Field emission from well-aligned carbon nanotips grown in a gated device structure

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Field emission from well-aligned carbon nanotips grown in a gated device structure

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Vertically well-aligned, high-aspect-ratio carbon nanotips have been directly grown upward on the gated device structure with 4 μm gate aperture. The nanotips rapidly nucleate and grow without any catalyst. In addition, selected area deposition of nanotips is achieved by using a Pt layer as inhibitor in the bias-assisted microwave plasma chemical vapor deposition. The field emission current of nanotips on the gated structure is 154 μA (at a gate-to-cathode voltage of $V_{gc}=50$ V). This results from the following reasons: (i) short gate-tips spacing, (ii) small gate aperture, and (iii) the high-aspect ratio of nanotips. © *2002 American Institute of Physics.* [DOI: 10.1063/1.1459109]

Up until now, there have been numerous reports on developing the different designs of field emission displays.[1,2] Since the discovery of carbon nanotubes, the application of field emission has attracted much interest.[3,4] However, catalysts (such as Fe, Co, Ni, etc.) are used to promote the growth rate of the nanotubes. Furthermore, the randomly oriented nanotubes also need the posttreatment before applications. In this study, well-aligned and high-aspect-ratio nanotips are directly synthesized in a 4 μm gated device structure. The gaseous mixture of CH_4/CO_2 is used in the bias-assisted microwave plasma vapor deposition. The growth rate of nanotips is higher in highly carbon-concentrated CH_4/CO_2 gas mixture than in conventional mixtures of hydrocarbons diluted in hydrogen.

A Pt-gated device structure with 50×50 circles was initially fabricated by semiconductor process technology. Starting substrates were mirror-polished *n*-type (100) oriented wafers. The width and the depth of each circle were 4 μm and 7000 Å, respectively. After the gated device structure was generated, specimens were put in the bias-assisted microwave plasma chemical vapor deposition system to deposit carbon nanotips. Reactive gaseous mixture of CH_4-CO_2 was used in deposition. The flow rates of CH_4/CO_2 and the deposition time remained constant at 30/30 sccm and 15 min, respectively. During deposition, the Si substrate was subjected to a negative bias voltage.

Figure 1 shows scanning electron microscopy (SEM) photographs of carbon nanotips grown under different biases. Each picture is only one of the 50×50 circles on the device. On the right-hand side of every picture is an enlarged image. The SEM images indicate that carbon nanotips can be uniformly grown only inside the Pt-gated device structure in the absence of amorphous carbon (*a*-C) on the Pt-gated surface. The selective area deposition of nanotips is attributed to the following two reasons. One is that carbon materials are more easily grown on silicon than on the Pt-gated layer because Pt is a highly chemically inert material that does not nucleate carbon materials on an unscratched Pt surface.[5,6] The other is that electrical field is concentrated on the silicon substrate surface because the *n*-type silicon conducts electrons, but electrons can not pass through silicon dioxide (dielectric layer) within a Pt-gated layer. Consequently, the local deposition biased effects are all within the silicon substrate. However, increasing the deposition time causes some *a*-C to form on the Pt-gated surface.

Figures 1(a)–1(c) reveal that applying a bias can enhance the growth of carbon nanotips in CH_4/CO_2 gas mixture. Thus, the higher bias drastically enhances the growth of carbon nanotips. The bias-assisted effect is also valid for the hydrocarbon diluted in hydrogen.[7] However, samples grown under a bias more negative than −130 V cause the height of the tips to exceed that of the Pt gate. In this situation, the gated device structure becomes a diode structure. By con-

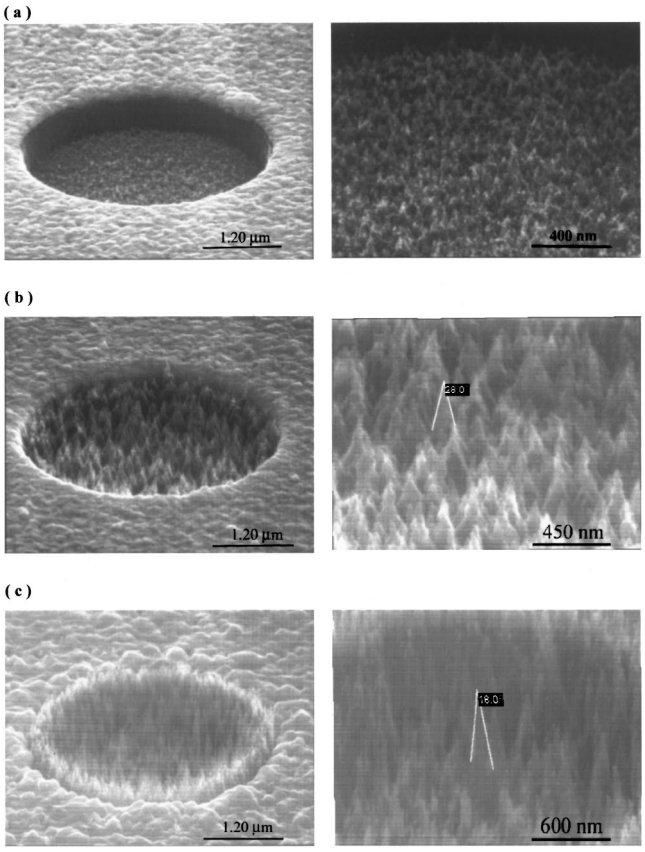

FIG. 1. SEM photographs of nanotips grown under (a) −100, (b) −130, and (c) −150 V.

