Application of Direct Growth ZnO Nanaotetrapods in Field Emission Device

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Abstract

Si-based ZnO nanotetrapods used as light emitting material in a field emission display device were successfully fabricated by low-cost techniques and equipment. The products show a low turn-on field in the field emission measurement under a pressure 10^{-5}Pa. The direct growth samples utilized in the diode-type field emission display (FED) were well analyzed. The green light was achieved from the ZnO: Zn phosphor at a relatively low applied electric field with a large luminescence area of 0.25cm^2 while the substrate is only 0.6cm^2. The electron emission at 1100V dc is stable with an emission current of 5.74×10^{-5}A. The developed technology has practical application in field emission devices.

Keywords: ZnO; Field emission; Luminescence

1. Introduction

Field emission character of nanostructure material is of great commercial interest for the application in display[1-4] or other electrical devices[5]. Field emission display, due to its advantages such as high brightness, low power consumption, fast response time, wide viewing angles, and a wide operating temperature range[1-4, 6-10], is considered as a promising technology for the next generation flat panel display.

Previous research works of field emission display (FED) focused on the carbon-based materials[1, 3, 5, 11-13], because their low work functions, stable mechanical properties, high aspect ratio, and high conductance. However, ZnO as a II-IV compound semiconductor with a direct band gap of 3.37eV and a large exciton binding energy of 60meV at room temperature is of great interest[2, 8-10], not only because its characters is similar to carbon but also its distinct properties including resistance against oxidation[8]. Up to now, lots of reports have been given on the successful realization of 1D ZnO[8-10], using various methods. In this paper, we report a process technology using the direct growth ZnO nanotetrapods by CVD as the field emission emitter.

2. Experimental details

Synthesis of ZnO nanotetrapods without any catalyst through a vapor phase transport method in a horizontal tube furnace as follow: 1g Zn powder as the source covered by a Si chip, was pushed into the tube when the furnace temperature was ramped to the desired temperature and kept for several minutes, under a constant flow of pure Ar (10sccm) and pure O_2 (260sccm). Then the sample was cooled down to the room temperature. The as-synthesized material was then analyzed by the scanning electron microscopy (SEM), transmission electron microscope (TEM) and X-Ray diffraction (XRD).

Field emission character and the application was analyzed under a pressure 10^{-5}Pa and DC electric field, with a suitable distance between anode and cathode (for this experiment 300μm & 350μm). After that, we replaced the anode metal plate of an indium tin oxide (ITO) glass with a phosphor (ZnO: Zn) layer. Then we repeated the process above, and at a fixed DC voltage we collected the data current vs time.

3. Results and discussion

Figure 1(a) show the SEM images of character of ZnO nanotetrapod. It can be seen from figure 1 (a) that the product is made of nanotetrapod structure, with a high ratio aspect. Figure 1(b) is a TEM image of ZnO nanotetrapod, and the selected area electron diffraction (SAED), as shown in inset, indicating the ZnO nanotetrapod with high purity. The image demonstrates the tip is a single crystal with a growth direction along c-axis <0001>. Figure 1(c) shows the XRD, where all diffraction peaks could be attributed to the hexagonal wurtzite structure ZnO with lattice constant of a=0.3249 nm and c=0.5205 nm. No diffraction peaks corresponding to other impurities were detected.

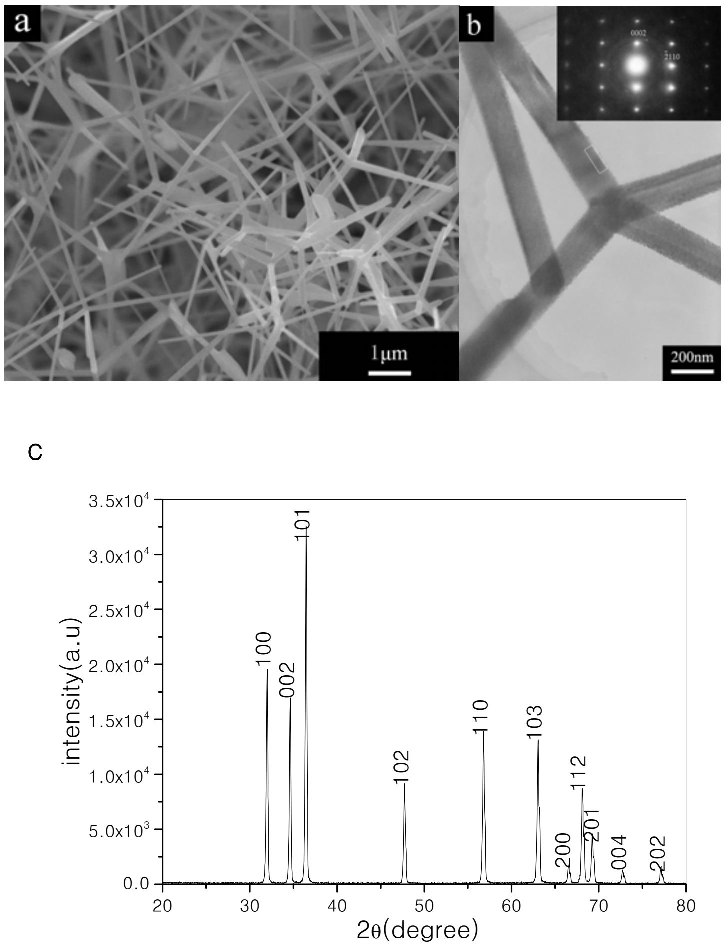

Figure 1. characers of as-synthesized products: SEM images: (a). TEM image of ZnO; the inset shows the corresponding SAED (b), X-Ray diffraction(c)

