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Physica B 403 (2008) 2662–2665
PHYSICA B
www.elsevier.com/locate/physb

High-field electron emission of carbon nanotubes grown on carbon fibers

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Received 18 October 2007; received in revised form 22 January 2008; accepted 26 January 2008

Abstract

Carbon nanotubes with uniform density were synthesized on carbon fiber substrate by the floating catalyst method. The morphology and microstructure were characterized by scanning electron microscopy and Raman spectroscopy. The results of field emission showed that the emission current density of carbon nanotubes/carbon fibers was 10 μA/cm^2 and 1 mA/cm^2 at the field of 1.25 and 2.25 V/μm, respectively, and the emission current density could be 10 and 81.2 mA/cm^2 with the field of 4.5 and 7 V/μm, respectively. Using uniform and sparse density distribution of carbon nanotubes on carbon fiber substrate, the tip predominance of carbon nanotubes can be exerted, and simultaneously the effect of screening between adjacent carbon nanotubes on field emission performance can also be effectively decreased. Therefore, the carbon nanotubes/carbon fibers composite should be a good candidate for a cold cathode material.

PACS: 61.48.+c; 79.70.+q

Keywords: Carbon fibers; Carbon nanotubes; Floating catalyst; Field emission

1. Introduction

Carbon nanotubes (CNTs) have many exceptional physical and chemical properties. It has important application in field emission displays because of the large aspect ratio, the small tip radii of curvature, the high chemical stability, and so on. In comparison with other cold cathode materials (metals, silicon micro-tips, diamonds films, etc.), CNTs have much predominance in field emission: the low threshold field, the large emission current, the long emitter lifetime, and the low fabrication cost. Therefore, CNTs have become one of the most promising field emission electron source materials [1–5]. To date, CNT films have been typically prepared by the screen-printing method and the electrophoretic deposition method [6,7]. However, organic impurity was easily brought about by the process of screen printing, which may lead to the instability of the emission current and the invalidation of the emitters. Electrophoretic deposition can lead to the unevenness of CNT films, which can easily burn the cathode because of the large local current. Moreover, in CNT films prepared by screen printing and electrophoretic deposition, most of the CNTs were flatly placed, and the tip predominance of the CNTs could not emerge. When aligned CNT films grown directly on the substrate were used as an emission cathode, the tip structure of the CNTs played in important role in field emission. However, most of the aligned CNT films have a very large density. The field emission performance of the aligned CNT films may have similar results as that of the flat panel cathode because of the large screening effects between adjacent CNTs. Some reports

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doi:10.1016/j.physb.2008.01.032

showed that less-dense "short and stubby" aligned CNT films have good electron field emission characteristics [8]. In order to sufficiently exert the superior field emission properties of CNTs, preparation of the CNT cathode should assure that the tip predominance of CNTs must be revealed and the screening effects between adjacent CNTs must be decreased (properly controlling the density and height of the CNTs). Using electrically conductive and chemically stable carbon fibers as substrate, the synthesized short and sparse CNTs should have good field emission performance.

In the previous work, we have synthesized CNTs on carbon fiber substrate by the floating catalyst method with the pretreatment of carbon fibers [9], and the density of CNTs on the carbon fiber surface is uniform and sparse. The method used in the experiment solved the growth difficulty of CNTs on the carbon fiber substrate [10,11], and simultaneously overcame the bad effect of screening effects on the field emission of CNTs. In this paper, we report the electron field emission properties of CNTs on carbon fibers. We characterize the morphology and microstructure of CNTs/carbon fibers by scanning electron microscope (SEM) and Raman spectroscopy. Finally, under the environment of ultra-high vacuum, we test the field emission performance of the CNTs/carbon fibers composite.

