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UTAM ZnO Nanostructured Thin Film CO Sensor

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Abstract

Zinc oxide nanowires/nanobelts thin films were prepared by atomic layer deposition (ALD) of Zn on Cr-glass substrates using an ultrathin aluminum membrane (UTAM). ZnO nanostructured based CO- gas sensing thin films were formed, and the morphologies of these films were investigated by scanning electron microscopy (SEM). The sensing response of the films toward CO gas at operating temperatures in the range of (25, 75, 125, 150, and 175)^oC was studied. The set-up designed to measure the gas sensing ability due to the change of the resistivity related to the gas addition, the electrical resistivity as well as the gas sensing properties of the ZnO nanostructured thin films changed significantly with the operating temperatures. The sensitivity increased with increasing operating temperature, particularly above 150 ^oC.

Key words: Zinc oxide thin films, UTAM, nanostructured thin films, gas sensors, ALD.

Introduction

Most of gas sensors based on zinc oxide thin films have been fabricated for detecting toxic and hazardous gases such as H_2, CO_2, CO, H_2S, and NO_2 [1-6]. Pure or doped ZnO or composites of ZnO with other materials have been used for detecting gases, in order to enhance the response and recovery towards both the oxidizing and the reducing analyte [7]. Furthermore, sensors based on ZnO nanobelts were found to be highly selective in their response to NO. The mechanism of improving the response to H_2 based on annealing has been proposed and discussed [8]. CO sensing properties were investigated for the grown structures, and the response of comb-like structures was found to be 1.4 at 75 °C, while belts and mixtures of belts and rod like structures did not show any response [9]. The influence of Mn on trimethylamine (TMA) and ethanol sensing properties has been reported [10]. ZnO nanorod sensors with embedded Ag nanoparticles ZnO nanorod sensors have shown long-term stability and exhibited highly enhanced gas sensing performance in their response and selectivity for detecting ethanol vapor. High sensitivity, fast recovery, and reliability have been achieved by Al doped ZnO prepared by RF magnetron sputtering. The characterization of sensing properties for detecting NO_2 and CO gases by nanocomposite thin films such as CdO-ZnO, ZnO-SnO_2, and ZnO-TiO_2 have been studied [11, 12].

The aim of this work is to produce high-quality nanostructured ZnO thin films by ALD using UTAM mask on a glass substrates. Special attention paid to form nanostructured thin films as well as to examine these films concerning the CO gas sensing properties. In this work, the authors produced a fast, strong and repetitive response ZnO sensor for CO gas detection which can be fabricated at low coast.

Experimental Work

Template of Ultra Thin Alumina Membranes (UTAM) first prepared by anodization, it was made under a constant cell potential condition (voltage= 40 volt) in oxalic acid solution, after that several chemical procedures was carried out to obtain UTAM masks.

Then zinc oxide nanostructured thin films are produce by atomic layer deposition (ALD) , after the deposition process was finished the samples were ready for synthesizing and characterizing measurements.

Characterization and Measurements

The surface morphology of the films was studied by a (NOVA NANOSEM 230) scanning electron microscope (SEM) with field emission cathode. Gas sensing studies have been carried out using a stainless steel chamber with multiple inlets, outlets and feed throughs connected to the electrometer (KEITHLEY 4200-SCS). The chamber was evacuated by a rotary pump (EDWARDS), and solenoid valves served to switch the test gas on and off Figure 1).

Fig. 1. The setup of the sensing equipment.

Results and discussion

The analysis of the surface morphology of the prepared ZnO thin films was carried out by scanning electron microscopy (SEM). Figure (2) shows the micrograph of the ZnO thin films deposited on the glass substrate by ALD on the UTAM mask. The micrograph shows the periodically arrangement different types of nanostructures. The figure clearly shows a regular distribution of hexagonal bee cell with a nanostructure.

