Carbon nanotube emitters and field emission triode

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Based on our study on field emission from multi-walled carbon nanotubes (MWNTs), we experimentally manufactured field emission display (FED) triode with a MWNTs cold cathode, and demonstrated an excellent performance of MWNTs as field emitters. The measured luminance of the phosphor screens was 1.8×10^3 cd/m^2 for green light. The emission is stable with a fluctuation of only 1.5% at an average current of 260 μA.

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Carbon nanotubes (CNTs) have attracted much attention because of their unique physical properties and their potential use in a variety of applications, especially for field emission display (FED)[1]. The high aspect ratios and small tip radius of curvature together with high chemical stability and high mechanical strength for the multi-walled carbon nanotubes (MWNTs) are outstanding advantages for electron field emission. Two basic types of methods are presently available to prepare MWNTs field emission cathode. One is screen-printing method by using MWNTs paste[2−7]. The large screen cathode can be made, but it is difficult to control the uniform distribution of MWNTs for such method. The other is chemical vapor deposition (CVD) that is ideally suited to grow film of nanotubes on pre-coating substrates with a metallic catalyst layer, which has been reported by many authors[8−11]. Moreover, since the initial report of electron field emission from CNTs, Saito *et al.* reported the first cathode ray tube lighting elements with carbon nanotube emitter in 1998[12], in 2002, they developed ultra-high luminance light sources[13], the luminance of the phosphor screens measured on the tube axis is 10^6 cd/m^2 for green light under a direct current (DC) driving with an anode voltage of 30 kV and an anode current of 400 μA, but the MWNTs were produced by a DC arc discharge, and the tube was fabricated using a traditional structure. This method is too troublesome in application. In this paper, we have studied the synthesis of MWNTs directly on stainless steel substrates by microwave plasma CVD (MPCVD) without pre-coating of catalyst layer. Based on our study on field emission from MWNTs, we experimentally manufactured a new type of FED triode with a MWNTs cold cathode, which could be used as lighting elements for outdoor large size displays, and demonstrated an excellent performance of MWNTs as field emitters.

Stainless steel plates were used to be substrates as the combined catalyst and supporting material for the synthesis of CNTs, the diameter of stainless steel plates is 6 mm. The source gas for growing the CNTs was a mixture of H_2 and CH_4, the hydrogen gas serves as both etching reagent for the formation of catalyst nanoparticles issued from the substrate and diluted gas. The typical gas flow rates of H_2 and CH_4 were 100 and 8 sccm, respectively, with total pressure of 6.5×10^3 Pa. Substrate temperature was maintained at 700 °C. The deposition time was kept for 10 minutes. The substrate of sample was mechanically polished by various SiC polishing powders.

Figure 1 shows scanning electric microscope (SEM) micrograph of carbon nanotubes for the growth time of 10 minutes, wherein the growth of high-density, uniform carbon nanotubes is demonstrated.

The field emission characteristics of the CNTs film were measured by using a diode structure. The transparent anode was made of an indium-tin-oxide (ITO) coated glass plate. The CNT samples used as the cathode were separated from the anode by a mica sheet with a suitable hole as the emission area. The gap between the anode and the cathode was 120 μm. The experimental measurement was conducted under pressure of 3.6×10^{-5} Pa. Figure 2 shows the electron emission properties of the CNTs film, the current density of sample attains 31 mA/cm^2, at the electric field of 6.67 V/μm. The CNTs film could be a good cold cathode for flat panel display applications. The Fowler-Nordheim (F-N) plot of the sample almost follows a linear relationship over the measuring range, which indicates that the electron emission from such samples complies with a conventional tunneling mechanism, described by F-N theory. The slope of the F-N plot is about −9148, the value of β is equal to

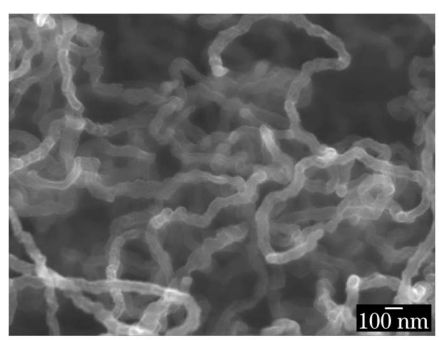

Fig. 1. SEM image of carbon nanotube films.

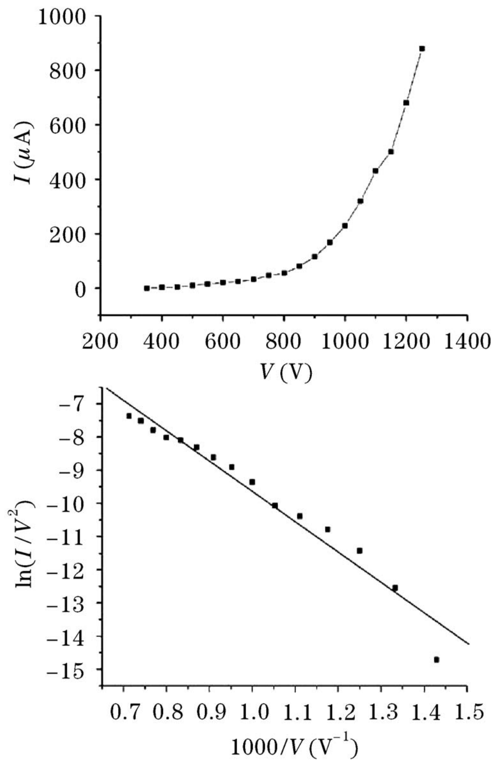

Fig. 2. *I-V* characteristics of CNTs and the corresponding Fowler-Nordheim plot.

