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Gas Sensing Properties of Semiconducting Metal Oxide Thin Films

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ABSTRACT

Gas sensors based on semiconducting metal oxide nanostructures are expected to exhibit better sensing properties like sensitivity and selectivity, than gas sensors based on other materials. Majority of the semiconducting materials possess n-type conduction and it is due to the presence of bulk oxygen vacancies. The sensitivity of the semiconducting material depends on the surface reaction between the chemisorbed oxygen and the reducing gases. Optimized indium zinc oxide thin films deposited at room temperature by electron beam evaporation technique were engaged as sensing elements for the detection of ethanol in this present study.

Keywords: Gas sensors, Indium zinc oxide thin films, electron beam evaporation technique.

INTRODUCTION

Semiconductor sensors are widely used for gas sensing and recently semiconducting nanostructures have earned attention due to their huge surface to volume ratios. Usually, a gas sensors performance is strongly dependent on the sensor materials surface area. The sensitivity of the semiconducting material depends on the surface reaction between the chemisorbed oxygen and the reducing gases. The adsorption of oxygen on the film surface has two forms: physisorption and chemisorption. At elevated temperature, chemisorption is dominant. The transition from physisorption to chemisorption needs activation energy, which can be accomplished by increasing the operating temperature. The surface oxygen vacancies play the role of chemisorption sites in the presence of oxygen.

MATERIALS AND METHODS

IZO thin films were deposited on glass substrates using a sintered indium zinc oxide target by electron beam deposition technique. The target material was prepared which was required for the electron beam evaporation by mixing of high purity Sigma Aldrich ZnO and In_2O_3 powder in the proportion 99:5 (wt. %) using ball mill for 2 hrs and the material was made as a pellet and was sintered at 1100 ^oC. Thin films were deposited for 3 minutes with the approximate current of 30 mA and 5 kV as accelerating voltage. The films were deposited at room temperature and the prepared indium zinc oxide film is introduced as a sensing element.

Instrumentation

Sensitivity measurements are being characterized by any of the two methods, dynamic and static system [1]. In the present study, static system is employed, which comprises an airtight chamber with air admittance and gas inlet valves. The entire setup for measuring sensitivity of the sensor is shown in Fig. 1.

The film sensor was placed inside an airtight chamber of known volume 25,000 cm^3. The sensor was kept above a resistive heater and the temperature was monitored with a PID temperature micro-controller of VI microsystems, India. Two gold electrodes were sputtered at the two ends on the surface of the film, from which ohmic contact were made. The gas injection was carried out with ethanol heater and through a needle valve, into the chamber. Initially, electrical resistance of the sensor layers was measured at a particular temperature in air ambient, using Keithley 2000 DMM, which is automated with the PC through the Agilent VEE PRO software. The response measured in air ambient is considered as a reference response for the calculation of sensitivity. After noting the reference, the test gas is injected inside the bell jar through a needle valve. In order to inject the gas easily, the chamber is evacuated to a base pressure of 10^{-3} Torr using a rotary vacuum pump. After injecting the test gas, all the valves are closed to avoid the leakage of the test gas. The resistance of the sensor is measured, with respect to time upto the saturation of the sensor to the gas, and then the air was allowed into the chamber. The resistance measurement of the sensor is continued up to the complete recovery of the sensor resistance to the air ambient value. The measurement was repeated for number of cycles to determine the cyclic nature of the sensor. The resistance of the sensor is measured for different temperatures in ethanol vapor-air ambient.

RESULTS AND DISCUSSION

Sensitivity Of The Sensor With Change In Operating Temperature

In the present study, the resistance of the indium zinc oxide film decreases on sensing the ethanol vapor. The sensitivity of the sensor is calculated using the equation,

$$S = \frac{R_{gas} - R_{air}}{R_{air}} \qquad (1)$$

The decrease in resistance on sensing the ethanol vapor may be due to chemisorption that exchange charges between absorbed gaseous species and the metal oxide surface.

FIGURE 1. Experimental setup used for sensitivity measurements.

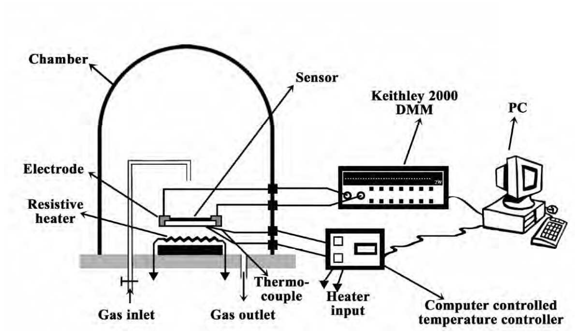


FIGURE 2. Transient response curve of indium zinc oxide ethanol sensor at various operating temperatures.

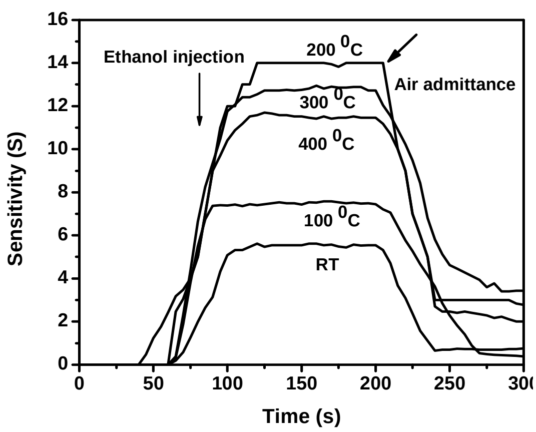
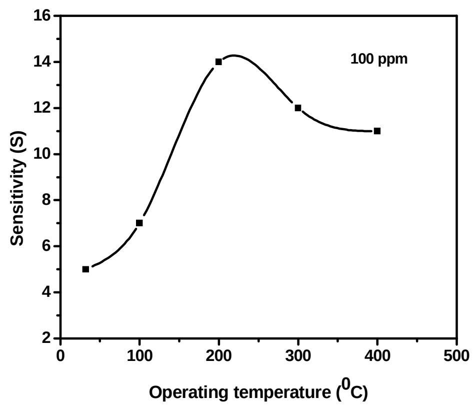


Fig. 2 shows the variation of sensitivity of the indium zinc oxide sensor with operating temperature in the range 27 ^{0}C (RT) – 400 ^{0}C for 100 ppm ethanol concentration. It is reported that the operating temperature has an obvious influence on the sensitivity of the sensors to the corresponding gases [2]. The sensitivity of the indium zinc oxide ethanol sensor increases with the operating temperature (*Top*) upto 200 ^{0}C. When the operating temperature is above 200 ^{0}C, the sensitivity of the films decreased. The exothermic effect in the surface reaction of the oxide film with ethanol is difficult to proceed with increasing operating temperature (Top) above 200 ^{0}C, thus decreasing their sensitivity.

Fig. 3 shows the variation of sensitivity with various operating temperature for 100 ppm of ethanol concentration.

FIGURE 3. Variation of sensitivity with various operating temperatures for 100 ppm ethanol concentration.



CONCLUSION

From the gas sensor characterization studies, it is clear that the indium zinc oxide can be used as an ethanol sensor effectively. The optimized operating temperature for the indium zinc oxide film is 200 ^{0}C. These results showed that the indium zinc oxide film based ethanol sensor has high response quick recovery time and selectivity to the ethanol vapor.

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