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Research Article

Stable Emission of SnO_2 Nanowires Array at Low Field

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SnO_2 nanowires were synthesized by thermal evaporation, and the field emission characteristics of SnO_2 nanowires are investigated in detail. The results show that the turn-on field is as low as 1.39 V/μm. And the fluctuation of field emission currents is as low as 2.8% for 24 h. The results reveal that SnO_2 nanowires hold promise for field emission display application.

1. Introduction

Great attention has been paid to one dimensional nanomaterials, such as carbon nanotubes (CNTs), SiC, ZnO, SnO_2, CuO, and AlN [1–7]. They are considered to be ideal cold cathode materials because the high aspect ratio of one-dimensional nanostructure contributes to field emission. SnO_2, which is an n-type semiconductor with wide-band gap (3.6 ev), exhibits fascinating electric characteristics and high chemical and thermal stability. Recently some studies have focused on field emission properties of various nanostructures of SnO_2, implying that it would have a potential application in field emitter [8–11]. However there are few reports specialized on its emission stability. In this work, SnO_2 nanowires were synthesized by thermal evaporation. The morphology investigation and field emission measurement revealed that the SnO_2 nanowires exhibit excellent field emission property at low turn on electric field.

2. Experiment

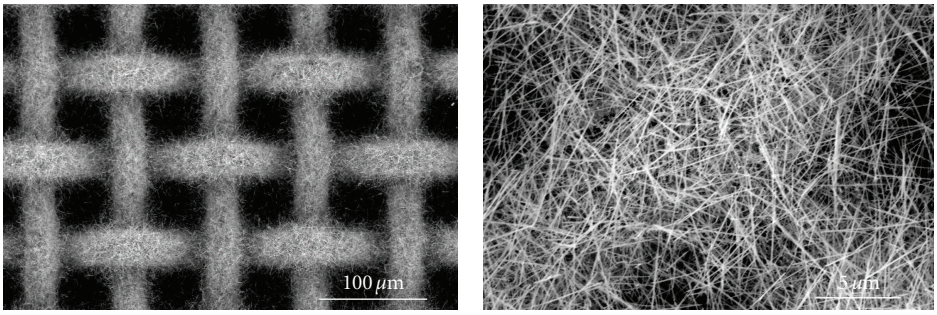
The experiment was carried out in a horizontal electronic resistance furnace. A ceramic boat with Sn powder spread on it was placed at the centre of the furnace. And a stainless steel mesh with pore diameters of 500 μm was placed 5 cm far away from the source along the down airflow to collect the product. The furnace was quickly heated to 950°C, and then oxygen gas was introduced at a rate of 10 SCCM (cm^3/min). After 30 minutes' reaction, the system was shut down and cooled down to room temperature. Some white wool-like products were found on the mesh.

The morphology observation was performed by scanning electron microscopy (SEM) (Hitachi-S3000N) and X-ray diffraction (XRD, D/Max-γA, and CuKα radiation). Field emission measurements of SnO_2 nanowires were performed in a vacuum chamber under a pressure of 2×10^{-4} Pa at room temperature. The anode was an indium tin oxide (ITO)-coated glass, and the cathode was the as-synthesized SnO_2 samples on stain steel mesh. They were separated by a space of 1 mm in height.

3. Results and Discussion

Figure 1 show the SEM image of SnO_2 nanowires synthesized at 950°C. The pictures indicate that SnO_2 are grown upward on the stainless steel mesh, and the nanowires have perfect dimensional uniformity. The average diameters of the nanowires is about 180 nm; however, the length reachs up to tens of micrometers. As shown in Figure 2, the XRD spectrum detached from the substrate indicates that the nanowires are tetragonal rutile structure with the lattice constants of $a = b = 0.443$ nm and $c = 0.372$ nm, which correspond with the data of SnO_2 powders recorded in the JCPDS document (powder diffraction file compiled by the joint Committee on Powder Diffraction, 1985, Card No. 03-1116). No other impurities were detected.

The growth of SnO_2 nanowires can be explained by the vapour-solid (VS) mechanism. When the temperature



(a) (b)

Figure 1: (a) Top view of SnO_2 nanowires. (b) The enlarged magnification SEM image of nanowires.

