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Optimization of field emission properties of carbon nanotubes cathodes by electrophoretic deposition

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Abstract

Cold cathodes of carbon nanotubes (CNTs) were deposited on the glass substrate by the electrophoretic deposition (EPD) method. The cathodes were tested in the diode construction with the cathode–anode gap of 170 μm in vacuum. The emission characteristics of the CNTs film cathodes have as good properties as those by screen printing and better emission uniformity. The influence of the voltage between electrodes in the electrophoretic process of flat cold cathode fabrication on the uniformity of the CNTs film distribution was studied. The results indicate that the uniformity of CNTs film cathode by EPD depends on the voltage between electrodes during the electrophoretic deposition. The uniformity of CNTs film and optimized emission properties of the cathode have been achieved when the voltage is 25 V.

Keywords: Carbon nanotubes (CNTs); Electrophoretic deposition (EPD); Field emission; Uniformity

1. Introduction

Carbon nanotubes (CNTs) based electron field emitters have been investigated as the next generation cold electron emission source [1], and flat panel field emission displays (FEDs) with CNTs cathodes have attracted much attention. Different methods and technologies of flat cold cathodes fabrication are used nowadays, for example, chemical vapor deposition (CVD) [2], spin-coating [3], spraying [4] and screen-printing technologies [5,6]. Most of them have some imperfections, such as a high complexity and high cost of the technological process for the CVD method, or the creation of conducting chemical reactionless and vacuumproof binders for printing technologies. One of the promising methods of carbon powder materials-based cold cathode fabrication is the electrophoretic deposition method (EPD) [7–9]. EPD is based on the presence of small charged particles in a liquid, which on the application of a DC electric field, will move to and deposit on an oppositely charged electrode. Electrophoretic deposition is a high throughput and automated industrial process that has been widely used for coating of colloidal particles [10] and has been recently applied to the CNTs [11,12]. The EPD method has the advantages of short formation time, simple deposition apparatus, low cost and suitability for

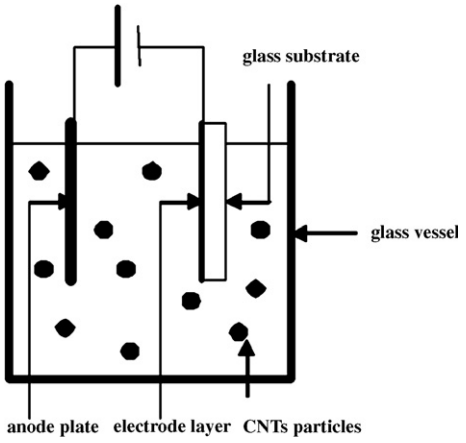

Fig. 1. Scheme of the carbon powder electrophoretic deposited on the substrate.

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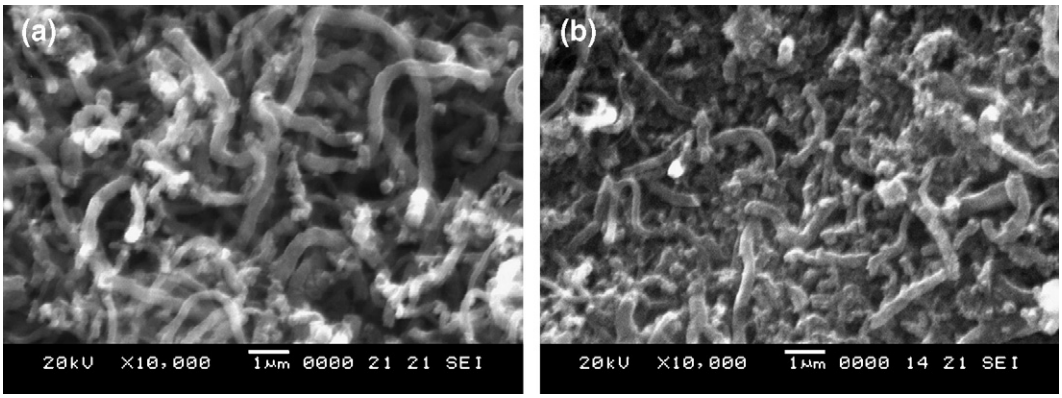

Fig. 2. The SEM images of CNTs: (a) as-grown CNTs and (b) EPD CNTs cathode.

mass production as in electric coating industry. Most importantly, there is little restriction in the shape of the substrates formed. All these make EPD promising in better preparation of nano-structured devices. Gao et al. [11] and Du et al. [14] first reported to electrophoretically deposit CNTs in stable organic suspensions. In a related research, Thomas et al. [13] investigated uniform deposition of multi-walled carbon nanotubes on stainless-steel. Other research groups [8,12,15,16] fabricated carbon nanotubes field emission cathodes by EPD and studied their emission properties.

