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Fabrication and characterization of gas sensor micro-arrays

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ABSTRACT

A novel structures of nanomaterials gas sensors array constructed using ZnO, and ZnO doped with Al via sol–gel technique. Two structure arrays are developed; the first one is a double sensor array based on doping with percentages of 1% and 5%. The second is a quadrature sensor array based on several doping ratios concentrations (0%, 1%, 5% and 10%). The morphological structures of prepared ZnO were revealed using scanning electron microscope (SEM). X-ray diffraction (XRD) patterns reveal a highly crystallized wurtzite structure and used for identifying phase structure and chemical state of both ZnO and ZnO doped with Al under different preparation conditions and different doping ratios. Chemical composition of Al-doped ZnO nanopowders was performed using energy dispersive X-ray (EDS) analysis. The electrical characteristics of the sensor are determined by measuring the two terminal sensor's output resistance for O_2, H_2 and CO_2 gases as a function of temperature.

1. Introduction

Nowadays, there is a great interest in implementing sensing devices in order to improve environmental and safety control of gases [1]. There is also a great need of this kind of sensors to carry out the optimization of combustion reactions in the emerging transport industry and in domestic and industrial applications [2]. It has been known for a long time that, the adsorption of gas molecules on a metal-oxide semiconductor surface can cause a significant change in the electrical resistance of the material [3].

Nanostructured materials have attracted extreme attention due to their novel properties that are strongly depended on the size, specific surface area, and morphology [4,5]. In particular, ZnO, as one of the most important semiconductors, has attracted much interest due to its unique material properties, such as wide band gap (3.37 eV), big excitation binding energy (60 meV), and large piezoelectricity constant [6,7]. Therefore, ZnO-based nanomaterials have been widely used in electronics, optoelectronics, sensors, photocatalysis, and biomedical sciences [8–11].

As the present research results on all kinds of semiconductor metal oxides have shown, ZnO may be one of the most hopeful candidates due to its mature fabrication technology, which can produce all kinds of ZnO nanostructures, such as nanowires, nanorods, nanobelts [12], nanoribbons, etc.

It is well known that the sensing performance of the gas sensors can be enhanced by adjustment of the microstructure, doping of dopant or using a small amount of noble catalyst, etc. [13–17]. Although it is proved that the nanocrystalline ZnO is one of the most promising metal oxides for gas sensors due to the unique conductance characteristics and large surface to volume ratio, their sensing performances can also be improved dramatically by the synergistic effects of the catalyst or dopant on the pure nanocrystalline ZnO.

Even though many ZnO-based gas sensing elements with high specific surface areas have been investigated and reported [18], and some of their grain sizes are as low as a few tens of nanometers, their gas sensitivities deriving from these ZnO nanomaterials have not been greatly enhanced as yet. The reasons for this phenomenon have not been discussed systematically up to now.

The sol–gel process is defined generally as: the process that involves the transition of a system from a liquid "sol" (mostly colloidal) into a solid "gel" phase [19]. Hydrolysis, condensation and drying are tree key steps in determining the properties of the final product in sol–gel processing. Sol–gel processes have several advantages over other techniques for synthesizing nanopowders of metal oxides. These include the production of ultrafine porous powders and homogeneity of the product as a result of homogenous mixing of the starting materials on the molecular level. Also, sol–gel processing holds strong promise for employment industrially on

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large scales [20]. In this work we have chosen the sol–gel technique for the previous advantages.

In this work, sol–gel route was used to prepare ZnO and ZnO:Al nanomaterials. Different Al doping ratios were incorporated into the ZnO matrix and their effects on the morphological structures of the prepared nanopowders and properties of gas sensing were also studied. Two different array structures were designed and prepared from undoped and doped ZnO to be utilized as a gas sensor array for different kinds of gases as a function of temperature.

2. Materials and methods

2.1. Preparation of ZnO and ZnO:Al nanopowders and films fabrication

The ZnO nanopowders were investigated using sol–gel technique by mixing 6 ml of 1 M zinc acetate aqueous solution and a 6 ml of 10 M NaOH aqueous solution and added into 15 ml alcohol and 1 ml of triethanolamine (TEA). Then the mixture was stirred at room temperature in a glass beaker under magnetic stirring for 30 min. In case of preparing 1, 5 and 10 wt% Al-doped ZnO; an equivalent amount of aluminum chloride is added to the mixture zinc acetate dehydrate, alcohol and TEA then stirred for 30 min. The resulting solutions were aged at 70 °C for 60 min. The final obtained white powders were filtered and washed several times with alcohol and distilled water to remove any residual salts, centrifuged at 6000 rpm for 30 min, and then dried at 60 °C under air atmosphere.

