A Field-emission X-ray Source using an Anisotropically Focused Electron Beam

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ABSTRACT

A field-emission x-ray source for dental imaging with an anode voltage of 70 kV and an anode current of more than 1 mA was designed and assembled using an anisotropically focused electron beam. With up to 3 kV (5 V/um) applied to a grid, the emitted electrons from a carbon nanotube based cathode were shaped into an elliptical beam by an anisotropic electron lens. The electron beam was accelerated by an 13.5-degree angled stationary anode target and focused to a small spot size, which results in an circular-shaped effective x-ray focal spot with a diameter of less than 400 um.

Keywords: field emission, X-ray source, electron beam

1 INTRODUCTION

X-ray radiography presents anatomical and dynamic information for medical diagnostics, nondestructive inspection and security screening. Conventional thermionic-emission x-ray source has disadvantages such as limited temporal resolution, random spatial distribution, and high operating temperature.[1,2,3] A field-emission x-ray source, on the other hand, has high temporal, spatial resolution, a low operating cost and a compact size due to instantaneous response time, low divergence, low operating temperature and low power consumption.

Carbon nanotubes (CNTs) have advantages over other field emitters such as microfabricated metal/silicon tips and diamond-based emitters: low threshold field for emission and high, stable current capability. In particular, carbon nanotubes exhibit extraordinary field emission properties because of their high electrical conductivity, their high aspect ratio shape for optimum geometrical field enhancement, and remarkable thermal stability. [4]

Spatial resolution of x-ray imaging systems depends on the x-ray focal spot size. Reducing the focal spot is essential in achieving high resolution for x-ray imaging. The x-ray focal spot is usually reduced by focusing the emitted electrons that impinge on the anode target. Comparing to a magnetic focusing lens, an electrostatic focusing lens only requires one or more simple metal electrodes and can be easily miniaturized. [3]

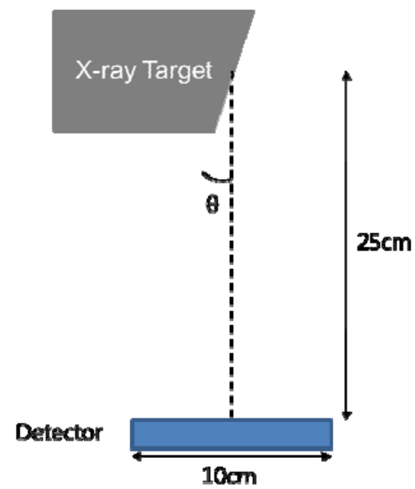

Figure 1: Configuration of a x-ray detector and the x-ray target of the CNT based x-ray tube.

Here we report a detailed study on the design of a CNT based x-ray tube with one anisotropic electrostatic focusing lens integrated in a gate(or grid) electrode. Based on a series of electron beam trajectory simulation data, the required focal spot size was achieved from both elliptical and circular-shaped electon beam. A triode-type field-emission experiment of the x-ray tube with CNT emitters made by direct-growth and electrophoresis methods has been performing. Also, x-ray experiment following the CNT based x-ray tube design is implemented to verifiy the simulated results.

2 ANISOTROPICALLY FOCUSED ELECTRON BEAM

The schematic of the CNT based x-ray tube with an stationary anode target is shown in Figure 1. The distance between the detector and the x-ray target is 25 cm and the length of the detector is 10 cm. Because the effective x-ray focal spot size depends on the anode target tilting, 11.5 degree to 14.0 degree can be chosen as a target angle as shown in Table 1. Here, 13.5 degree was chosen due to the heel effect and the effective focal spot size.

Target Angle (degree)	Source to Detector Distance (cm)	Field of View (cm)
11.0	25.0	9.8
11.5	25.0	10.2
12.0	25.0	10.6
12.5	25.0	11.0
13.0	25.0	11.6
13.5	25.0	12.0
14.0	25.0	12.4
14.5	25.0	13.0
15.0	25.0	13.4

Table 1: The relation of a target angle, source to detector distance, and the field of view.

