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Letter

A generic approach for controlled synthesis of In_2O_3 nanostructures for gas sensing applications

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ABSTRACT

Large-scale synthesis of In_2O_3 nanoparticles, nanowires and nanorods were realized by improved chemical vapor deposition method on Au-coated silicon substrate. Field emission scanning electron microscopy revealed that the flow of carrier argon gas has profound effect on the shape and morphology of In_2O_3 nanostructures. Detailed structural analysis showed that the In_2O_3 nanostructures are single crystalline with a cubic crystal structure. Room temperature PL spectrum showed broad and intense blue emission at 375 nm. The In_2O_3 nanowires sensor can successfully detect hydrogen gas with response time as low as 50 s at 250 °C.

1. Introduction

Metal oxide nanostructures have been extensively investigated as building blocks for nanoscale electronic and optoelectronic devices, with the applications ranging from chemical, molecular and biological nanosensors to field emission devices [1–5]. Controlled synthesis of metal oxide nanostructures is exceptionally crucial as a bottom-up paradigm for the fabrication of functional nanodevices. Synthesis of one-dimensional (1D) nanostructures in the form of nanowires/nanorods has stimulated rigorous research activities because of their novel physical properties and their potential applications [6]. In_2O_3, an important wide band gap (3.6 eV) semiconductor, has been widely used in the optoelectronic field as window heaters, solar cells and flat panel display materials [7–9]. In_2O_3 nanostructures with well-defined shapes are useful in a wide range of application fields, including photonics, nanoelectronics, information storage, catalysis and gas sensing [10–16].

Different methods have been developed for the synthesis of 1D and 2D metal oxide nanostructures [17–21]. Among them chemical vapor deposition method was demonstrated to be an efficient technique for the fabrication of 1D metal-oxide nanowires. Two major growth mechanisms have been examined: vapor–solid (VS) and vapor–liquid–solid (VLS). Various research groups reported the synthesis of In_2O_3 nanowires at a high temperature (1300–1500 °C) [22,23]. However, the fabrication of In_2O_3 nanowires at low temperature range of below 1000 °C is particularly desired. Synthesis of nanowires below 1000 °C does not require expensive equipments, demand low power consumption and easy handling. In this work we report the controlled growth of In_2O_3 nanowires by chemical vapor deposition at 800 °C. The shape of In_2O_3 nanostructures was modulated by regulating the flow of carrier argon gas. The hydrogen gas sensing characteristics of In_2O_3 nanowires is investigated.

2. Experimental details

The synthesis of In_2O_3 nanostructures was performed in an improved chemical vapor deposition (CVD) system (as shown in Fig. 1). The one end of quartz tube was made the airflow reverse and increased the saturation ratio of the reagent species. The other end was kept open with small outlet, and the source material placed under the substrate. In a typical experimental procedure 0.5 g of high-purity indium grains was placed on an alumina boat. A silicon wafer coated with an Au film with a thickness of 10 nm was placed 6 mm above the In grains, with its surface directed towards the In grains. The tube chamber was purged for 30 min with high-purity Ar gas at a rate of 100 mL min^{-1} and then the furnace was heated to 800 °C at a rate of 25 °C min^{-1} and kept at this temperature for 1 h. After cooling to room temperature, a layer of yellow product was found deposited on the silicon wafer. In order to study extensively the effect of carrier gas on the morphology of In_2O_3 nanostructures, the synthesis was also carried out in Ar flow at a rate of 50 and 150 mL min^{-1}. The crystalline phase, morphological and structural properties of the products were investigated by X-ray diffraction (XRD) (Shimadzu XRD 6100 Cu Kα (0.15419 nm) radiation), field emission scanning electron microscope (FESEM), and high-resolution transmission electron microscope (TEM). Photoluminescence (PL) spectra were measured by Spex Fluorolog-3 spectrometer using an excitation of 325 nm with a 150-W Xe lamp at room temperature. Hydrogen gas sensing measurement was also carried out. For the gas sensing test, a quartz tube furnace was

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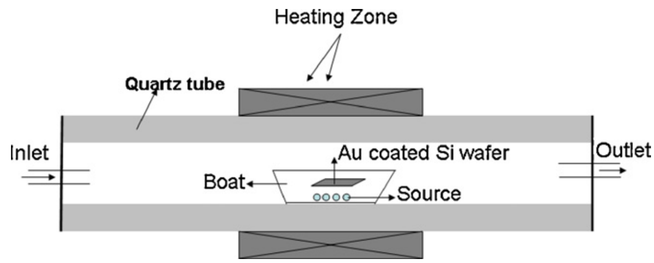

Fig. 1. Schematic diagram of improved CVD system.

used. Dry synthetic air was applied as a reference gas. The gas flow was controlled with mass flow controller. The resistance of the samples was determined by measuring the electric current when a voltage of 10 V was applied to the two electrodes. A computerized Agilent 34970A multimeter was used for the electrical measurement.

