Fabrication and characterization of a carbon nanotube-based point electron source

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Abstract

We have made point electron sources using carbon nanotubes (CNTs). For the fabrication of point electron sources, CNTs were dispersed in a solution and attached on electrochemically etched W tips using electrophoresis. In our study, we have utilized various CNTs such as single-walled CNT (SWCNT), multi-walled CNT (MWCNT), and thin-MWCNT and threshold current, turn-on voltage, filed enhancement factor of each emitter have been studied upon a tube/bundle diameter and length. In addition, field-emitted electron energy distribution of various CNT emitters is characterized.

1. Introduction

Conventional point electron-sources for transmission electron microscopy and scanning electron microscopy used a hair-pin type field emission emitters or thermionic emitters. The latter operates at high temperature with providing larger emission current and bigger geometrical structure. The structure of thermioinc emitter degrades not only the spatial resolution, but also surrounding objects through radiational heating. The former has a higher spatial resolution with no thermal damages from the tip. However, the cold cathode requires a higher degree of vacuum environment for preserving the initial performance. In addition, periodic flushing action is required to remove adsorbed gas molecules.

Carbon nanotubes (CNTs) have shown excellent physical and chemical properties, including high mechanical strength, high electrical and thermal conductivity, high melting temperature, and chemical stability. All these properties combined with nanometer wide diameter and a few micron long length have ignited world wide researches for developing various types of electron emitter. In particular, using CNT as a point electron-source can be very beneficial and even ideal only if we can manipulate individual tubes.

Previous study has shown the performance of CNTs as a point electron-source. However, in the study, they have attached an individual CNT on W tip using manipulators inside a scanning electron microscope (SEM). Also, an adhesive paste was used to hold a CNT at the end of W tip. In this study, we used dielectrophoresis to precisely mount CNT only on the apex of W tip.[2] The adhesion between the tube and W tip was secured using thermal annealing.

2. Experimental

Various CNTs are dispersed in either an organic or aqueous solution. For an acquous solution, no surfactant has been used. In these solutions, we immersed two electrodes and one of them, positive electrode, is charged with W tip. The W tip was prepared by an electrochemical etching in 1 M of NaOH solution. After etching, W tip shortly dipped in DI water and HF for the removal of NaOH. It is found that the W tip has an average apex diameter of less than 100nm.

For attaching the tube on W tip, AC bias was applied. The amplitude and frequency are 5~10 V and 2MHz respectively. After dielectrophoresis, W tip was brought to vacuum furnace for annealing. The annealing was carried out at 700-800 ^{o}C for 10 minutes. The annealing process is intended to enhance the adhesion the contact nature between the W tip and CNTs.

Figure 1(a) shows scanning electron microscopy (SEM) of W tip prepared through the process described above. A careful examination on the W tip reveals that many CNT are mounted on the apex of W tip. These tubes are assumed to form during the dielectrophoresis, not the dispersion process. The serial connections of the tubes imply that the tube can grow further if the electric field is applied longer.

The CNT tip was transferred into a vacuum chamber whose base pressure is 1 x 10^{-8} torr. The anode, a copper plate, was set at 1mm apart. The I-V curve in Fig. 1(b) is from arc-grown MWCNTs. The maximum current is about 51.93 μA, which is three times larger that the state-of-the art cold field emission point source. We also have tested the long-term stability. The bias of 4200 volt has been applied on the tip and maintained for 12 hours. Fig. 1(d) is a current plot in time at the bias. During the test, the fluctuation remains within 5 % from the average current.

3. Conclusions

We have fabricated a point electron source using dielectrophoresis. The CNT emitter has shown a stable emission behaviors together superior current density. However, the serial interconnection of CNTs needs more systematic studies to optimize the parameters for dielectrophoresis process.

4. Acknowledgements

This work was supported in part by the MOST through the NRL program and through the CNNC at SKKU.

7. References

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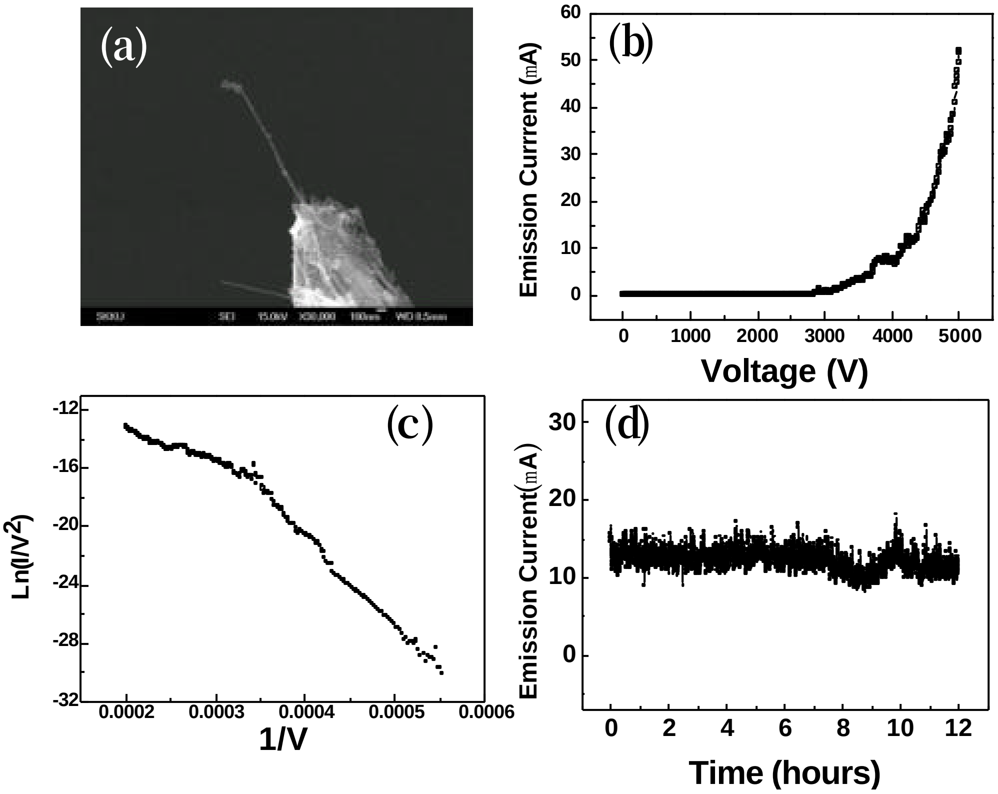

Figure.1 (a)SEM image of thin bundle of MWCNT at W tip. (b) Characteristic I-V from (a). (c) Fowler-Nordheim plot of (a). (d) long-term stability of (a).