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Photoluminescence properties of SnO_2 nanowhiskers grown by thermal evaporation

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Abstract

SnO_2 nanowhiskers were synthesized by thermal oxidation with and without a gold film as a catalyst. The SEM images reveal wire-like and rod-shaped nanowhiskers about several hundred micrometers in length and 100 nm in diameter. The three observed Raman peaks at 474, 632, and 774 cm^{-1} indicate the typical rutile phase which is in agreement with the X-ray diffraction results. The photoluminescence properties were measured at room temperature. The peaks at 342 nm corresponding to the excitation transitions from the conduction band to the valence band of the SnO_2 nanowhiskers were not observed. However, a strong emission band at ~600 nm was detected indicating the existence of oxygen vacancies in both samples. A new emission band at ~398 nm was also observed in the sample with the gold film and it could be attributed to the near band-edge emission.

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1. Introduction

SnO_2, an n-type semiconductor with a wide band gap of 3.6 eV at 300 K, is regarded as one of the promising materials for gas sensors [1,2] and dye-based solar cells [3] and is used in transparent conducting electrodes. In addition, a one-dimensional (1D) SnO_2 structure may find wide applications in many fields. Such 1D nanostructured SnO_2 nanowires and nanorods having a rectangular cross section have been observed [4,5] and are expected to be important building blocks for nanodevices and offer exciting opportunities in both fundamental research and applications. Hence, considerable efforts have been made to fabricate SnO_2 nanostructures via various methods [6,7]. Among these methods, the method of thermal evaporation has advantages due to its simplicity and high-quality products [7]. We have successfully fabricated ZnO nanowires and tetrapod-like nanostructures using this thermal evaporation method [8,9]. Here, we report the use of this method to synthesize SnO_2 nanostructures. The structure was produced with and without a gold film as a catalyst on tin at 800 °C (sample A − with Au film) and 900 °C (sample B − without gold film). We observed a new emission band at ~398 nm (3.11 eV) in the photoluminescence (PL) spectrum from the SnO_2 nanorods. Our results suggest that it is related to the quantum confinement effect and excellent quality of the SnO_2 nanowhiskers.

2. Experimental details

In the synthesis, a horizontal quartz tube (inner diameter of 50 mm and length of 100 cm) that was open on one side was mounted inside a high-temperature quartz tube furnace. Metallic tin powder (1 g in weight, 99.99% pure) was placed in an alumina boat serving as the vapor source. Au-coated (20 nm) Si wafer (sample A) and a bare Si [p-type, (100)] wafer (sample B) were used as the substrates. After transferring the boat to the center of the quartz tube, the furnace was rapidly heated to 800 °C (sample A) and 950 °C (sample B) and kept for 60 min. During the whole process, a constant flow of Ar (99.99%) was maintained at a rate of 50 sccm. After the furnace cooled down to room temperature, white wool-like products were found on substrates.

The morphology and crystal structure of the synthesized materials were characterized by X-ray diffraction (XRD) using a D/max 2550 V and CuKα radiation, scanning electron microscopy (SEM) employing a JSM-6700F, high resolution transmission electron microscopy (HRTEM) using a JEM200F equipped with energy-dispersive X-ray fluorescence (EDX) and micro-Raman spectroscopy using a LABRAM-HR confocal laser micro-Raman spectrometer at room temperature. The photoluminescence (PL) spectra were measured at room temperature from 340 to 600 nm using an He–Cd laser with a wavelength of 325 nm.

3. Results and discussion

The structure and phase of the two samples were examined by X-ray diffraction (XRD) and the results are depicted in Fig. 1(a). Both samples possess the same structure that can be indexed to a pure rutile phase SnO_2 with lattice constants of $a = 4.738$ Å and $c = 3.189$ Å.

Fig. 2 shows the typical scanning electron microscopy (SEM) images of the samples. A large amount of rod-shaped SnO_2 nanowhiskers can be observed on sample A as shown in Fig. 2(a). These SnO_2 nanorods appear to grow randomly on the Si substrate with several micrometers in length. Fig. 2(b) shows the magnified SEM image of a single SnO_2 nanorod and the transverse