2.2. Preparation and Characterization of solid state semiconductor gas sensor array

Different colloidal suspensions were obtained by mixing the synthesized ZnO nanopowders either doped with various doping ratios or un-doped with ethanol and stirring the resulting suspension overnight. Ethanolic solution with ZnO content of about 20% by weight was attended. The glass substrates is ultrasonically cleaned in acetone for 15 min, and then rinsed several times with demonized water and ethanol. The heater (platinum heater) was deposited onto the previously cleaned glass substrate by sputtering machine (Turbo Sputtering RF & DC Power Supplies Deposition System Model Hummer 8.1) (P = 100 W RF, t = 5 min). Then the suspension of ZnO was applied by a wafer spinner machine (100 rpm, 2 min) (Model Polos 300 AWS). The film was then allowed to dry in air. ZnO films were sintered shortly after deposition in air flow at 400 °C for 5 min.

The copper masks shown in Fig. 1(a) and (b) were placed over prepared ZnO films to gain double or quadrature gas sensor array. Finally, Pt contact electrodes were deposited on doped and un-doped ZnO films using a sputtering machine (P = 100 W RF, t = 5 min).

All tested gases (O_2, H_2 and CO_2) were passed inside the homemade gas chamber through opening the chamber valve. The resistivity of the gas sensor device was evaluated and the resultant sensitivity was plotted as a function of gas temperature for all gases. The sensor response for different sensor arrays (double or Quadrature

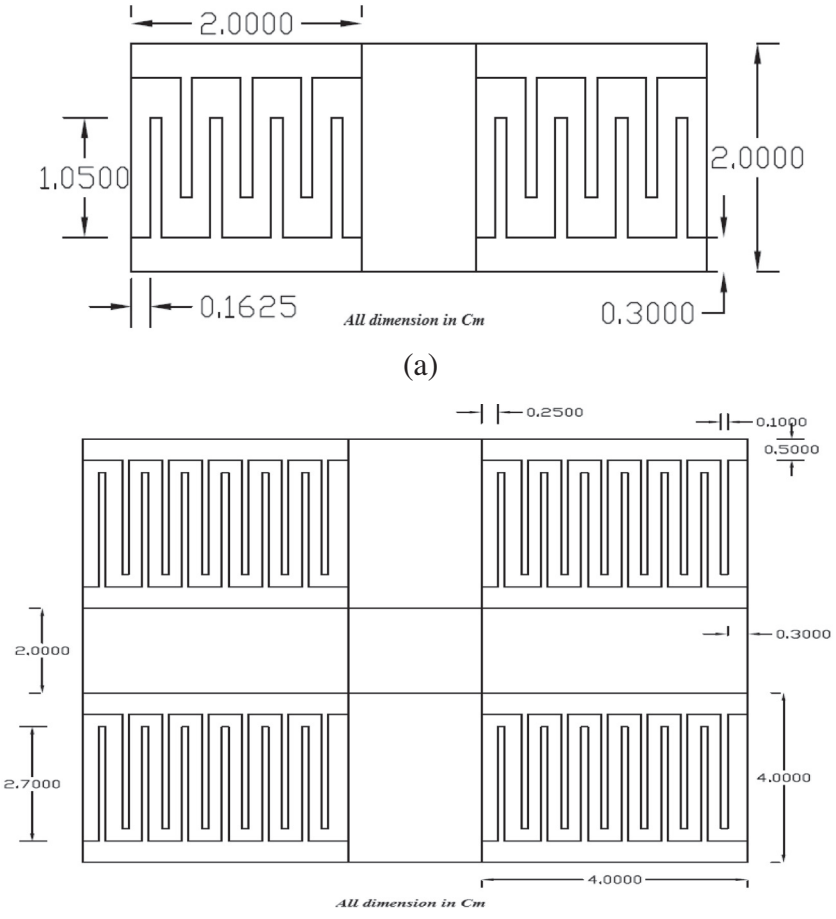

Fig. 1. (a) Mask of double sensor array, (b) Mask of Quadrature sensor array.