SYNTHESIS OF ZnO WHISKERS BY A SIMPLE THERMAL EVAPORATION

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Abstract. Single-crystalline zinc oxide (ZnO) whiskers were successfully synthesized on the Si/SiO_2 substrates by thermally evaporating metal zinc powders at temperatures of 600 and 650 °C. EDS microanalysis and XRD measurement showed that the product was single-crystalline ZnO with a hexagonal wurtzite structure. SEM analysis revealed that the synthesized ZnO whiskers have an average diameter of 200 nm and typical lengths of up to 1 àm. The PL spectrum of the synthesized sample excited at a wavelength of 325 nm consisted of a ultra-violet emission at about 378 nm and a much broader green emission band centered at about 495 nm. They were attributed to the NBE and the deep-level emissions, respectively.

1. Introduction

Highly oriented and well patterned arrays of zinc oxide (ZnO) nanostructures have been demonstrated to have potential applications in nanoscale lasers [1], field effect transistors [2]. There are various techniques that have been successfully employed to synthesize well aligned ZnO nanorods on solid substrates. Among them, the simple thermal evaporation technique has been widely used due to its simplicity and relatively high-quality products. In this report, we demonstrate a simple route of fabricating fairly aligned ZnO whiskers in air at relatively low temperature without the presence of either carrier gas or metallic catalyst. The crystal structure and morphology as well as optical properties of the synthesized samples were investigated.

2. Experiments

The synthesis of ZnO whiskers was carried out in a horizontal tube furnace. Strips of polished and unpolished (100) Si were used as substrates. They were faced downward on the top of an alumina boat loaded with metal zinc powders at a vertical distance of about 5 mm. Thermal evaporation of the zinc powder source was then carried out at 600 and 650 °C for 45 minutes in air. After cooling down, a white layer of materials was found over the Si substrate. The crystal structure and morphology of the synthesized samples were characterized by a Siemens D5005 XRD diffractometer and a JEOL-JSM5410LV scanning electron microscopy (SEM), respectively. The SEM equipped with the OXFORD-ISIS 300 energy dispersive X-ray spectrometer (EDS) was also employed to conduct the EDS spectroscopy and element mapping. Photoluminescence (PL) spectra were measured at room temperature using a Fluorolog FL3-22 Spectrofluorometer with a Xenon lamp of 450 W as an excitation source.

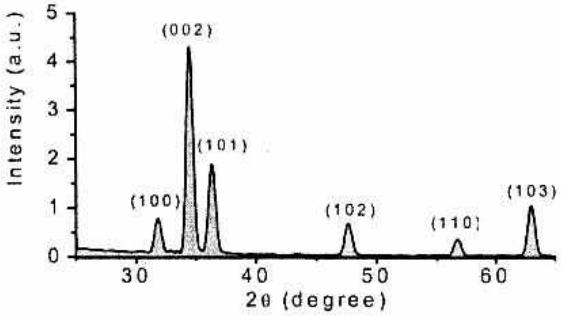

Figure 1. XRD pattern of ZnO whiskers.

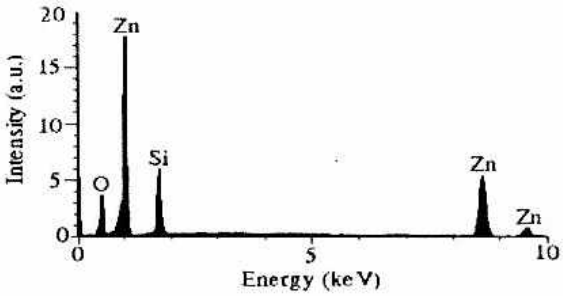

Figure 2. EDS spectrum of ZnO whiskers.

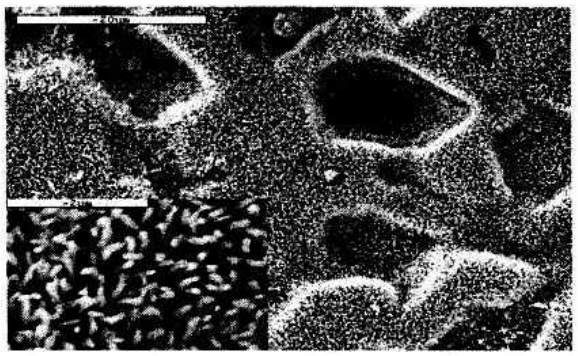

Figure 3. SEM image of ZnO whiskers grown at 600 °C on rough Si substrate.

