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Fabrication and characteristics evaluation of applicator system of miniature X-ray tube based on carbon nanotubes emitter for treatment of skin cancer

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1. Introduction

A miniature X-ray tube is a small X-ray tube that can generate X-ray. Miniature X-ray tube generally has with a diameter and length of less than 1 cm, 5 cm respectively [1-2]. Because of the feasible installation in a spatially constrained area and the possibility of electrical on/off control, miniature X-ray tubes can be used widely area such as electric brachytherapy, and interstitial or intracavitary radiation therapy or imaging with the substitution of radioactive isotopes, nondestructive handheld X-ray spectrometers ,X-ray radiography [1]. Miniature X-ray tubes have been developed mostly using thermionic electron sources [2] or secondary X-ray emission.

Furthermore, X-ray tubes based on carbon nanotubes (CNTs) field-emission electron sources have been widely developed than thermionic electron sources because CNT emitters have several advantages compared with other sources like thermionic electron. The advantages of CNT emitters include (1) simplicity and easy controllability in a pulse operation [3]; (2) cold electron sources, and hence, little heat is generated inside the tube which is important for the minimization of an X-ray tube; (3) high current density for electron and X-ray microscopy devices [4]. Several types of X-ray tubes have also been developed using CNT field emitters.

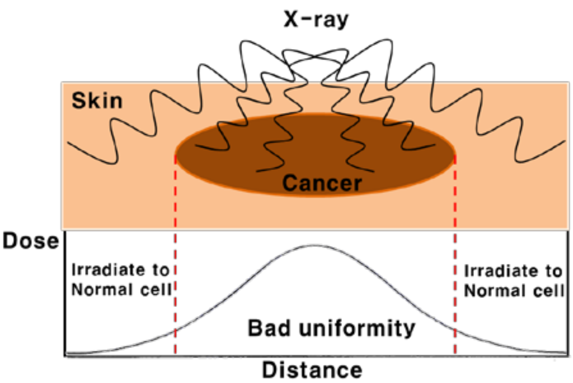

Figure 1. A schematic of the skin cancer therapy using non-uniform X-ray dose distribution.

Meanwhile, miniature X-ray tubes can't be applied directly to skin cancer treatment. In order to use the miniature X-ray tube for skin cancer therapy, applicator system is an important factor for treatment of skin cancer. As an example, the X-ray dose distribution of conventional X-ray tubes is not uniform that had just Gaussian shaped distribution. If a non-uniform X-ray was irradiated to a skin cancer on a patient, some cell parts of the skin cancer can be irradiated excessively or healthy cells can be also damaged. In this reason, the applicator system should be made for the skin cancer therapy.

2. Methods and Results

2.1 X-ray tube and applicator system

The design and fabrication of the applicator system was carried out for the application for the miniature X-ray tube which created earlier [5]. The fabrication processes of miniature X-ray tubes and applicators for the skin cancer therapy are schematically displayed in Figure 2a. The X-ray tube has a diode structure, which consists of a CNT cathode tip and a focusing electrode on one side and a conical-shaped transmission-type X-ray target on the other side. The X-ray target was fabricated by coating W on a conically machined beryllium (Be) X-ray window using a magnetron sputter. The thickness of the coated W film is 1.5 μm, which is optimized to produce a maximum X-ray output for a given electron beam input. Figure 2b is shown about design of applicator with miniature X-ray tube. This applicator consists of X-ray shielding part and X-ray dose flattening filter.

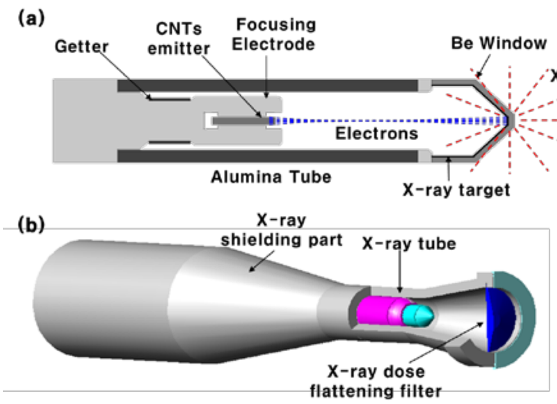

Figure 2. Schematics of (a) a vacuum-sealed miniature X-ray tube based on a CNT field emitter and (b) applicator system for the skin cancer therapy, respectively.

Figure 3a shows an optical image of the fabricated X-ray tube. The diameter of the X-ray tube is 7 mm and total length is 47 mm. The X-ray shielding part consist of stainless steel 316 (SUS316) as shown in Figure 3b. This shielding part is designed by MCNP6 Code for shielding of unnecessary X-ray exposure. Figure 3c is shown the X-ray flattening filter as made by graphite.

