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Aluminum doping impact on morphology and sensing response of zinc oxide nanostructures

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Abstract:

In this piece of work, we have synthesized pure and aluminum doped *zinc oxide* and then studied their sensing response towards ethanol. We adopted a chemical route to synthesize pure and aluminum doped ZnO, in this work we added different concentrations of aluminum by weight (1% to 4% by percentage weight). The XRD studies revealed that synthesized materials are having wurtzite hexagonal crystalline structures. With the addition of dopant the crystallinity of the structures has decreased. FESEM images have clearly shown the modification of morphology of material with the addition of the dopant. With the addition of dopant sensing responses also have changed significantly.

Key words: Zinc Oxide; nanomaterials; doping; chemical synthesis; gas sensors

Introduction

Volatile organic compounds are the primary sources of indoor environmental pollutants and are considered seriously harmful to the human. Therefore, work is required concerning the vapour detection and its development. In the past few decades, gas sensors have been one of the key areas of interest. Semiconducting metal oxide based gas sensors are one of the most extensively studied groups of gas sensors. For observable reasons n-type semiconductor gas sensors such as SnO_2 and ZnO have attracted the attention of many users and scientists [1,2]. For continuous use, the sensors should exhibit a high reliability, sensitivity, and stability.

It is well known fact that gas-sensing properties of semiconducting oxide gas sensors can be modified by choosing an appropriate dopant [3,4].

Sensing, dominantly being a surface involved phenomenon, the particles on the surface and more importantly their morphology and size play a crucial role in the sensing mechanism. In the recent years with the advent of nanostructured materials, the study on gas sensors has gained an impetus [5]. The enhanced surface activity is attributed to the surface-to-bulk ratio for the nano sized materials, which is much greater than that for coarse materials because large fractions of atoms are present at the surface due to which the surface properties become dominant.

In this work, we are reporting synthesis and sensing response of pure and aluminum doped zinc oxide.

Experimental details

(i) Synthesis and doping of nanostructured ZnO

We started with a 0.2M solution of $ZnCl_2$ prepared in distilled water, in this solution aluminum nitrate was added in different concentration such as 1, 2, 3 and 4 % by weight. Then resulting solutions were precipitated by adding an ammonium hydroxide drop wise at room temperature. The precipitates thus obtained were separated from rest of the liquids by filtering and were dried into powder at 120^{o}C. Then the powders were sintered at temperature of 500^{o}C for three hours.

The crystal structure of the materials produced was characterized by powder X-ray diffraction (XRD) using Cu Kα radiation with Shimadzu 700 Diffractometer system. Morphologies of the materials were analyzed from FESEM FEI Quanta 200F.

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(ii) Fabrication of sensors and their testing

The synthesized powder samples were processed into water based pastes. The paste was coated onto an alumina substrate (12mm × 5mmsize) between gold electrical contacts (2mm apart) to obtain a thick film (~20µm thickness). These samples were sintered at 350°C for 30 min to give them final shape ready for sensing.

The sensing characteristics of ZnO sensors were obtained with a home built apparatus consisting of a simple potentiometric arrangement and a test chamber of known volume in which a sample holder, a small temperature controlled oven and a mixing fan were installed. The fabricated sensor was placed in the oven kept at suitable temperature and a measured quantity of test gas ethanol was injected into the test chamber. The variation of voltage signal across a resistance connected in series with sensor was monitored and recorded with a Keithley KUSB -3100 data acquisition card.

Same procedure was repeated for different test gases sensing with all the samples at temperatures from 200 to 450°C. Vapour sensing response of the sensor was determined as the G/G_o, where G_o is the conductance of thick film sensor in an air ambience and G is the conductance in a mixture of air and ethanol vapour.

Results and discussion

Figure 1 represents X-ray diffraction plots for pure ZnO and doped ZnO with different weight percentage of Aluminum. From the peaks we can clearly note down the wurtzite hexagonal geometry of the synthesized powders. Another significant observation from Fig. 1 the crystallinity of ZnO film was deteriorated with increasing Al content and no extra phases involving aluminum compounds were observed. Moreover, the peak intensities of those films decrease with increasing Al content, similar results were also observed by Caglar et al [6] for thin films.