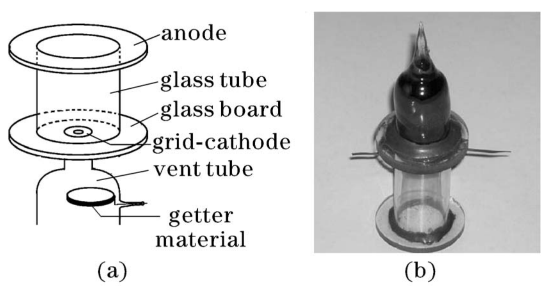

Fig. 3. The structure schematic (a) and photograph of FED triode with CNTs cathode (b).

4173 that indicates the strong concentration of electric field.

The fabricated tubes are three electrode types, and 18.5 mm in diameter and 35 mm in length. The structure of the FED triode is shown in Fig. 3. The advantage of such structure is to simplify sealing process, comparing with traditional structure. The MWNTs cathode was separated from the grid electrode by a insulating sheet with a suitable hole as the emission area, the gap ($d_{\mathrm{T-G}}$) between the cathode and the grid is 0.5 mm in present case. The transparent anode was made of phosphor /ITO coated glass plate. After sealing the vacuum tube, getter material was flashed to attain a high vacuum of the order of 10^{-6} Pa.

The measurement circuit of FED triode is showed in Fig. 4. The cathode is grounded (0 V), and the control grid is biased to a positive voltage to render the electric field on the nanotubes cathode strong enough to extract electrons by tunneling. The turn-on electric field was 1.1 V/μm. The high voltage applied to the anode was from 3 to 6 kV. When grid voltage was 750 V and anode voltage

Fig. 4. Measurement circuit schematic of FED triode with CNTs cathode.

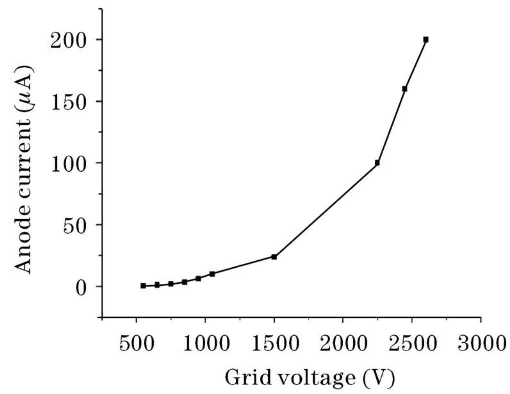

Fig. 5. Anode current as a function of voltage applied to the grid.

5.8 kV, the maximum current of anode attained 1.1 mA. Figure 5 shows the anode current as a function of voltage applied to the control grid. About 60% of the emission current passes through the grid and strikes the anode.

Figure 6 shows a typical time trace of the anode current at a fixed grid voltage of 600 V and anode voltage of 4 kV, and exhibits a stable emission with a fluctuation of only 1.5% at an average current of 260 μA. Stability of the total emission current was excellent even at a high current, the standard deviation of the current fluctuation was 4% at anode voltage of 5.8 kV.

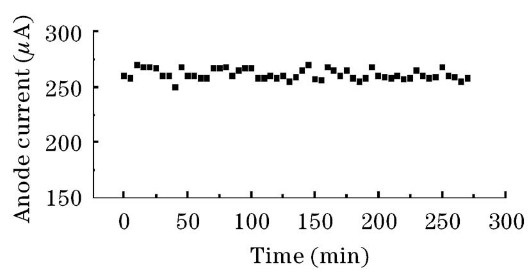

Fig. 6. Time trace of the anode current recorded at a fixed grid voltage.

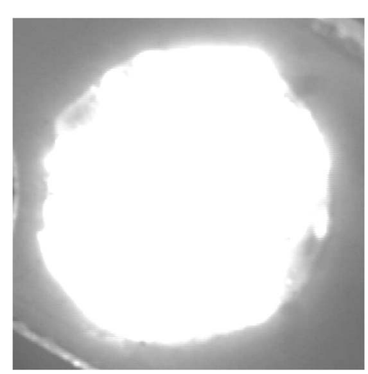

Fig. 7. Luminance image of phosphor screen of the FED triode.

The measured luminance of the phosphor screens was 1.8×10^3 cd/m^2 for green light at an anode current of 500 μA. The typical luminance image of samples is shown in Fig. 7. The luminance intensity increased with anode current increasing.

In summary, a new type of FED triode was fabricated using MWNTs film. Stable electron emission and adequate luminance demonstrate that MWNTs are a very promising material for field electron emitters, and such FED triode could be used as lighting elements for outdoor large size display.

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