Figure 3. (a) An optical image of the fabricated X-ray tube. (b) X-ray shielding part and (c) X-ray flattening filter, respectively.

Experiments were conducted using the miniature X-ray tube and applicator. The experiments were followed about measurements of 1) Dose rate 2) Percentage depth dose (PDD) and 3) Flatness.

2.2 Dose rate

The dose rate of applicator equipped miniature X-ray tube was measured as shown in Figure 4a. UNIDOS E Dosimeter and PTW Ionization Chamber T34013 were used as measurement devices. There should be nothing in the vicinity of the ion chamber a few centimeters when the ionization chamber is placed because there should be no interaction of interspecies material. Figure 4b is shown that the dose rate of 70.76 Gy/min was obtained at -50 kV.

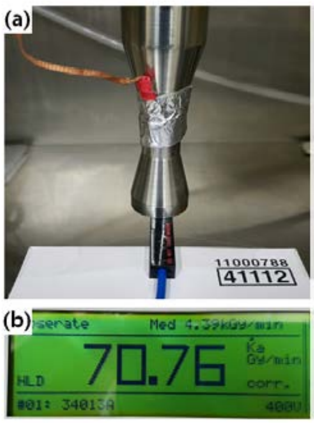

Figure 4. (a) Dose rate measurement of miniature X-ray tube with applicator and (b) the result of dose rate, respectively.

2.3 Percentage depth dose (PDD)

The percentage depth dose (PDD) is relative value of the absorbed dose deposited by a radiation beam into a medium as it varies with depth along the axis of the beam. In order to measure PDD, the water-like phantom named RW-3 (density ρ=1.03 g/cm^3) is placed on the ionization chamber as shown in Figure 5a. The measurement of PDD was followed from 0 mm (surface) to 6 mm. In addition, comparison between experimental and theoretical results was proceeded to identify the difference with theory and experiment using MCNP6 code. Figure 5b shows the PDD plot. There are very similar plot between theory and experimental value.

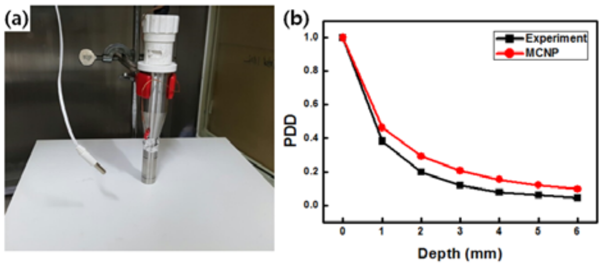

Figure 5. Percentage depth dose (PDD) measurement of miniature X-ray tube with applicator and (b) obtained PDD plot compare with MCNP result and experiment, respectively.

2.4 Flatness

Furthermore, a spatial X-ray uniformity generated by the fabricated X-ray tube was measured for a skin cancer therapy. The spatial uniformity of generated X-ray is not good flat and rough. When this situation happen, obtained uniformity of the X-ray distribution had a higher than 20%. Therefore, the flatness filter is necessary. X-ray flatness filter is designed by MCNP6 code and the filter was fabricated. When flatness filter is used for great property, the uniformity obtained by the X-ray tube with the flatness filter was a lower than 5% as shown in Figure 6.

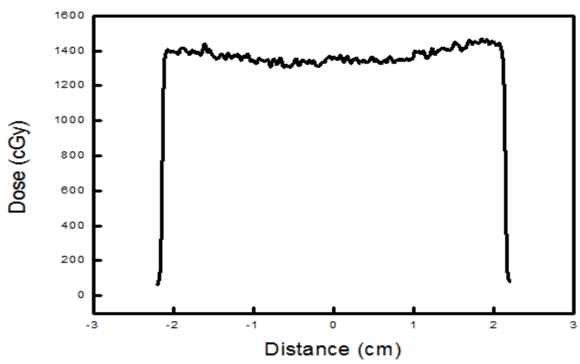

Figure 6. Dose spatial distribution obtained with flattening filter.

3. Conclusions

Miniature X-ray tube based on carbon nanotubes and applicator system were fabricated after design. The applicator shows excellent value of dose and good PDD plot. Also, the flattening filter was made to irradiate uniformly. The X-ray dose radial uniformities between installed flattening filter and non-installed flattening filter were measured. When flattening filter is equipped, X-ray uniformity was improved from higher than 20% to lower than 5%. As a result, the fabricated applicator system of the miniature X-ray tube using optimized flattening filter exhibited fairly excellent properties. However, many properties are required to treat skin cancer such as half value layer (HVL), leakage evaluation and so on. After this research, other properties will be obtained to evaluate for treatment of skin cancer.

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