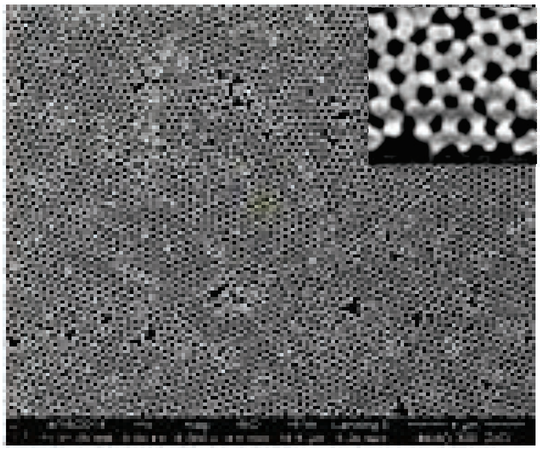
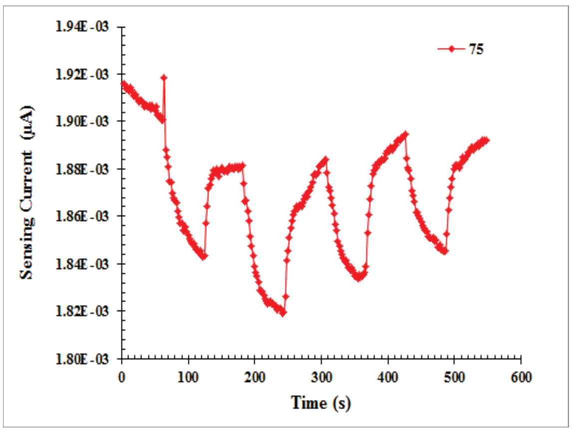


Fig. 2. SEM photo of the beehave-like structure of the ZnO deposited film on the UTAM mask.

Increasing the temperature of the sensing measurements enhance the results, the sensing current increased instantaneously to a maximum value, which was maintained at the maximum current upon exposure to CO and recovered completely to the initial value upon the removal of CO. The sensor shows high stability during repeated test cycles. The significant enhancement in the response of the ZnO nanostructured thin films to CO gas by increasing the temperature was attributed to the decrease of the contact resistance between the grains. Figures (3-7) show the increasing in sensing current with the temperature increase in the range of (75-175)^{o}C respectively by a step of 25^{o}C.

Fig. 3. Sensing current at 75 ^{o}C.



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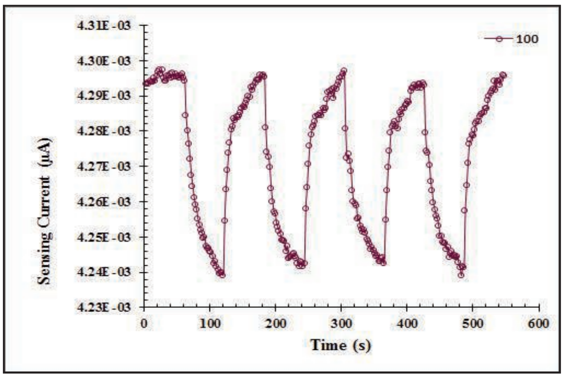

Fig. 4. Sensing current at 100 °C.

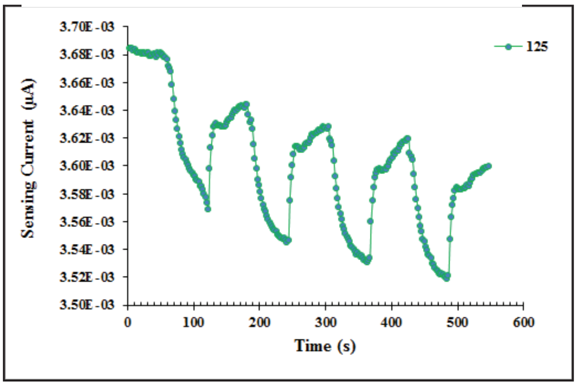

Fig. 5. Sensing current at 125 °C.

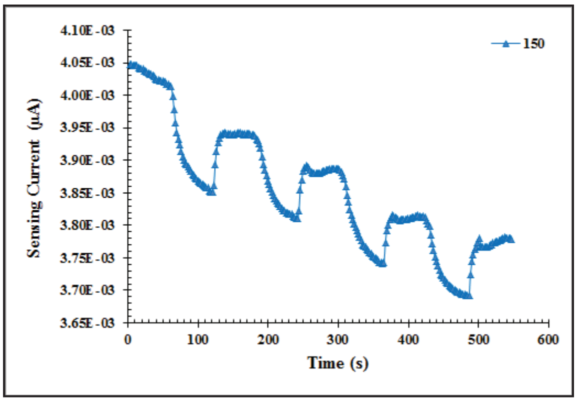

Fig. 6. Sensing current at 150 °C.

