrast, humidity would strongly affect the sensing behaviors at room temperature. Precious study shows that adopting light illumination is a feasible method to eliminate the influence of water molecules [2].

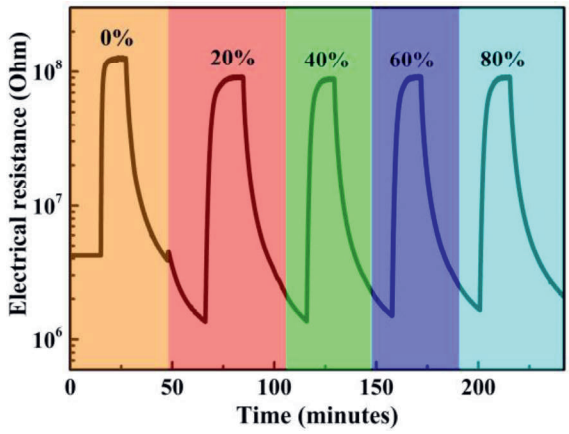

Fig. 4. Effect of variation of relative humidity on the prepared sensor towards 400 ppb NO_2.

Fig.4 exhibits the effect of humidity on the sensing performance towards 400 ppb NO_2 in the humidity range of 0-80% at room temperature. It can be found that the effect of humidity on the sensitivity is insignificant. The base resistance decreases when humidity increases, especially from 0 to 20%. When it further increases, the decrease in base resistance becomes not obvious. As a result, the prepared sensor is not sensitive to humidity.

References

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