Generation of high field emission current from carbon nanotubes

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Abstract

We have fabricated a high electron source from carbon nanotubes (CNTs) using hot-press method. Using hot-press method, we are able to control the tube density and the morphology of CNT films. We propose that the high emission current is due to the solid adhesion between the CNTs and substrates and uniform morphology of CNT film.

1. Introduction

Carbon nanotubes (CNTs) is one of the leading materials in nanoscience and nanotechnology owing to their strong applicabilities in various disciplines. In particular, a significant breakthrough has been realized in the field emission displays with naturally formed carbon nanotubes that are chemically stable, mechanically strong, and electrically semiconducting or metallic [1,2]. In fact, stable and high emission current, low turn-on voltage, and large field enhancement factor of CNTs have opened new application fields in CNT-based devices such as x-ray source, light bulb, and electron amplifier.

Even though the CNTs have shown such superior properties as an field emitters, the main reason that the their practical applications still require further researches is rather inferior stability, uniformity, life time in emission operation to current competing materials.

In this study, we introduce a new method, which can easily control the morphology and the tube density of chemical vapor deposition (CVD)-grown multi-walled carbon nanotubes (MWCNTs). In general, the CNT films prepared with CVD method result in many tubes protruding above their neighboring tubes. These longer tubes contribute to the local emission that degrades the emission pattern and emission current. For uniform emission and higher emission current, these longer tubes should be trimmed off and the homogeneity on the film surface should be obtained.

2. Experiment

For the growth of MWCNTs, either a Si substrate or Ni foil was transferred to a magnetron sputter, in which TiN and Ni layers are deposited, respectively. After the metal layer deposition, we moved the substrate into a CVD chamber for a subsequent growth. The average tube diameter and height are about 50 nm and 15 μm, respectively. As we can see in Fig. 1(a), MWCNTs are well aligned in vertical direction and it is noted that some of tubes are much longer than the other tubes [3]. These longer tubes play as local emission spots when an electric field is applied. Therefore, for the uniform emission pattern, it is required to remove these tubes. One way to remove the protruding tubes is high voltage annealing. However, this process usually takes longer than 24 hours. In addition, during the process, vacuum breakdown sometimes ruins the device. Thus, we used plasma etching.

Figure 1(b) shows the film morphology of plasma-etched MWCNTs. We have examined various gas species such as O_2, NH_3, and Ar. In our case, the oxygen plasma is most aggressive etching agent and gives a prominent result, as shown in Fig. 1(b). After exposing the CNTs to oxygen plasma, we have studied the emission properties. During the emission test, we have experienced frequent breakdowns, which may be caused by the structural deformation of CNT tip from plasma etching. This breakdown consistently occurred even after thermal annealing for 10 minutes at 700 ^{o}C that is near growth temperature. This indicates that the curing process of MWCNTs may take palace above the growth temperature.