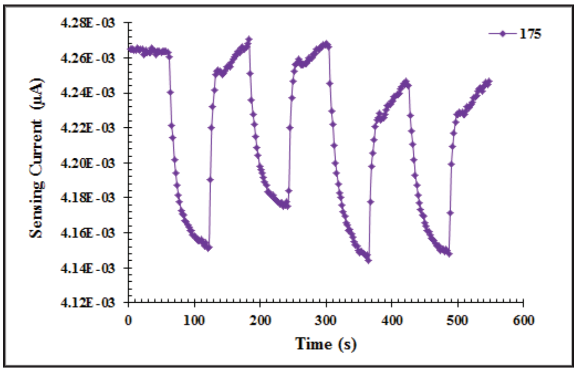

Fig. 7. Sensing current at 175 °C.

The sensitivity and typical response of ZnO nanowires and nanobelts to CO gas measured at different temperatures are shown in figures 8 and 9. Here, the sensitivity (S) is defined as:

$$S = \frac{Ig - Ia}{Ia} x100 \quad \text{.........................(1)}$$

Where, I_g and I_a are the sensing currents in the presence of gas and in air respectively.

The sensitivity of the prepared films was increase with the raise of the operating temperature because it provides a reliable conditions for more chemical interactions between the additive gas and the oxygen vacancies in the surface layer, the results illustrate in the Figure 8

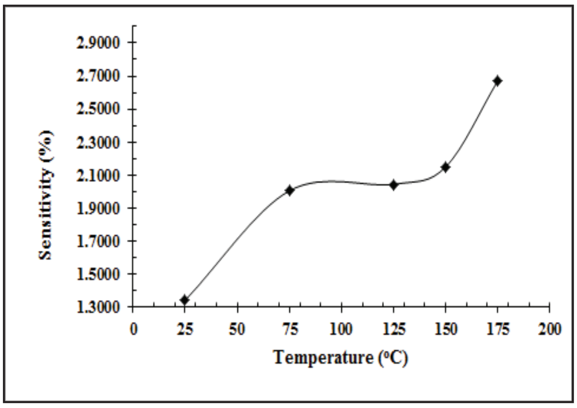

Fig. 8. Sensetivity various with the temperature.

The response of the film towards the CO sensing has been shown in the figure 9.

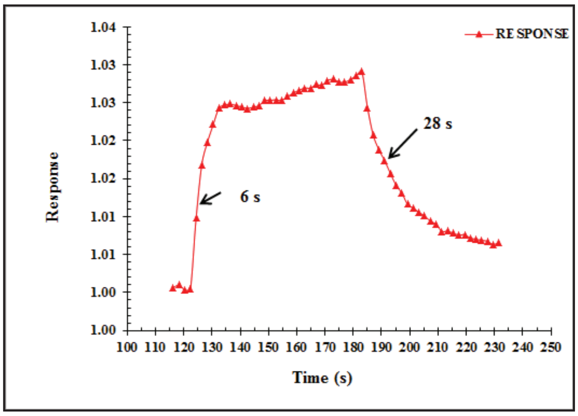

Fig. 9. Response of the prepared film.

Conclusion

To conclude, ZnO thin films have been synthesized and deposited on the glass substrates. Nanostructured thin films are grown by optimizing the deposition parameters of the ALD system. The present work discusses and compares the sensing characteristic of ZnO nanostructured films as CO sensors. The deposited films are characterized concerning their microstructure and concerning their sensing behavior towards CO at different operating temperatures 25, 75, 125, 150 and 175 oC. The sensor response and recovery time of deposited films on glass substrates is found to increase with the temperature. However, considering the response and recovery time characteristics, ZnO nanostructured sensors at an operating temperature of 175 oC shows the best sensing performance.

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