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Carbon nanotube field emitter based super miniature x-ray tube design and demonstration for brachytherapy radiation source

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1. Introduction

The electric brachytherapy radiation source has been developed under common sense of miniaturized tip shape x-ray emitter[1,2,3], which can be applicable to the inside of human body for radiation cancer therapy. The filament cathode based miniaturized x-ray source with the diameter of several millimeters, the Xoft Axxent x-ray source[3], has been applied to breast cancer. Even the size of the x-ray tube is still not small due to outer cool loop, effective clinical testes have been reported using special applicator and insertion method.[3] There are possibilities the electric x-ray source can substitute Ir-192 isotope radiation source.[4]

However, the filament based x-ray tube has limitations for heat removal, miniaturization, increasing x-ray power, and life time due to a random electron generation by high temperature of thermionic electron emitter.[5] Here we designed and demonstrated a cold field emitter based miniature x-ray tube, which can be more miniaturized without thermal heating and can generate a higher x-ray power using the brighter electron emitter[5].

2. Methods and Results

Super miniature x-ray tube has been designed and demonstrated under purpose of 1W tube power (50 kV, 20 μA) within 2 mm diameter and 5~8 cm length. The carbon nanotube (CNT) field emitter, electron transport simulation, and electron emission results are described.

2.1 Carbon Nanotube Field Emitter

Carbon nanotube that has a high aspect ratio can emit electrons using a lower electric field and is strong at even bad vacuum ambient of 10^{-4} torr.[5] The miniature x-ray tube has been shaped as closed pumping system, the gas can be remove by only use of a small getter target. The CNT is the most adequate for the miniature x-ray tube fabrication.

The CNT field emission cathode has been fabricated by coated CNT source on one end tip of 0.25 mm diameter of tungsten wire, as shown in figure 1. The coated side of the tungsten wire has been polished to prevent an irregular electric field. The multi-walled carbon nanotube was grown as 50 nm diameter and 2 μm length by chemical vapor deposition, and coated using the printing method that are explained in a reference[7].

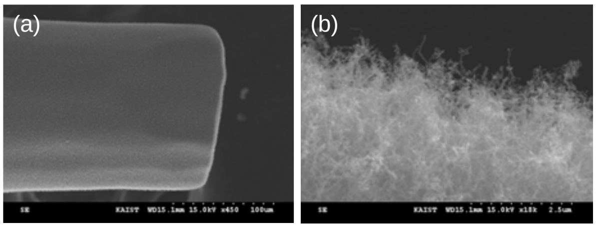

Fig. 1. The scanning microscopic image (SEM) of the carbon nanotube field emission cathode. (a) Multi-walled CNT are coated on 0.25 mm diameter of cylindrical tungsten wire. (b) Multi-walled CNT has the diameter of 50 nm and the length of 2 μm.

2.2 Electron Transport Simulation

The super miniature x-ray tube consisted with the CNT cathode, gate electrode, and transmission x-ray target and window as an anode. Electrons are emitted at the CNT by applied electric field between the cathode and gate electrode, and are accelerated to anode with 30 ~ 50 keV. Because of focusing electric field generated from differences of electrode shape and electric voltage among three electrodes, the electron beam is conversed at inclined regions near cathode and gate electrode. The accelerated beam can be finally changed its size slightly by use of field suppress electrode nearby anode. The field suppress electrode can change the electric field shape near anode. The electron beam transport simulations are carried by EGUN code, and the results are shown in figure 2.

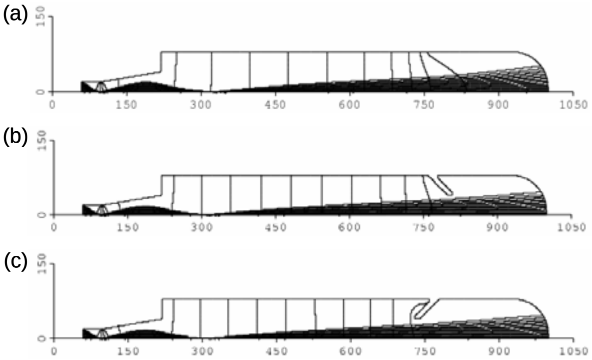

Fig. 2. The electron beam transport simulation results that carried by EGUN code. (a) No field suppress electrode. (b) Concave type of field suppress electrode. (c) Convex type of field suppress electrode. The electron beam size can be changed maximum 30% by the calculation.

2.3 Electron Beam Current and Distribution

The electron beam emission curve from a diode test is shown in figure 3. The CNT cathode can emit electron higher than 300 μA at the applied electric field of 2.6 kV/mm. The electron beam distribution has been measured less than 5 % differences on 2 axes of the beam plane using a phosphorous screen.

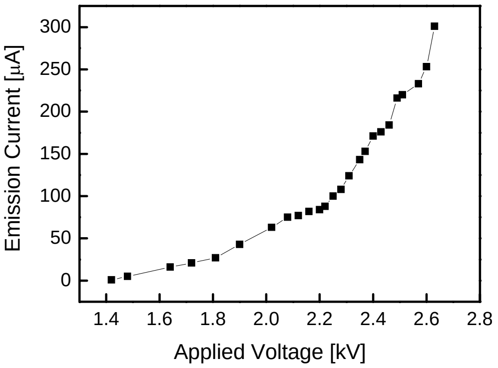

Fig. 3. Electron beam emission current from the CNT cathode. The cathode to anode distance was 1 mm. the emission curve are well following the Fowler-Nordheim relations[7].

3. Conclusions

Super miniature x-ray tube has been designed and demonstrated using the CNT field emitter, electron transport simulation, and electron emission results. The cold field emitter based miniature x-ray tube, which can be more miniaturized and can generate a higher x-ray power using the CNT field emitter.

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