Figure 2 represent FESEM of pure ZnO and ZnO with doping of different concentrations of Al by weight. These images clearly show modification in the morphology of ZnO due to doping of Al. Fig 2(a) shows that pure ZnO is having well defined rod type morphology. With the increase in the concentration of the dopant ZnO has lost its morphology and rods are no longer prominent in the powder (Fig 2(b) - (e)).

Figure 3 represents the sensing response of pure and Al doped ZnO thick films for 250 ppm ethanol at optimum operable temperatures. It can be seen in the figure that response has increased with the addition of dopant.

Another important point that is apparent from the figure is that with the increase in the concentration of the dopant (from 1% by wt. to 4%) sensitivity towards ethanol has reduced.

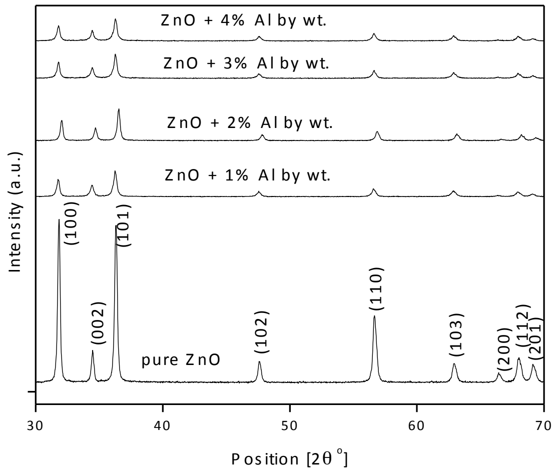
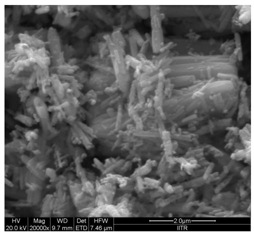
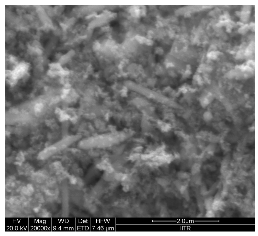


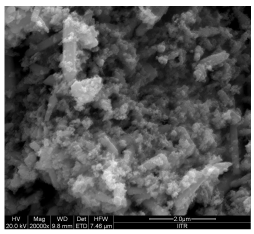
Fig. 1 XRD plot of pure ZnO and doped ZnO with different %age of Al by wt.



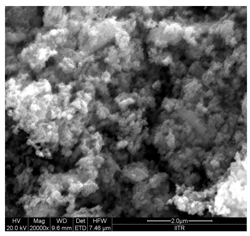
(a)



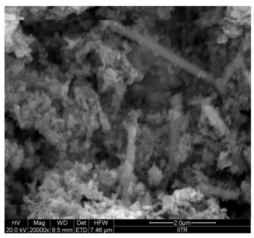
(b)



(c)



(d)



(e)

Fig. 2 FESEM images (a) Pure ZnO, (b) ZnO: 1% Al (c) ZnO: 2% Al (d) ZnO: 3% Al (e) ZnO: 4% Al

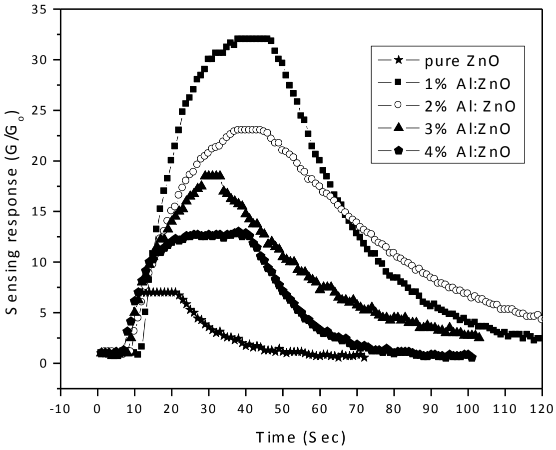


Fig.3. Sensing response of pure and Aluminum doped Zinc Oxide towards 250 ppm of ethanol at various operating temperatures.

Conclusions

In this work, we were successful in modifying the morphology of the ZnO with the addition of different concentrations of aluminum by weight as a dopant. As sensing response is the surface phenomenon, so sensing behaviour was expected to change. With the addition of the dopant sensing responses towards ethanol have enhanced significantly.

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