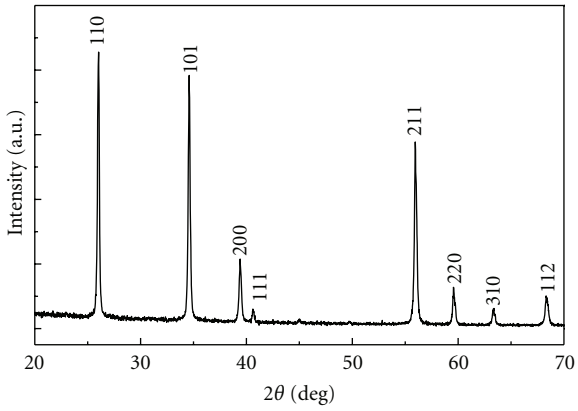
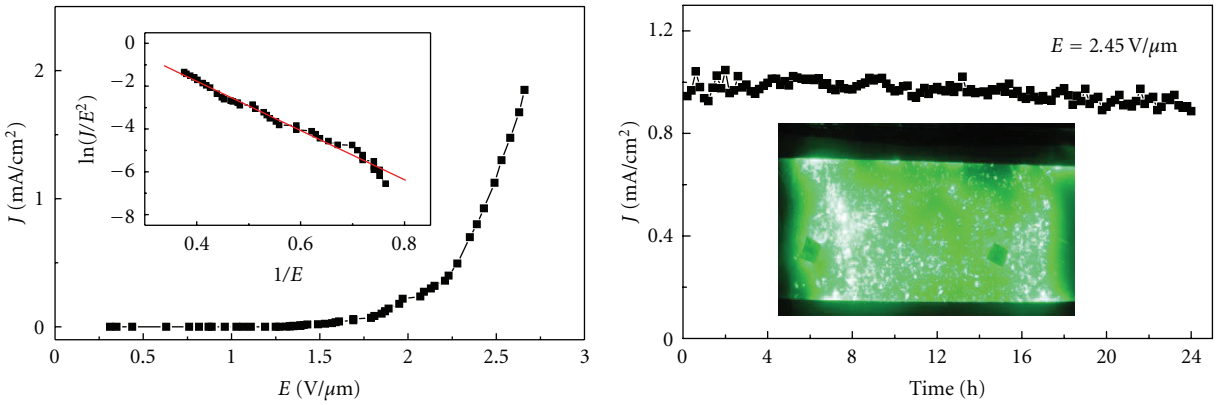


Figure 2: The XRD patterns of SnO_2 nanowires.



(a) (b)

Figure 3: (a) J-E characteristics of SnO_2 nanowires. The inset shows the F-N plot. (b) Stability curve at an applied field of 2 V/μm. The insert is field emission photograph of SnO_2 nanowires.

reached to the peak, the oxygen combined with Sn vapour and then deposited on the substrate. The substrate may have some catalyzation, and it is very easy for SnO_2 to grow on it. During the system cooling down, there was still many Sn or SnO vapour surrounding the substrate.

The emitting current density versus the electric field (J-E) plot is shown in Figure 3(a). The turn-on field, which is defined as required electric field when current density comes to 10 uA/cm^2, is observed to have only 1.39 V/μm. And the threshold field (defined as the field where the current density reaches to 1 mA/cm^2) is 2.45 V/μm. The emission current elevates rapidly with the increase of the applied field. When the electric field reaches to 2.66 V/μm, the current density is as high as 1.85 mA/cm^2. The efficient electron emission from SnO_2 nanowires may be due to that SnO_2 can provide enough electrons. And the high length-diameter ratio of nanowires can greatly enhance the field around the cathode; thus, the turn-on field is reduced. The high current density

results from the good electrical contact between SnO_2 and the substrate.

Shown in the inset of Figure 3(a), the Fowler-Nordheim (F-N) plot exhibits approximately straight lines. It demonstrates that the emission electrons are extracted by electric field and come through the barrier tunnelling. According to F-N law, the relationship between current density (J) and the applied field (E) can be described as (1)

$$J = \left(\frac{AE^2}{\varphi}\right)\exp\left(-\frac{B\varphi^{3/2}}{\beta E}\right), \quad (1)$$

where φ is the work function of the emitting material, A and B are constants, $1.56 \times 10^{-10}\,\mathrm{AV^{-2}\,eV}$ and $6.83 \times 10^{9}\,\mathrm{VeV^{-3/2}m^{-1}}$, respectively. As the work function of SnO_2 is 4.3 eV, we can figure out that the field enhancement factor β is 5272. That demonstrates that the structure of nanowires greatly enhances the electric field and promote field emission.

Figure 3(b) shows the fluctuation of current density at the field of 2.45 V/μm. At first, the electric current experience a short period of fluctuating, that may be due to some emitters in the condition of preemission. Then the current density tends towards stability, and the current fluctuation is about 2.8%. It is regarded that the SnO_2 nanowires electrons emit stably without degradation for 24 hours. The insert is the emission photograph of SnO_2 nanowires at 2.45 V/μm. The effective light area is 1 cm × 2 cm, and its luminous intensity is 350 cd/m^2. It can be seen that the margin is a little brighter than the centre, but the luminescence is uniform on the whole.

4. Conclusion

In summary, SnO_2 nanowires have been successfully synthesized on stainless steel mesh by thermal evaporation. The morphology and field emission investigation revealed that the turn-on field SnO_2 nanowires are as low as 1.39 V/um, and the emission current density is as high as 1.85 mA/cm^2 at the field of 2.66 V/um. SnO_2 nanowires exhibit good luminescent capability and excellent stability at low field. The results reveal that SnO_2 nanowires potentially applied in field emission and other photoelectric devices.

Acknowledgments

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