As shown in Figure 2, an anisotropic electron beam collides against an 13.5-degree angled stationary anode target with more than 70 keV energy. Consequently, x-rays with less than 400 µm circular-shaped effective focal spot radiate. As illustrated in Figure 2, while the major axis of the elliptical electron beam is compressed into d' from D by the target angle, there is no change in the minor axis d. Therefore, to obtain the circular-like x-ray effective focal spot, the elliptical-shape electron beam was used and its size was determined. To obtain the determined electron beam size, the focusing aperture size was adjusted. The electron beam focused by the anisotropic electrostatic lens was simulated using OPERA 3D computer code. [5]

Figure 3(a) shows an oblate-shaped CNT emitter by direct-growth. To obtain a CNT emitter by direct-growth methode, first of all, the growth-site patterns were micro-fabricated on a nickel/silicon (Ni/Si) substrate. After furnacing at 600 °C for 30 minutes, PECVD (Plasma-enhanced chemical vapor deposition) process was performed by Acetylene (C2H2) and ammonia (NH_3) gases which were for CNT growth. Finally, an oblate-shaped CNT emiter of 2.0 mm x 5.0 mm was obtained from the above processes. OPERA 3D simulation code predicts the electron beam is compressed into 0.4 mm x 1.2 mm from 2.0 mm x 5.0 mm by the anisotropic-focusing electrostatic electron lens.

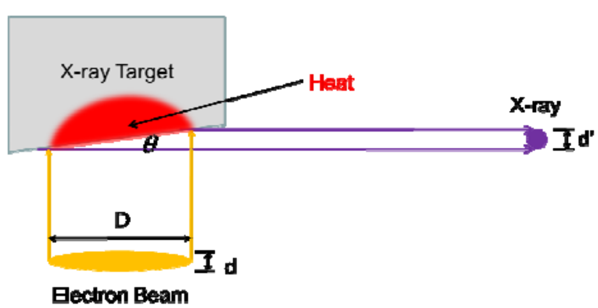

Figure 2: Schematic illustration of the relation between electron beam focal spot size and x-ray effective focal spot size in an x-ray tube with an angled target (d=d').

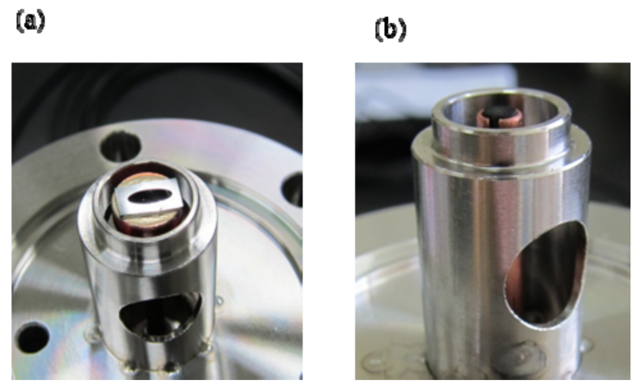

Figure 3: Picture of carbon nanotube emitters: (a) an oblate shape CNT emitter by direct-growth and (b) a circular shape CNT emiter by electrophoresis