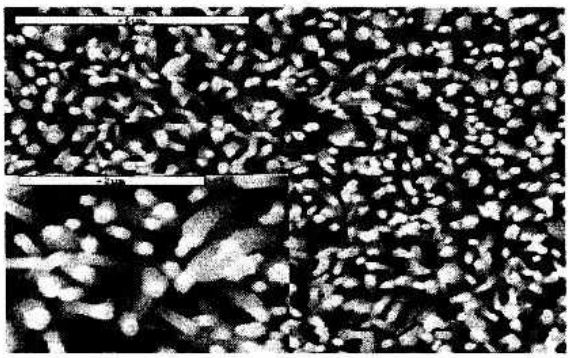

Figure 4. SEM image of ZnO whiskers grown at 650 °C on polished Si substrate.

3. Results and discussion

Figure 1 shows a typical XRD pattern of the synthesized sample. All the diffraction peaks can be well indexed to a hexagonal wurtzite structure of ZnO. No other phases such as Zn are detected. A strongest and sharpest (002) peak in the spectrum indicates that the ZnO whiskers grew preferentially along the *c*-axis (<0001> direction) oriented normal to the Si substrate. It should, however, be noticed the presence of the relatively strong (101) and (103) diffraction peaks which implies that there is a certain degree of isotropic and random orientation in the sample. The EDS spectrum is depicted in Fig. 2. It is clear that, beside the trace of Si substrate, all the EDS peaks are attributed to the binding energy of the Zn and O elements.

Figures 3 and 4 show SEM images of the ZnO samples synthesized at 600 °C on unpolished side and at 650 °C on well polished side of Si substrates. In both cases, high density array of fairly well-aligned ZnO whiskers is observed. The whiskers are oriented nearly perpendicular to the substrate surface. High magnification SEM images shown as insets in these figures reveal that the whiskers are straight and about 1 μm in length. The hexagonal facets on the tips can be clearly identified confirming that the whiskers actually grew along the <0001> direction. The average diameters of ZnO whiskers grown at 600 °C and 650 °C are about 150 nm and 200 nm, respectively. Higher grown temperature results in the formation of larger diameter whiskers.

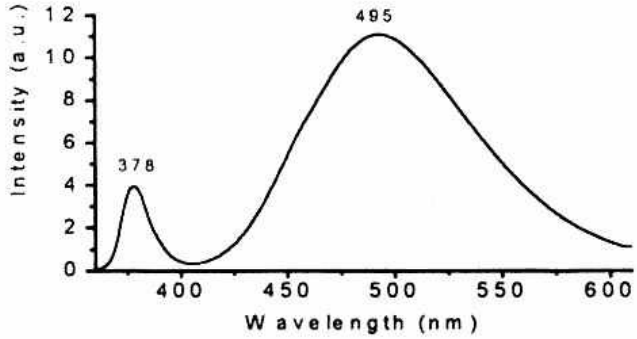

Figure 5. Room temperature PL spectrum of the ZnO whiskers synthesized at 600 °C.

The PL spectrum of the synthesized ZnO whiskers, excited at a wavelength of 325 nm, consists of a ultra-violet (UV) emission at about 378 nm (3.28 eV) and a much broader green emission band centered at about 495 nm (2.5 eV) as shown in Fig. 5. The UV emission band can be attributed to the near band-edge (NBE) transition, namely, the recombination of free excitons through an exciton-exciton collision process [3]. The green emission band results from the radial recombination of electrons with holes trapped in singly ionized oxygen vacancies [4] and it is commonly seen in ZnO materials synthesized under oxygen-deficient conditions. The stronger green emission in comparison to the NBE emission indicates that the synthesized ZnO whiskers are rich in atomic defects.

4. Conclusions

Arrays of fairly aligned ZnO whiskers were successfully synthesized on the Si/SiO_2 substrates via simple thermal evaporation method. The whiskers grew preferentially along the *c*-axis (<0001> direction) oriented normal to the Si substrate. The average diameter is in the range of 150 nm to 200 nm depending on the grown temperature. The PL spectrum is dominated by a strong green emission, although UV emission is also observed.

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