In order to optimize the production of carbon nanotubes cathode, a detail study of EFD must be completely understood. This paper describes a simple EPD method to produce carbon nanotube field emission cold cathode. The emission properties of the cathode are also investigated compared with those of the screen printed cathode. The uniformity and thickness of the nanotube coating, which will affect the emission property of the cathode, are found to be controllable by the applied voltage and the electrophoretic deposition time.

2. Experimental

As an emitting material, carbon powder with a portion of multiple-wall nanotubes (MWNT) was used. MWNTs with a diameter range of 70 to 150 nm have been synthesized by the CVD method, using Ni catalyst in the mixture atmosphere of C_2H_2/H_2 at about 600 °C.

The general scheme of the electrophoretic deposition process, used for the sample preparation, is shown in Fig. 1. The powder of carbon nanotubes was placed into the vessel with acetone and ethanol with different volume ratios after being milled for several minutes, which has been used as a dispersion medium. The charger salt $Al(NO_3)_3$ was added into the suspension to increase the deposition rate and improve the adhesion of the powder particles to substrate. The amount of $Al(NO_3)_3$ should be proper (10–20 mg) to obtain 1–10 mA direct current to EPD good CNTs film cathode. Few CNTs can be deposited on the substrate when less $Al(NO_3)_3$ is adopted or an unwanted Al film will form on the

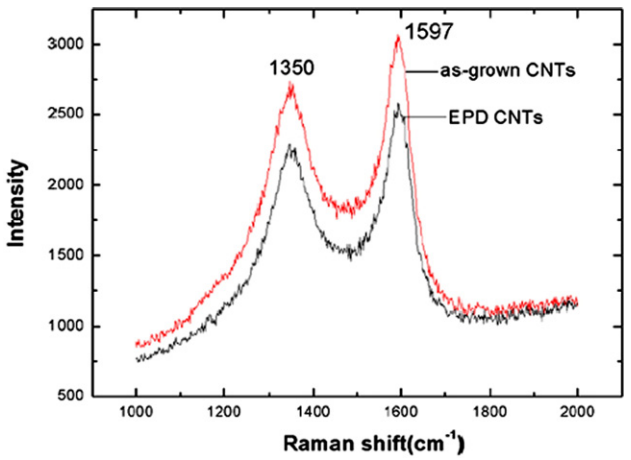

Fig. 3. Raman spectra of CNTs.

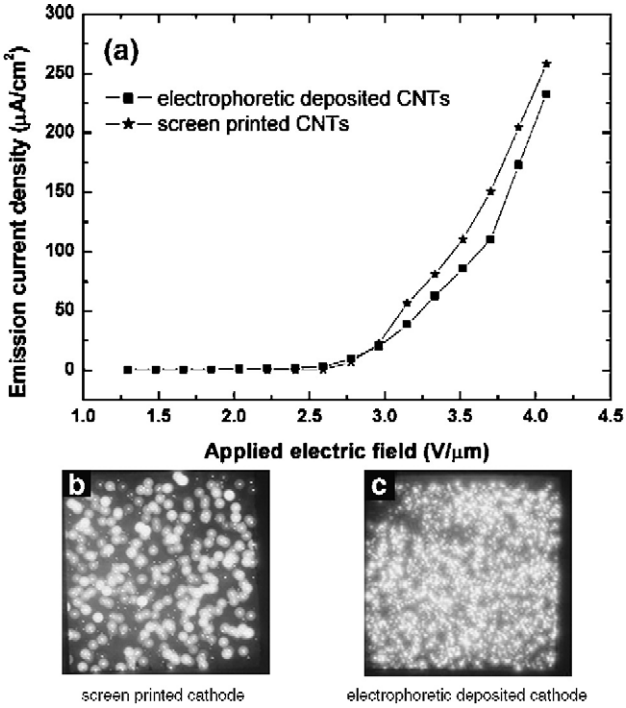

Fig. 4. Field emission properties of the samples produced by electrophoresis and screen printing: (a) E–J curve of CNTs cathodes image taken after the first switch-on of the cathode. (b) The luminescence image on anode from the CNTs cathodes by electrophoretic deposition (J=125.35 μA/cm^2, E=3.52 V/μm) and (c) luminescence image of cathode by screen printing (J=147.87 μA/cm^2, E=3.52 V/μm).