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Field emission properties from aligned carbon nanotube films with tetrahedral amorphous carbon coatings

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Abstract

Tetrahedral amorphous carbon (ta-C) film was coated on aligned carbon nanotube (CNT) films via filtered cathodic vacuum arc (FCVA) technique. Field electron emission properties of the CNT films and the ta-C/CNT films were measured in an ultra high vacuum system. The $I-V$ measurements show that, with a thin ta-C film coating, the threshold electric field (E_{thr}) of CNTs can be significantly decreased from 5.74 V/μm to 2.94 V/μm, while thick ta-C film coating increased the E_{thr} of CNTs to around 8.20 V/μm. In addition, the field emission current density of CNT films reached 14.9 mA/cm^2 at 6 V/μm, while for CNTs film coated with thin ta-C film only 3.1 V/μm of applied electric field is required to reach equal amount of current density. It is suggested that different field emission mechanisms should be responsible for the distinction in field emission features of CNT films with different thickness of ta-C coating.
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Keywords: Carbon nanotube; Tetrahedral amorphous carbon; Field emission

1. Introduction

As a new member of the carbon family, carbon nanotube (CNT) is attractive as a new type of field emission (FE) electron source, which could be used to replace the conventional metallic or silicon-tip field emission arrays (FEA), and have crucial applications on flat panel display, microwave tubes and other vacuum microelectronic devices [1–4]. Recently, many kinds of one-dimensional materials such as ZnO nanowires [5,6], In_2O_3 [7], SnO_2 nanobelt arrays [8] and Fe nanocluster wires [9] have shown FE phenomena. However, none of them could match with CNT on the performance. It is widely accepted that the excellent FE property of CNTs mainly resulted from their high aspect ratio, which means an enhancement of the electric field near the CNT tips and so exhibits higher FE current at lower voltage. Theoretically, the superior FE properties of CNTs can be further improved by decreasing the high work function of CNTs [10]. In fact, in the early 1990, when the hydrogen-terminated diamond film was discovered to have negative electron affinity (NEA) and could be prepared by low pressure chemical vapor deposition (CVD), diamond and diamond-like carbon (DLC) films were thought as the potential candidate for FE. Thereafter, Xu et al. [11] found that tetrahedral amorphous carbon (ta-C), another kind of DLC with smooth surface, could enhance the FE of silicon-tip arrays remarkably. They proposed that decrease of the effective work function of the emitters and a quasi-tunneling process should be responsible for this effect. It is interesting for us to study if ta-C film also could decrease the effective work function of CNTs so that has similar enhancement effect on the FE property of CNTs film. Recently, Nagatsu et al. [12] reported that, when CNTs were coated with amorphous carbon (a-C) of about 0.6∼1 μm by surface-wave plasma (SWP) technique, the FE property of CNTs could be improved. To our knowledge, there has no a report on the FE effect of CNTs film with ta-C coatings. In this article, we have shown that, through coating with several nanometers of ta-C film by using FCVA technique, the FE performances of CNTs have been signifi-

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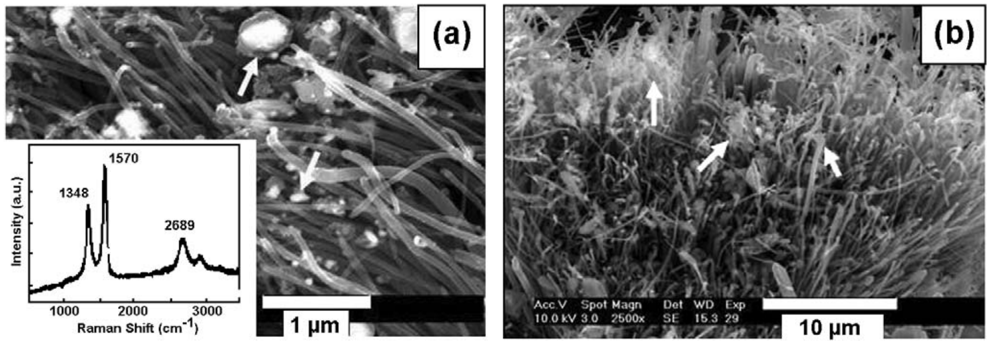

Fig. 1. SEM images of (a) CNTs film and (b) ta-C/CNTs film. The inset shows the vis-Raman spectrum of the CNTs film.

cantly improved. The possible physical mechanism responsible for the phenomena has also been discussed.