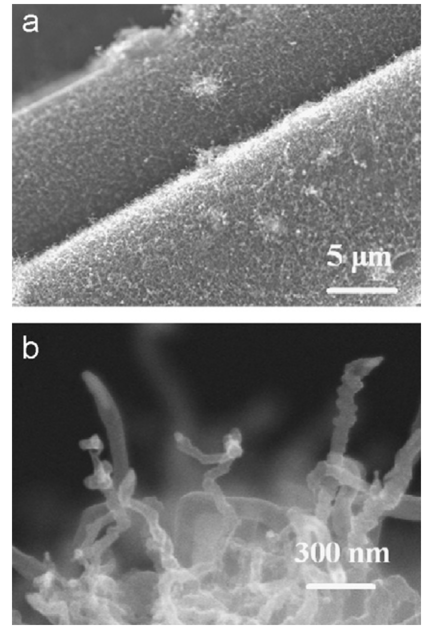

Fig. 1. The low-resolution (a) and high-resolution (b) SEM images of CNTs on carbon fiber substrate.

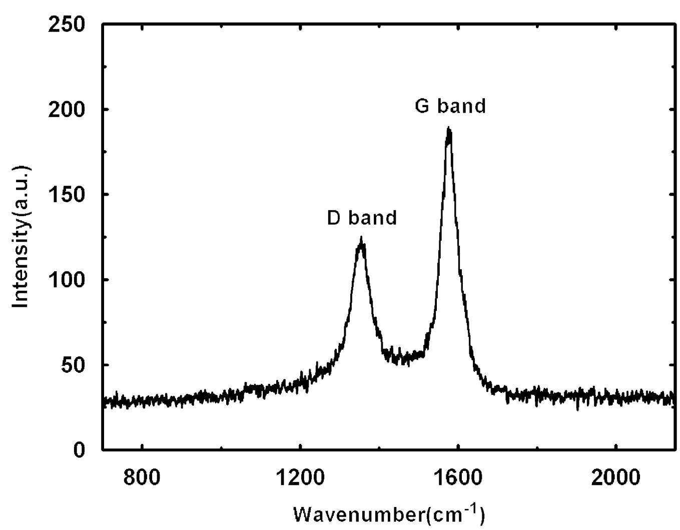

Fig. 2. Raman spectrum of CNTs on carbon fiber substrate.

2. Experimental details

Before the growth of CNTs, the carbon fiber substrate needs to be cleaned and activated. The growth of CNTs was carried out in a tubular furnace by the floating catalyst method. The detailed experimental process was introduced in the previous report [9].

The morphology and Raman spectroscopy of CNTs/carbon fibers were characterized by a SEM (Hitachi S-4800) operated with an accelerating voltage of 15 kV and by a Raman spectrometer (Jobin Yvon HR800) with a laser wavelength of 488.0 nm by an Ar^+ laser, respectively. Under the condition of high vacuum, the field emission performance of CNTs/carbon fibers was tested by a diode assembly.

3. Results and discussion

Fig. 1 shows the morphology of CNTs on a carbon fiber substrate. As seen in Fig. 1(a), the surface of carbon fibers was entirely covered by CNTs. The root of CNTs forms a netty structure and its top is basically perpendicular to the surface of the carbon fibers, as shown in Fig. 1(b). The diameters of the CNTs range from 40 to 60 nm, and the length of the emerging part is about 500 nm. Compared with the aligned CNTs films, the density of CNTs grown on carbon fiber substrate is lower, in which the average spacing between adjacent CNTs is estimated to be about 300 nm.

Fig. 2 shows the Raman spectrum of CNTs grown on carbon fibers. Two bands can be observed: the D band at about 1352 cm^{-1} and the G band at about 1578 cm^{-1}. The stronger G peak shows the high crystal quality and graphitization degree of CNTs. Furthermore, the ratio of I_D/I_G is also related to the quality of CNTs. Based on the Raman spectrum in Fig. 2, the ratio of I_D/I_G can be estimated to be about 0.632. The lower ratio of I_D/I_G indicates the high graphitization degree of CNTs.

The measurement of the field emission performance of CNTs/carbon fibers was carried out in a diode assembly with the vacuum pressure of 2.5×10^{-4} Pa. The circuit diagram of the field emission test is shown in Fig. 3. First,