The dependencies of field-emission-current density on the applied electric field are shown in Figure 2. The overlap of two curves indicates that the ZnO nanoscale material exhibited fairly satisfactory repeatability. Usually, the turn-on field is defined as the applied field (E) where the current density (J) is distinguished from the background noise. In this experiment, the turn-on fields are 2.0V/μm for distance of 300μm and 2.6V/μm for distance of 350μm. When the emission-current density arrives 10μA/cm^2 , the fields are 2.36V/μm and 3.0V/μm, respectively.

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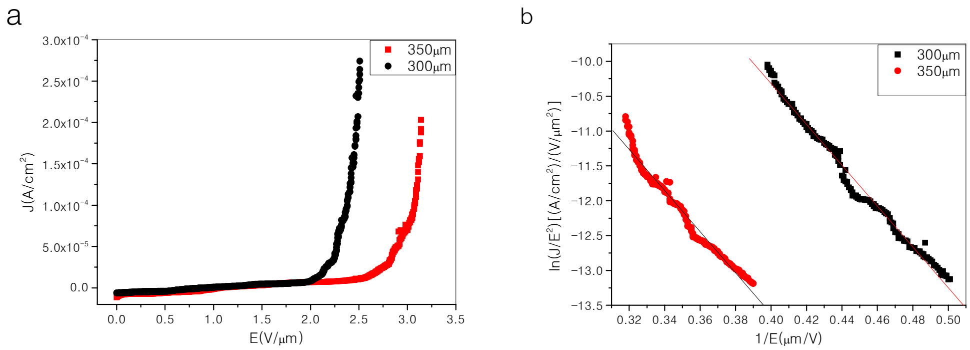

Figure 2. Field emission measurement with different distances: 300μm & 350μm (a) the corresponding F-N plots (b)

The corresponding Fowler-Nordheim (F-N) plot exhibits linearity, as shown in Figure 2(b). It can be found that the field-emission data usually fit to the linear relation given by:

$$\ln(J/E^2) = -(B\Phi^{3/2}/\beta)V^{-1} + \ln(A\beta^2/\Phi)$$

where the universal constants $A=1.54\times10^{-6}AeVV^{-2}$ and $B=6.83\times10^{3}eV^{-3/2}V\mu m^{-1}$, β is the field-enhancement factor, Φ is the word function and its value is 5.3eV for ZnO material. According to the F-N law, the data lines from figure 2(b) are parallel and the calculated field-enhancement factor β is about 2834 for 300μm and 2826 for 350μm as expected.

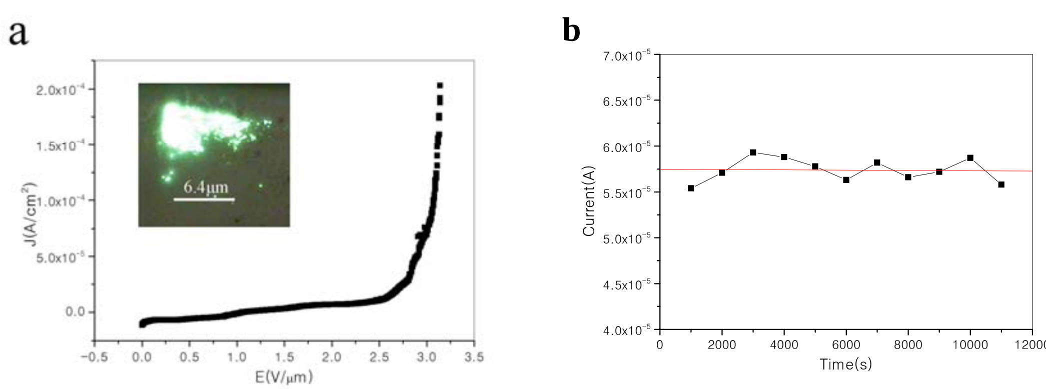

Figure 3. Electron emission image of ZnO nanotetrapod, inset shows luminescence area(a). Emission current at 1100V (b)

Figure 3 (a) show an electron emission image of the ZnO nanotetrapod that reveals an efficient field emission. The brightness is enhancing with the increase of the applied voltage and the luminescence area reaches $0.64\times0.36cm^2$ while the Si-substrate is approximate $0.6cm^2$. The emission current vs. emission time at 1100V is shown in Figure 3 (b). The I vs. t curve demonstrates the stability of ZnO nanotetrapod emitters under electrical field, with a average current of $5.74\times10^{-5}A$, which is a significant indicator for the FED manufacture and other field emission devices.

4. Conclusions

In summary, we demonstrate the ZnO nanotetrapod synthesized by a simple vapor phase transport process can be good field emission emitters. The field emission measurement as-synthesized materials reveal that these samples have low turn-on field and threshold field. The technique in this work opens the door for quite simple and easy fabrication with low cost. The one-dimensional ZnO nanostructures could possess a potential application in FED and other optoelectronic devices.

5. Acknowledgment

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