Characterization of X-ray tube using a carbon nanotube (CNT) fiber

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1. Introduction

The electron field-emission properties of carbon nanotubes (CNTs) enable the fabrication of new cold cathodes for many X-ray instruments. The utilization of these cathodes is an attractive alternative for thermo-ionic cathodes for generating X-rays. A new X-ray tube using carbon nanotube based cold cathodes may be a significant innovation in X-ray technology development and could lead to portable and miniature X-ray sources for medical and industrial applications. [1]

The purpose of this study is to investigate the feasibility of CNT fiber to a cold cathode for enhancement of X-ray tube performance.

2. Preparation, Method and Results

A carbon nanotube is an ideal field emitter due to its high aspect ratio, reasonable electrical and thermal conductivity, and high mechanical properties. Thus many researchers have focused on a technical breakthrough by replacing conventional field emitters with carbon nanotubes for applications such as field emission displays, back light units and x-ray tube cathodes. [2, 3] However, most of the attempts have failed due to the unstable field emission and short lifetime of carbon nanotubes stemming from field evaporation by a high current density and a detachment by an electrostatic force. In addition, a non-uniform field emission has limited the application of carbon nanotubes to a field emission display. Therefore, critical issues in the development of a carbon nanotube based field emitter are increasing their stability, lifetime, and uniformity.

2.1 Fabrication of the CNT fiber

Fabrication processes of a carbon nanotube fiber from a carbon nanotube forest have been reported in the literatures. [4, 5] Thickness of a catalyst and the ratio of the reaction gases are critical parameters for a super-aligned growth of a carbon nanotube forest. Aluminum (10nm) as a buffer layer and iron (1-2 nm) as a catalyst layer were deposited on a silicon wafer by a sputtering. The catalyst wafer was oxidized at 550℃ in an oxygen atmosphere followed by a reduction at 720℃ in a hydrogen atmosphere. Carbon nanotubes were grown in a microwave plasma assisted chemical vapor deposition chamber at 720℃ for a 20 minutes. Gas flow rates of H_2, CH_4, Ar, O_2 were 12 sccm, 66 sccm, 21 sccm, and 1 sccm, respectively while maintaining a total pressure of 20 Torr. The plasma power was 600W.

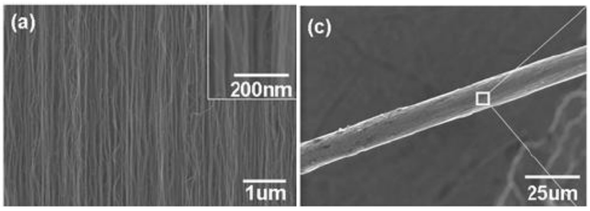

Fig. 1 SEM images of the carbon nanotube forest (a) and fiber (c)

2.2 Manufacturing of a X-ray tube

The carbon nanotube fiber was cut with a steel knife and mounted on a cathode base by using a silver paste. A x-ray tube was manufactured by the conventional vacuum tube process as shown in Figure 2.

Fig. 2 Fabricated X-ray tube with a CNT fiber

2.3 Test Results

Figure 3 shows a typical current-voltage (IV) plot which was taken by increasing the tube voltage. In order to achieve 10 μA of the anode current, an anode voltage of 12 *kV* needs to be applied. Thus, the power consumption on the CNT cathode is less than that of the thermo-ionic cathode.

The field emission nature of a CNT fiber shows the linear relationship between the tube current and the tube voltage, which is different from the conventional Fowler-Nordheim (F-N) behavior. These experimental results are unstable and inconsistent due to the flexibility and aging of a CNT fiber.

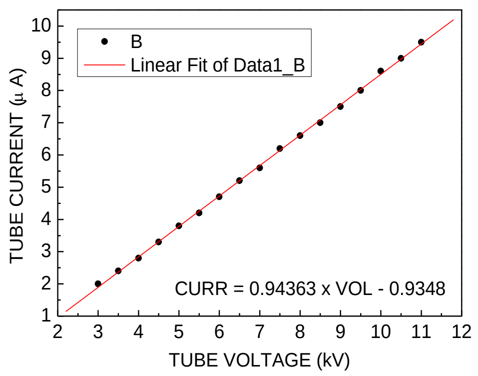

Fig. 3 Current-Voltage (I-V) plot with a CNT fiber cathode

Energy spectrum can be obtained by electron bombarding to a tungsten (W) target as shown in figure 4. When the tube voltage is above 10 kV, the counts are increased dramatically which is needed to adjust the y-axis scale. It is confirmed that the tube voltage was applied under a normal condition because of the fact that the ends of right sides are almost the same. L-lines of characteristic X-ray are appeared at 11 kV and are shown as the peaks at 12 kV.

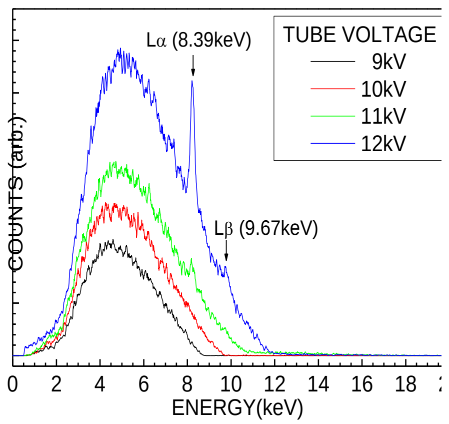

Fig. 4 Energy spectrum with a CNT fiber cathode

3. Conclusions

CNT fiber has been successfully incorporated into the x-ray tube. CNT fibers offer some advantages than CNT coating for a new generation of X-ray tube, such as, low power consumption, long lifetime due to the unraveling effect, high resolution due to the micro-scale emission area.

Further research is needed for CNT fiber for x-ray tube in order to increase the stability and consistency for an application to a portable x-ray machine and high resolution x-ray equipment.

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