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RESEARCH ARTICLE

ALCOHOL SENSING CHARACTERISTICS OF INDIUM DOPED ZNO THIN FILMS

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ABSTRACT

Indium doped ZnO thin films are deposited on quartz substrates using sol-gel spin coating technique. The structural characteristics of the deposited films are studied by x-ray diffraction (XRD) and field emission scanning electron microscopy (FESEM). The sensing properties of the films are investigated at different concentrations of ethanol and butanol by varying the operating temperature. The response% and response time are found to be 32% and 6 sec respectively, by exposing the film to 500 ppm of ethanol at 200°C which is quite encouraging. Also the recovery of the sensor is quite fast. This indicates that the grown films have the potential for its application as high performance and low power consuming sensors. The selectivity of the sensors is also studied using pattern recognition analysis.

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INTRODUCTION

ZnO is an II-VI semiconductor with a hexagonal wurtzite structure. It is a wide band gap material having $E_g \sim 3.37$ eV (Janotti and Van de Walle, 2009). It is an n-type semiconducting metal oxide. This n-type conductivity can further be improved by doping it with higher valent impurities, such as Al, In, Ga and so on (Kim *et al*., 2010). It is used as a potential candidate in various device applications including semiconductor devices (Look, 2001), solar cell (Nuruddin and Abelson, 2001), gas sensors (Pati *et al*., 2015), and so on. For gas sensing application both doped and undoped ZnO are fabricated widely in various forms, such as thick films (Sahay *et al*., 2008), thin films (Pati *et al*., 2015), nanorods, nanotubes, nanowires (Jia *et al*., 2010; Guo *et al*., 2012; Zeng *et al*., 2012), and so on using different growth techniques including chemical solution deposition technique (Wang *et al*., 2008), MOCVD (Pati *et al*., 2014), PLD (Yong Zhang *et al*., 2012), etc. Numerous literature reports indicate the effective use of undoped and indium doped ZnO thin film gas sensors for detection of gases, such as H_2, CO, CH_4 and various hydrocarbons including ethanol, butanol, etc. (Pati *et al*., 2015; Pati *et al*., 2014; Yong Zhang *et al*., 2012).

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Zhang *et al*. (Yong Zhang *et al*., 2012) reported the ethanol sensing characteristics of ZnO thin films synthesized by pulsed laser deposition technique at low operating temperatures. In our previous study we have also reported the sensing characteristics of ZnO and indium doped ZnO thin films in presence of different gases (Pati *et al*., 2015, Pati *et al*., 2014). Though gas sensing applications of ZnO are studied extensively, still the high operating temperature and lack of selectivity hinders its use in device applications. In this work, indium doped ZnO thin films were deposited by a low cost sol-gel spin coating technique. The gas sensing characteristics are investigated in presence of various concentrations of ethanol and butanol at different operating temperatures. Pattern recognition technique is used to study the selectivity of the sensors. It is said that this sensor can be used as a selective gas sensor for its potential application in our day today life.

Experimental

Initially Zinc acetate dihydrate and indium nitrate dihydrate powders were mixed. Then the powder was dissolved in 2-methoxyethanol at room temperature MEA (monoethanolamine) was added to the solution and was stirred for 2 h at 60 °C to obtain ~0.4 M solution. Then the solution was spin coated onto quartz substrates using a spin coater unit (SCU 2007, apex instruments co.). Finally, the films were annealed at 600 °C for 1 h in air. A detail of the experimental procedure is illustrated elsewhere (Pati *et al*., 2015). The structural characteristics of the deposited films were studied from X-ray diffraction pattern using a diffractometer (Ultima III, Rigaku, Japan). The micro structural characteristics of the films were investigated using field emission scanning electron microscope (FESEM) (SUPRA-40, Carl Zeiss, Germany). The sensing characteristics of the deposited films were studied in a static gas sensing set up.

