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Zinc oxide nanorod and nanowire for humidity sensor

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Abstract

ZnO nanorod and nanowire films were fabricated on the Si substrates with comb type Pt electrodes by the vapor-phase transport method, and their humidity sensitive characteristics have been investigated. These nanomaterial films show high-humidity sensitivity, good long-term stability and fast response time. It was found that the resistance of the films decreases with increasing relative humidity (RH). At room temperature (RT), resistance changes of more than four and two orders of magnitude were observed when ZnO nanowire and nanorod devices were exposed, respectively, to a moisture pulse of 97% relative humidity. It appears that the ZnO nanomaterial films can be used as efficient humidity sensors.

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Keywords: Zinc oxide nanomaterial; Vapor-phase transport; Humidity sensor

1. Introduction

The humidity control is essential for various fields of industry as well as human life. There is a substantial interest in the development of humidity sensors for application in monitoring relative humidity (RH) in moisture-sensitive environment (such as glove boxes and clean rooms), detection of trace moisture in many types of pure gases for semiconductor manufacturing and packaging, cryogenic process, medical and food science application, and so on. Several transduction techniques have been explored, for example, changes in the capacitance and resistance of polymer and

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ceramic films, in the oscillation frequency of thin piezoelectric quartz plates and in the luminescence of microporous silicon, thin films are being used to measure humidity levels [1,2]. The desirable characteristic of humidity sensors are high sensitivity, chemical and thermal stability, reproducibility, low-operation temperature, low cost and long life. So far, however, there has been no optimum material that could fulfill all those requirements simultaneously [3–6]. ZnO is a versatile II–VI semiconductor with numerous applications ranging from optoelectronics to chemical sensors because of its distinctive optical, electronic and chemical properties. It is well known that dimension or the surface-to-volume ratio has great influence to the material performance. In recent years, one-dimensional (1D) ZnO nanostructure, such as nanowire, nanorods, nanobelts and nanotetrapod, have attracted much attention [7–11].

In this work, ZnO nanorod and nanowire films were fabricated, respectively, on the Si substrate with a grid of pre-deposited Pt electrodes by the vapor-phase transport process, and their humidity sensitivity characteristics have been investigated. It is experimentally demonstrated that ZnO nanorod and nanowire films show a promising application for humidity sensors.

2. Experimental

Silicon (1 0 0) substrate was cleaned in a sonicating bath of acetone for about 1.5 h. A SiO_2 insulating layer with thickness of about 200 nm was formed on the surface of Si substrate by thermal oxidizing. A comb type Pt electrode (Fig. 1) was deposited on the substrate. The substrate was coated by an Au thin film with thickness of about 5 nm using a JS-450 cold sputter unit. An equal amount of ZnO powder (purity 99.99%) and graphite powder (purity 99.9%) were mixed and loaded in a 15 cm long quartz boat. The substrate with gold thin film was put ~5 cm downstream of the starting materials. The assembly was then placed in the middle of a quartz tube in a horizontal furnace. The furnace temperature was increased to 450–600 °C at a flow rate of 150 sccm Ar (99.9%), and O_2 was then added at a flow rate of 15 sccm for a further 1 h. After the system had cooled to room temperature (RT), light or dark gray material film was found on the surface of the substrate. Scanning electron microscopy (SEM, JEOL-JSM-6700F), X-ray diffraction (XRD, D/max 2550 V) and high-resolution transmission electron microscopy (HRTEM) (Hitachi H-9000, NAR 300 kV) were used to characterize the morphology and crystal structure of the products, respectively. The electrical properties of the materials were investigated using a LF impedance analyzer and electrometer. The layout of the sensor is shown in Fig. 1.

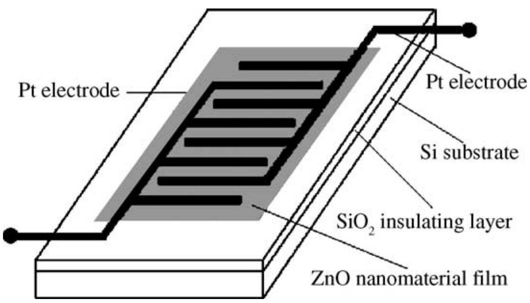

Fig. 1. Scheme of a ZnO nanomaterial humidity sensor.

The controlled humidity environments were achieved using anhydrous P_2O_5 and saturated aqueous solutions of LiCl, $MgCl_2$, NaBr, NaCl, KCl and K_2SO_4 in a closed glass vessel at an ambient temperature of 25 °C, which yielded approximately 12.0, 33.2, 57.6, 75.8, 84.3 and 96.7% relative humidity, respectively. These RH levels were independently monitored by using a standard hygrometer.

3. Results and discussion

Fig. 2(a) and (b) show the XRD patterns of products grown on the substrates under 450 and 600 °C, respectively. The strong diffraction peaks can be indexed as those from the known highly crystallized wurtzite-structure ZnO with lattice constants of a = 0.325 nm and c = 0.521 nm. Fig. 3(a) and (b) show a top-view SEM images of high-density ZnO nanorods and nanowires grown on the substrates under 450 and 600 °C, respectively. As shown in Fig. 3(a), a lot of short ZnO multipod nanorods with a mean diameter of about 300 nm and an average length of about 1.0 μm were obtained at low temperature (450 °C). When the temperature went higher (600 °C), ZnO nanowires