2. Experimental

The aligned CNTs film was grown on mesoporous silica plates by using microwave plasma chemical vapor deposition technique [13]. The grown CNTs film was then cut into pieces with area of about 1 mm^2 and some of them were selected and divided into two groups (defined as group A and group B). To compare the surface morphology and the field emission properties of CNTs with and without ta-C coatings, half of the samples in the two groupings were selected to carry out the field emission measurements, the rest were characterized by scanning electron microscopy (XL-30FEG and Dx-4i), respectively. Afterward, all the samples were coated with ta-C film in

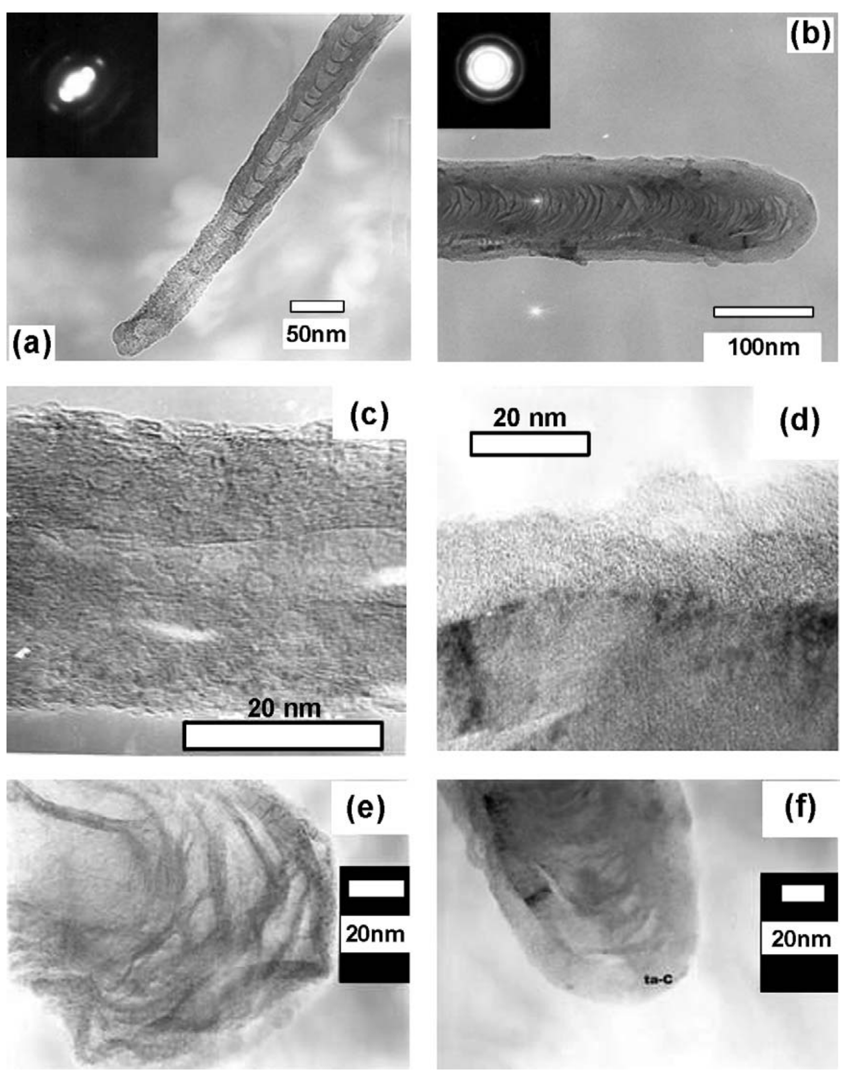

Fig. 2. HRTEM patterns of a bare CNT (a, c, e) and individual ta-C/CNT (b, d, f). The insets show the corresponding selected area electron diffraction (SAED) patterns.

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