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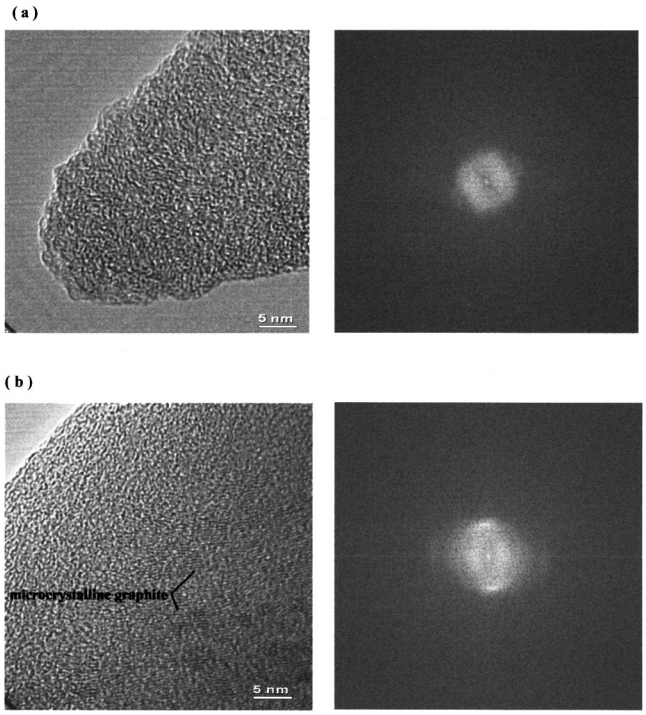

FIG. 2. TEM images and Fourier filtering transformation (FFT) of (a) the end section and (b) lateral section of an individual tip.

trast, a bias less negative than −130 V only leads to tiny tips inside the hole. In addition, all the tips grow upward under biased conditions. The tip angle of the nanotips decreases as the bias increases. In other words, a higher bias generates higher density, sharper, and higher-aspect-ratio nanotips. CH_4/CO_2 can promote the growth rate over that with conventional gas mixtures (hydrocarbons diluted in hydrogen, for example, CH_4/H_2)[8] because of the high carbon concentration in the CH_4/CO_2 gas mixture.

Figure 2(a) displays the transmission electron microscopy (TEM) images of an end section of an individual nanotip. The main feature of note is the transmission electron microscopy somewhat irregular shape of the tip with one primary protrusion. The Fourier filtering transformation (FFT) indicates that the end section is *a*-C. Moreover, Fig. 2(b) displays the lateral section of the same tip. It shows microcrystalline graphite on the lateral section. The FFT of Fig. 2(b) also proves the existence of the microcrystalline graphite.

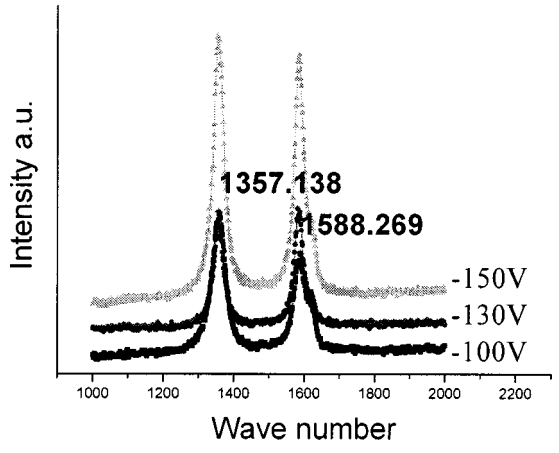

FIG. 3. Raman spectra of nanotips growing under different applied biases.

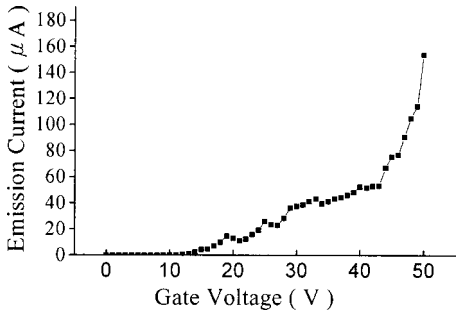

FIG. 4. Emission current versus the gate voltage of nanotips on a gated device structure.

Figure 3 presents Raman spectra of tips grown under various applied biases. The spectra do not obviously differ. All of them have two sharp peaks located on about 1355 cm^{-1} and 1582 cm^{-1}, respectively. The peaks imply that the nanotips are characteristic of microcrystalline graphite. The Raman spectra of *a*-C can be decomposed into two features located approximately at 1550 cm^{-1} (corresponding to the G-line associated with the optically allowed E_{2g} zone center mode of crystalline graphite) and 1350 cm^{-1} (roughly corresponding to the D-line associated with disorder-allowed zone-edge modes of graphite). The positions, widths, and relative intensities of these two peaks are found to vary systematically with deposition conditions and properties of the tip.[9,10] The intensity of these two peaks is the same indicating that the samples contain much *a*-C.

Figure 4 displays the electron-emitting characteristic of the nanotips on gated device structure. The field emission properties are measured by using a triode technique. An anode plate, an indium tin oxide glass, is placed above the Pt gate and biased to +800 V. A 100 μm slide glass is used for the spacer. The anode current (I_A) is then measured as a function of gate-to-cathode bias voltage in a vacuum of 1×10^{-6} Torr. The gate-to-cathode voltage (V_{gc}) is varied from 0 to 50 V. The field emission current (I_a) of nanotips on the gated device structure is about 154 μA (at a gate-to-cathode voltage of V_{gc}=50 V). Therefore, the higher emission current of the nanotips results from the following causes: (i) short gate-tips spacing, (ii) small gate aperture, and (iii) the high-aspect-ratio of the nanotips.

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