Fabrication of high performance carbon nanotube cold cathode electron beam (C-beam) for various devices

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We fabricated high performance cold cathode electron beam with carbon nanotube (CNT) emitters. High performance cold cathode electron emitters show more than 150 mA electron emission current and long-time operational stability. Stability of operation further enhanced with thermal annealing and electrical aging. With the CNT cold cathode, we fabricated electron beam with triode structure and shows more than 15 mA anode current within less than 1 cm² area.

Keywords – Carbon nanotube (CNT), cold cathode, electron beam, microscopy, triode.

Introduction

We fabricated high performance carbon nanotube (CNT) electron emitters with direct current plasma enhanced chemical vapor deposition (DC-PECVD). The performance of CNT emitters depend on the various process conditions such as, catalytic seed formation, patterned dot size, barrier layer, bias voltage on mesh electrode during growth and etch sequences, etc. For high performance cold cathode electron beam, a fully vertically aligned CNT emitter should be grown with pre-defined densities. In previous, we developed CNT emitters with high electron emission current, more than 100 mA.[1] Based on the performance, we applied the emitters for various device applications, such as sensors [2], x-ray [3], thin film structural modification [4], UV lamp [5], blue luminescence devices. [6]

In this study, we developed high performance CNT emitters (Fig. 1) with a novel CNT growth and post-growth treatment technique. The structural rigidity and enhanced electron emission could be achieved with the process. With the CNT emitters, we obtain more than 150 mA electron emission current in diode mode and 15 mA anode current with triode mode. By using the high performance CNT emitters as electron source, we developed a cold cathode electron beam and applied for various devices, such as microscopy, UV-C lighting and x-ray imaging.

Fabrication of carbon nanotube cold cathode electron beam

A. Growth of CNT electron emitters

The CNT emitters were fabricated on catalytic nickel island with a diameter of 3 μm and a pitch of 15 to 30 μm on the Si wafer.

The CNT emitter shows fully vertically aligned structure and excellent in thermal resistance. The CNT emitters were growth using the triode direct current plasma enhanced chemical vapor deposition (DC-PECVD) technique. The DC-PECVD system has triode structure with gate bias of 300 V and substrate
of – 600 V. The source gas, C$_2$H$_2$ and NH$_3$ were feed into the system with the ratio of 1 to 5. The growth time of CNT emitters were during 150 min at the pressure of 1.8 Torr and the temperature of 600 °C.

A reduction of gate leakage current at high emission current should be solved in near soon.

![Electric field (V/μm)](image)

**B. Fabrication of electron beam with CNT emitters**

Cold cathode electron beam with the CNT electron emitters were fabricated. Electron emission characteristics of CNT emitters measured with in diode configuration between cathode and anode with gap distance of 270 μm. As shown in Fig. 2, we obtained more than 150 mA anode current at 2,000 V anode bias. The current is the very enough for various devices, such as x-ray tube, UV lighting source and gyrotron devices.

To fabricated electron beam, we used specially designed ceramic base as spacer between gate and cathode with gap of 270 μm. Gate electrode with mesh wire grid fabricated with chemical etching technique with hole size of 400 μm and pitches between hole-to-hole of 500 μm. CNT emitters with square shaped island formed to smaller than mesh holes to enhance the transmission rate of electron through the gate hole.

Electron emission characteristics measured as shown in Fig. 3. We obtained more than 20 mA emission current in triode configuration. When anode current increases more than 5 mA, gate leakage current start increases, resulting higher gate leakage ratio.

\[
\text{Gate leakage ratio} = \frac{\text{anode current}}{\text{cathode current}} \times 100
\]

![Schematic diagram for evaluation of electron emission characteristics.](image)

**B. Applications of the electron beam**

Cold cathode electron beam with the CNT emitters (C-beam) were applied for electron microscopy, ultraviolet lighting and x-ray tubes. Fig. 4 shows beam profile of one island of emitters with various number of array.
Beam shape measured with digital camera and then profile analyzed with commercial software program (Image J). The beam profile shows the narrower with reduced number of emitters. We calculated beam diameter based on the previous report [7]. Beam diameter sharply decreases with smaller array. We could reach beam diameter of 20 μm with one emitters.

Also, the high performance cold cathode electron beam applied for UV light sources and x-ray tubes. We obtained UV lighting with wavelength less than 250 nm with more than 10 mW irradiance. For x-ray tubes we obtained more than 100 μm resolution. Detail of the performance of UV light and x-ray tubes would be presented.

Conclusions

We fabricated high performance carbon nanotubes (CNT) emitters with direct current plasma enhanced chemical vapor deposition technique. The CNT emitters show more than 150 mA anode current with less than 1 cm² area. With the CNT emitters, we fabricated cold cathode electron beam (C-beam) with high performance. The C-beam shows 21.4 mA emission current at gate bias of 1,950 V. For electron microscope application, we made various m × m emitters array and beam performance analysed. One single emitter shows 20 μm beam diameters.

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