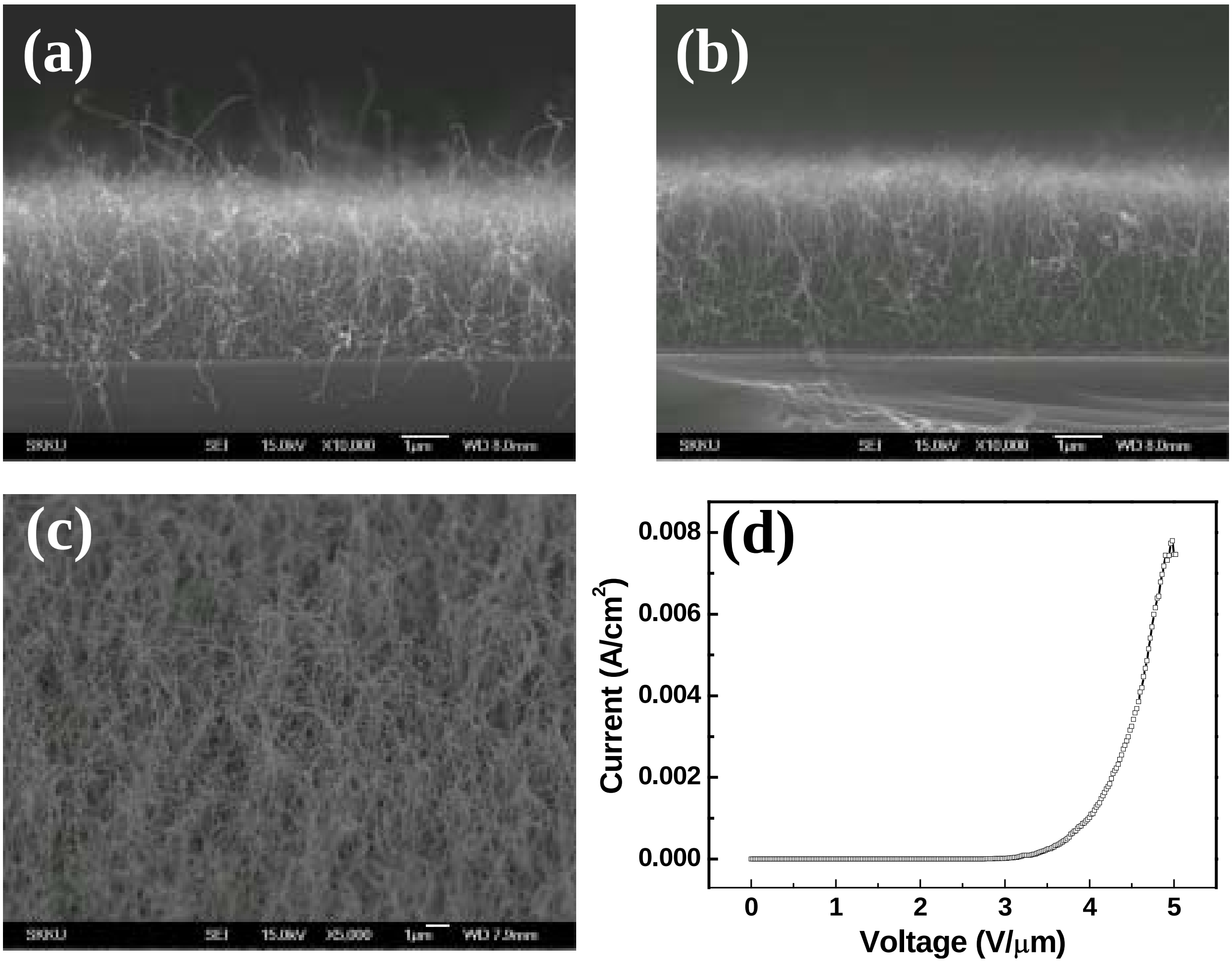

Figure 1. SEM image of (a) as-grown MWCNTs, (b) oxygen plasma-etched MWCNTs, and (c) hot-pressed MWCNTs. (d) I-V curve of hot-pressed MWCNTs.

Comparing to high voltage annealing and plasma etching, hot-press is very handy and advantageous since the process can modulate the tube density. For hot-press method, we evaporate Indium on a CNT film and substrate. The layer thickness was about 250 nm. Then, we placed a substrate on CNT film. For hot-press, we grew MWCNTs on Ni foils since the single crystalline Si substrate is so fragile under the pressure. The counterpart was Mo cylinder with a diameter of 3 mm. The pressure range applied on the substrate varies from 30 to 150 bars. At the same time, the temperature increased from room temperature to 150 ^{o}C. Fig. 1(c) shows the surface morphology of hot-pressed CNT films. The film morphology is very uniform. The film was compressed at 30 bars at room temperature. As we increased the substrate temperature, we observed that the tube density has varies dramatically. However, we find that the applied pressure is not such influential on the tube density. On the contrary, the pressure is more effective on the orientation of tubes. That is, the tubes are not aligned in vertical direction at 150 bars. Therefore, we proposed that the significant reduction in tube density even at 50 ^{o}C may be originated from melting of the metal layer under a pressure. Using the field emitter prepared at 30 bars room temperature, we have examined the field emission properties. Fig.

1 (d) is an I-V curve measured at the gap distance of 500 μm. In DC mode, the obtained maximum current density is about 7.5 mA/cm^2.

3. Conclusions

We have obtained a uniform film morphology and controllability on tube density using hot-press process. This process is simple and controllable as well. The high current density from hot-pressed emitters is presumed to be both a solid adhesion between the tube and substrate and uniform film morphology. Such high emission-current source has an application for x-ray source.

4. Acknowledgements

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6. References

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