RESULTS AND DISCUSSION

The structural and micro structural characteristics of the deposited films are studied from XRD pattern and FESEM images respectively. The details of these results are reported in our previous work (Pati *et al*., 2015). We have also studied the sensing performance of the deposited films in presence of various hydrocarbons, such as ethanol and butanol, at 200 ˚C as shown in Fig. 1(a-c).

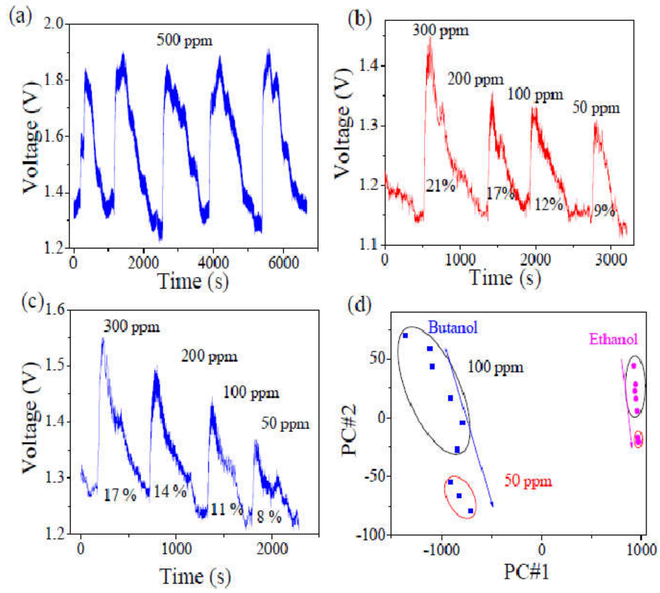

Fig. 1. Gas sensing performance of indium doped ZnO thin films, using static gas sensing unit, in presence of (a) 500 ppm of ethanol, (b) various concentrations of ethanol and (c) various concentrations of butanol, at 200 ˚C. Fig. 1 (d) shows the principal component analysis of the transients recorded during exposure of 100 and 50 ppm of butanol and ethanol

Fig. 1 (a) represents the sensing characteristics of the said films on injection of 500 ppm of ethanol. As observed from the figure, the sensor exhibits very good response towards the detection of ethanol and also offers good stability upon prolonged exposure of the gas. It may be noted that, there is marginal drifting in the base line. The response% and response time are found to be 32% and 6 sec respectively, which is quite encouraging as compared to the literature. Also the recovery of the sensor is quite fast. The sensing performance at various concentrations of ethanol is shown in Fig. 1 (b), keeping the operating temperature fixed at 200 ˚C. Here it can be observed that, decreasing the concentration of ethanol from 300 to 50 ppm reduces the response% from 21% to 9 %, while the base line remains unchanged. The sensing performance of the sensor is again studied on exposure of various concentrations of butanol, keeping the remaining parameters unchanged and is shown in Fig. 1 (c). It may be noted that, the deposited films can also detect butanol efficiently, though the response is poor as compared to the ethanol. Response% for various concentrations of butanol is marked in the given figure. Inspecting the Fig. 1 (b) and (c) it is observed that this sensor has a poor selectivity towards the ethanol and butanol. Therefore, we have studied the cross selectivity of the sensors towards lower concentrations of ethanol and butanol, using the pattern recognition analysis, discussed in the previous work (Pati *et al*., 2014) and the result is shown in the Fig. 1 (d). From the figure it is clear that both the gases (ethanol and butanol) at each concentration are well separated and the dispersion within each concentration of ethanol is much less as compared to butanol. This represents the selectivity of one gas in presence of the other one. Although using the pattern recognition analysis it is possible to discriminate the two gases at each ppm level, further research effort is needed to selectively sense a gas from a mixture of gases.

Conclusion

Indium doped ZnO thin films are deposited onto quartz substrates using sol-gel spin coating technique. Gas sensing characteristics of the deposited films are studied in presence of various concentrations of ethanol and butanol at different operating temperatures. We have utilized the pattern recognition techniques to study the cross selectivity in indium doped ZnO thin films for selective detection of ethanol and butanol. This work provides a promising material for fabricating high performance gas sensors with low power consumption.

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