3. Results and discussion

3.1. Structural and optical properties

Fig. 2 shows the XRD spectra of the obtained In_2O_3 nanowires. All the peaks in the XRD spectrum could be indexed to cubic In_2O_3 with a lattice constant of a = 10.11 Å (JCPDS card no. 06-0416). More-

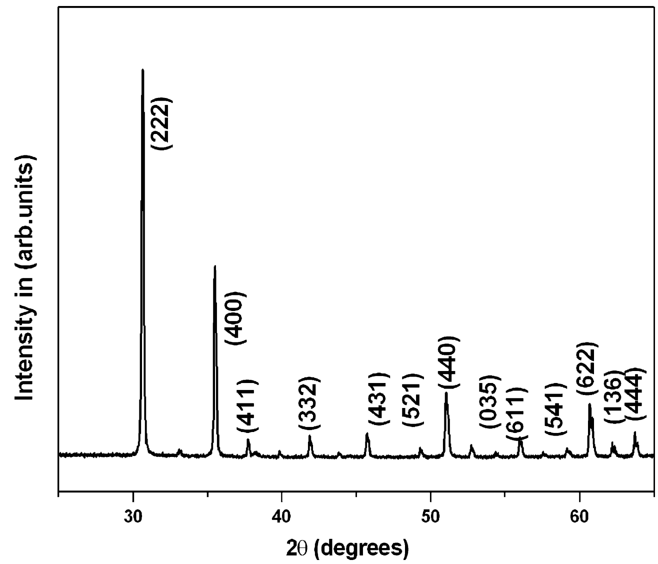

Fig. 2. XRD spectra of In_2O_3 nanostructures.

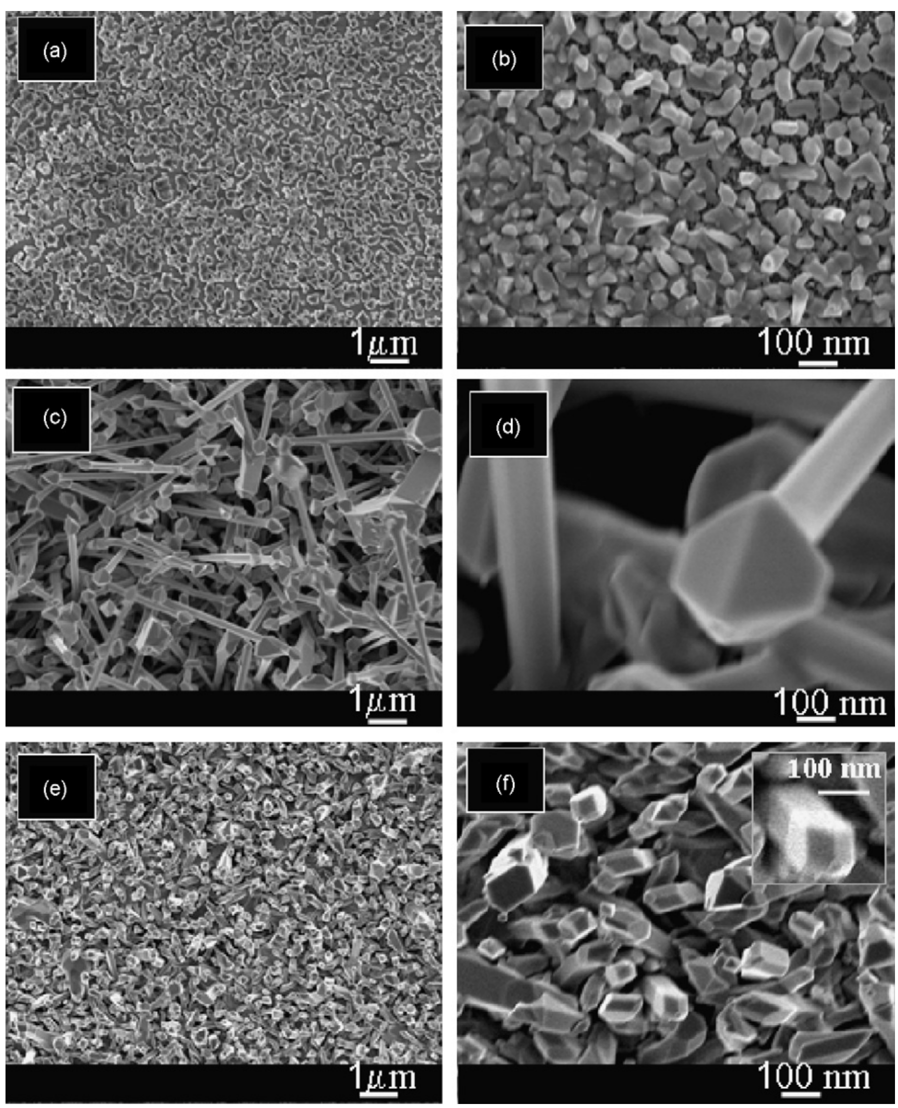

Fig. 3. Low and high magnification FESEM images of In_2O_3 nanoparticles (a) and (b), nanowires (c) and (d) and microrods (e) and (f).