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Gas sensing properties of zinc stannate (Zn_2SnO_4) nanowires prepared by carbon assisted thermal evaporation process

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ABSTRACT

Zn_2SnO_4 nanowires are successfully synthesized by a carbon assisted thermal evaporation process with the help of a gold catalyst under ambient pressure. The as-synthesized nanowires are characterized by X-ray diffraction (XRD), field-emission scanning electron microscopy (FESEM), and transmission electron microscopy (TEM) equipped with an energy dispersive X-ray spectroscopy (EDS). The XRD patterns and elemental mapping via TEM–EDS clearly indicate that the nanowires are Zn_2SnO_4 with face centered spinel structure. HRTEM image confirms that Zn_2SnO_4 nanowires are single crystalline with an interplanar spacing of 0.26 nm, which is ascribed to the d-spacing of (3 1 1) planes of Zn_2SnO_4. The optimum processing condition and a possible formation mechanism of these Zn_2SnO_4 nanowires are discussed. Additionally, sensor performance of Zn_2SnO_4 nanowires based sensor is studied for various test gases such as ethanol, methane and hydrogen. The results reveal that Zn_2SnO_4 nanowires exhibit excellent sensitivity and selectivity toward ethanol with quick response and recovery times. The response of the Zn_2SnO_4 nanowires based sensors to 50 ppm ethanol at an optimum operating temperature of 500 °C is about 21.6 with response and recovery times of about 116 s and 182 s, respectively.

1. Introduction

Metal oxide nanostructures with well-defined morphologies have attracted a great deal of attention because of their shape, size and surface dependent properties [1,2]. The ability to control the size and shape of nanostructures is crucial as it affects their overall properties. One dimensional nanostructures, for example, are of immense interest in the field of nanotechnology. To date, intensive studies have been carried out on binary metal oxides nanostructures in several applications [3,4]. There is a continuing need for specially designed semiconductors that has led to an interest in ternary oxides, such as Zn_2TiO_4 [5], $CdSnO_3$ [6], $ZnSnO_3$ [7], $LiNbO_3$ [8], Cd_2SnO_4 [9], Zn_2SnO_4 [10–12], $BaTiO_3$ [13], $CdIn_2O_4$ [14], $CuFeO_2$ [15], $SrTiO_3$ [13], and Cd_2GeO_4 [16]. Ternary oxides provide greater flexibility to tune the chemical and physical properties of the materials by varying the compositions [17].

Among these ternary oxides, Zn_2SnO_4 is an important n-type semiconductor with a large band gap of 3.6 eV [18], which is often called zinc tin oxide (ZTO). Studies verified that bulk Zn_2SnO_4 has high electron mobility and conductivity, good thermal stability, chemical sensitivity, and low visible light absorption [19]. For instance, Zn_2SnO_4 nanowires have been successfully used as electrodes in lithium ion batteries for its stability [20]. Hierarchical macroporous Zn_2SnO_4 nanoparticles also have highly efficient performance in dye-sensitized solar cells due to its superior light scattering ability [21]. Zigzag Zn_2SnO_4 nanowires have also been shown to exhibit high sensor performance in detecting toxic and volatile organic compounds with sensitivity towards 50 ppm ethanol around 12 [17]. Chen et al. [22] reported flower-like hierarchical Zn_2SnO_4 nanostructures based sensors that exhibited enhanced ethanol sensitivity of 8 when exposed at 20 ppm, which is ascribed to high specific surface area and increased number of surface defects. Further, hollow Zn_2SnO_4 microcrystals showed high sensitivity towards H_2S due to large surface area [23]. Recently, Park et al. [24] demonstrated that Zn_2SnO_4-core/ZnO-shell nanorod based sensors showed enhanced response to NO_2 with a sensitivity of 173–498% at a concentration range of 1–5 ppm. This value was 2–5 folds higher than that of the pristine Zn_2SnO_4 nanorod sensor owing to encapsulation of Zn_2SnO_4-core by ZnO-shell, and formation of heterojunction which acted as a lever in electron transfer. However, along with high sensitivity, there is a need to design a selective of sensor.

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