Dielectrophoretic assembly of ZnO nanorods for gas sensing

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Abstract

ZnO nanorods were prepared by hydrothermal growth in aqueous solution. Products were then deposited on coplanar and interdigitated gold electrodes using dielectrophoresis. It was observed that ZnO nanorods link together at both ends to bridge the gap. This effect was employed for the deposition and alignment of nanorods along each other to make connection between the two electrodes for CO gas sensing application. This paper describes an electrokinetic fabrication method for a gas sensor composed of ZnO nanorods using DEP.

Keywords: Dielectrophoresis; ZnO nanorods; Gas sensor

1. Introduction

One-dimensional nanostructures have distinctive properties in mechanical, chemical and electronic aspects. This makes these nanostructures a promising material for a variety of future applications [1]. ZnO nanostructures have been attracting much attention due to their novel electronic properties and their potential applications in device miniaturization. For the past several years, various single crystal/crystalline nanostructures of ZnO such as nanobelts, nanorods, nanorings, and nanohelices have been synthesized. Because of high production yield and simplicity of the method, the ZnO nanorods prepared by the solution-based methods are receiving more and more attention recently [2]. Precise and reliable handling of these nanomaterials is important for bottom-up assembly of nanodevices, and enormous efforts employing a variety of approaches have been made and reported [3]. Electrokinetic manipulation has been recognized as a useful technique for separation, alignment and positioning of carbon nanotubes and other one-dimensional nanomaterials [4].

AC electrokinetics is the study of the behavior of particles in suspension when they are subjected to AC electrical fields [5]. Most of the works on AC electrokinetics have been focused on biological particles and carbon nanotubes so far and only limited research is devoted to the interaction between AC electrokinetics and ceramic nanomaterials. Dielectrophoresis (DEP) is the electrokinetic motion of dielectrically polarized materials in non-uniform - usually AC -electric fields, and is an ideal technique to align and manipulate one-dimensional nanostructures for micro/nanosensors and circuits.
In the present study, interdigitated electrodes were employed for the alignment and manipulation of the hydrothermally synthesized ZnO nanorods. It was demonstrated that ZnO nanostructures link together at both ends to bridge the gap between the two electrodes, which is extremely important in nanoelectronics. CO gas sensing measurements of the aligned ZnO nanorods were then investigated at different temperatures and CO concentrations, introducing the dielectrophoresis as a manipulation technique for fabrication of micro/nano gas sensors.

2. Experimental

Aqueous solutions were prepared by mixing Zn(NO₃)₂·6H₂O (MERK) with hexamethylenetetramine (HMT; C₆H₁₂N₄) (MERK) while keeping the ratio 1:1. Ordinary glass plates were used as substrate. Hydrothermal growth in aqueous solution was carried out at 95°C in a sealed glass bottle and heated for several hours in a regular oven. Then, substrates were taken out of the solution and ultrasonicated for 10 min in pure acetone for dispersing nanorods in the solution. Coplanar and interdigitated gold electrodes were used to manipulate ZnO nanorods. Interdigitated electrodes on the front side and a Pt meandered heater on the backside were used for gas sensing measurements. Electric field was generated by applying a sinusoidal voltage (up to 20V) with a (0-50 kHz) function generator. The set up used for the deposition process has been reported elsewhere [6]. The SEM (Stereo Scan360-Leica/Cambridge) image and X-ray diffraction (PHILIPS-PW3710) pattern of the synthesized nanorods with Cu Kα radiation on glass substrate are presented in Figs. 1(a) and (b), respectively, showing the formation of well crystalline ZnO nanorods with no characteristic peak for any impurities. Scanning electron microscopy has also been used to evaluate the DEP manipulation results on electrodes. CO sensing measurements were conducted in a normal gas sensing station in the temperature range of 300-400°C and different CO concentrations (100-1000ppm). The gas response is given by the related resistance of R_air/R_CO, where R_air and R_CO denote the resistance of the sensor in air and in CO gas, respectively.

3. Results and discussion

The deposited ZnO nanostructures on coplanar electrodes at frequencies of 100 and 10000 Hz are demonstrated in Fig. 2. Images show that the material aligns across the electric field lines and bridges the gap between the electrodes through dielectrophoresis. This effect happens due to polarization of ZnO nanorods in an inhomogeneous electric field in vicinity of the electrode surface, and attracts the particles towards high/low electric field regions depending on the polarizability of the particle compared to that of the medium. Positive dielectrophoresis happens when the particles are pushed towards regions of high electric field and vice versa. It can be seen in Fig. 2 that deposition rate of ZnO materials decreases by increasing the applied frequency. Also, at higher frequencies ZnO
nanostructures form chains that connect the two electrode sides to each other and the alignment yield increases. The chain formation of CNTs and Au nanoparticles under AC electric fields has previously been reported.

Fig. 2. Assembly of ZnO nanostructures in the electrode gap in different applied frequencies (a) 100 Hz and (b) 10 kHz.

Interdigitated electrodes also were employed for the precise manipulation of ZnO nanorods (Fig. 3(a)). Fig. 3(b) shows the SEM image of the assembly of ZnO nanorods between the gaps of electrodes with a voltage of 5 volts and a frequency of 1000 Hz. This assembly was used as a gas sensor.

Fig. 3. SEM image of the (a) sensor electrode and (b) deposited ZnO materials on sensor electrode at a frequency of 100 Hz.

The dynamic response of the gas sensor loaded with ZnO nanostructures towards different concentrations of CO (100-1000ppm) at 400°C is presented in Fig. 4(a). Fig. 4(b) shows the sensing properties of the nanorods at different operating temperatures towards 750 ppm CO. As it can be seen sensor exhibited a clear response to the gas at different temperatures and its maximum response is at 400°C. These results are in good agreement with the results obtained for CO gas sensing properties of ZnO thin films [7].
Fig. 4. (a) Dynamic sensor response to pulses of CO at 400°C and (b) sensor response to 750ppm CO at various temperatures.

4. Summary

A gas sensor based on ZnO nanorods was prepared using DEP. Results show that nanorods are lined following the applied field bridging the electrodes. The sensor shows a relatively fast and stable response to CO gas with its highest sensitivity at 400°C.

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References