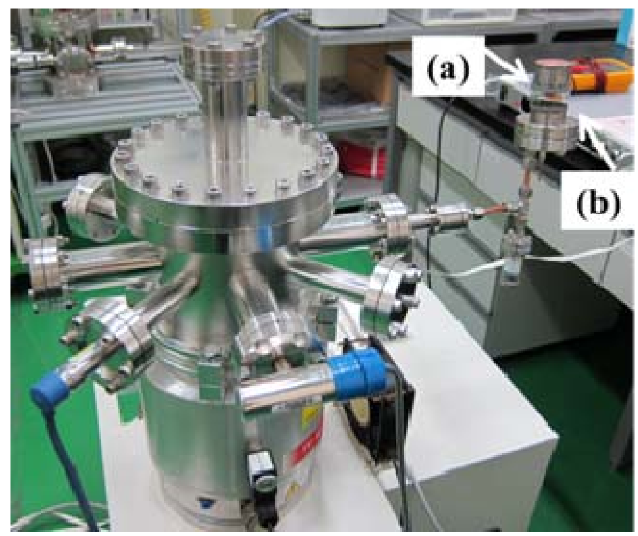

Figure 4: the experimental setup for a tryiode-type emission test: (a) an anode x-ray target and (b) a CNT x-ray emitter.

Figure 3(b) shows a 3.0 mm circular-shaped CNT emitter by electrophoresis. 100 mg MWCNT (Multi-walled carbon nanotube) powder purchased from Hyosung Co., Ltd. was mixed with 50 mL deionized water and 100 mg SDS (Sodium dodecyl sulfate) obtained from Aldrich. The mixture was sonicated for 10 minutes and then centrifuged at 1500 rpm for 25 minutes. MWCNT-SDS film was deposited on a graphite tip by the electrophoretic deposition. A stainless steel (SUS304) plate and the graphite tip (diameter 3 mm) were used as counter and working electrodes, respectively. Two electrodes were maintained at the distance of 1 mm. The constant dc voltage of 20 V was applied to the electrode for three minutes, which resulted in MWCNT-SDS film deposition on the graphite tip with positive bias. Finally, this cathode was dried at room temperature for four hours and then was fired for 30 minutes at 300 ^{o}C in a furnace. From these processes, a 3.0 mm circular-shaped CNT emitter was obtained.[6] According to the OPERA 3D simulation code, the electron beam is compressed into 0.35 mm x 1.0 mm by the anisotropic-focusing electrostatic lens.

Figure 4 shows the experimental setup for a tryiode-type field-emission test. The x-ray tube comprises (a) an anode x-ray target and (b) a CNT x-ray emitter. An x-ray tube with CNT emitters. The triode-type experiment of the x-ray tube with CNT emitters has been performing.

4 CONCLUSION

A field-emission x-ray source for dental imaging with an anode voltage of 70 kV and an anode current of more than 1 mA was designed and assembled using an anisotropically focused electron beam. The anisotropic electron beam was formed by the anisotropic-focusing electrostatic electron lens. The x-ray anode target's angle of 13.5 degrees was chosen because of the hill effect and the effective focal spot size.The electron beam focused by the anisotropic electrostatic lens was simulated using the commercial software, OPERA 3D. The triode-type emission experiment of the x-ray tube with CNT emitters made by direct-growth and electrophoresis methods has been performing.

ACKNOWLEDGMENT

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REFERENCES

[1] Y. Cheng, J. Zhang, Y. Z. Lee, and et al., "Dynamic radiography using a carbon-nanotube-based field-emission x-ray source," Rev. Sci. Instrum., Vol. 75, No. 10, 3264-3267, 2004

[2] G. Z. Yue, Q. Qiu, Bo Gao, and et al., "Generation of continuous and pulsed diagnostic imaging x-ray radiation using a carbon-nanotube-based field-emission cathode," Appl. Phys. Lett., Vol. 81, No. 2, 355-357, 2002

[3] Zejian Liu, Jian Zhang, Guang Yang, and et al., "Development of a carbon nanotube based microfocus x-ray tube with single focusing electrode," Rev. Sci. Instrum., 77, 054302, 2006

[4] W. I. Milne, K. B. K. Teo, and et al., "Carbon nanotubes as field emission sources," J. Mater. Chem., 14, 933-943, 2004

[5] Vector Fields Ltd., "OPERA 3D," Vers. 12.0, Computer software, August 2007

[6] Gui Sob Byun, Yang Doo Lee, and et al., "Field emission properties of electrophoretic deposited MWCNT film on graphite tip," Appl. Surf. Sci. (to be submitted)