The Miniature X-ray Tube based on CNT emitters and its Applications

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1. Introduction

Miniature X-ray tube is a small X-ray tube that has several millimeter of diameter and length and can produce several tens of keV X-ray energy [1]. Miniature X-ray tube based carbon nanotube field emitter is now becoming popular because it has many advantages. Miniature X-ray tube can be miniaturized, inserted into a human body and it is easy to control the X-ray energy. It can be applied as brachytherapy X-ay sources and X-ray radiography to be used at limited space or for special proposes. [2,3,4]

2. Methods and Results

We fabricated a vacuum sealed miniature X-ray tube that consists of X-ray target, ceramic tube, CNT emitter, getter and focusing electrode. The diameter and length of the fabricated miniature X-ray tube is 7mm and 47mm respectively. No vacuum pump is required for stable operation of X-ray tube. The fabricated miniature X-ray tube was stably operated up to 70kV without high voltage breakdown or discharges. Figure 1 show a photograph of the fabricated miniature X-ray tube.

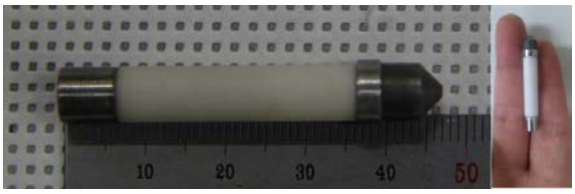

Fig. 1. Fabricated vacuum sealed miniature x-ray tube

2.1 Measurement of fabricated X-ray tube properties

Figure 2 shows the current-voltage (*I-V*) curve of the fabricated miniature X-ray tube based on carbon nanotube field emitters. The cathode and the focusing electrode of fabricated miniature X-ray tube were floated in negatively high voltage while the X-ray target was grounded. X-ray tube current of 265 μA was achieved at the tube voltage of 50 kV. The fabricated miniature X-ray tube operated stably up to 70kV tube voltage.

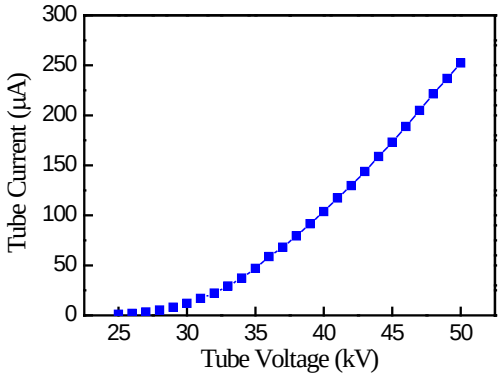

Fig. 2. Current-Voltage characteristics of the fabricated miniature X-ray tube

Figure 3 shows the X-ray dose rate spatial distribution for fabricated miniature X-ray tube. Measurements were made at 1 cm and 3cm apart from the miniature X-ray tube in air. The X-ray dose rate decreases slightly from an angle of 0° to more than ±120°. This indicates that the X-rays are comparatively uniformly produced in space, which means that miniature X-ray tube is very useful for brachytherapy or intra-cavity X-ray imaging such as intraoral diagnosis.

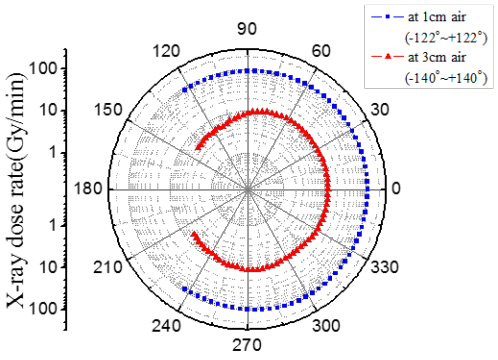

Fig. 3. X-ray dose distribution of the miniature X-ray tube measured at 1 cm and 3 cm in air.

An x-ray image of a 0.1 mm thickness of tungsten cross was obtained with the magnification factor of 1.02. The x-ray intensity profiles of the horizontal and vertical direction in Figure 4 have been analyzed by following the European standard EN 12543-5. The x-ray focal spot size is 0.67mm in the horizontal direction and 0.48mm in the vertical direction, respectively.

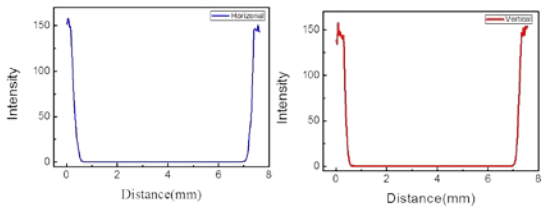

Fig. 4. X-ray intensity profile along the horizontal and vertical direction

Figure 5 shows the X-ray radiography of pig teeth, computer jack, earphone and computer chip taken using fabricated miniature X-ray tube and a CMOS photodiode array detector. The X-ray tube voltage was 50kV and the X-ray exposure time was 1 s.

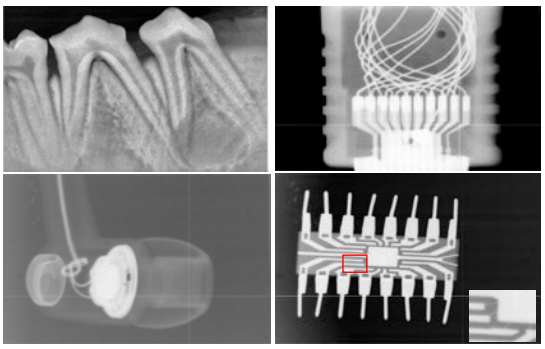

Fig. 5. X-ray images using fabricated miniature X-ray tube

We also used the miniature x-ray tube to obtain x-ray images of the USB flash drive. Figure 6 show x-ray image of USB flash drive obtained multi-direction. Because the vacuum sealed miniature x-ray tube produce x-rays uniformly, the X-ray image can be obtained any direction. All images are obtained at 0 degree, 45 degree and 90 degree by rotating the x-ray detector and USB flash drive simultaneously. We found no difference in the quality of the x-ray images.

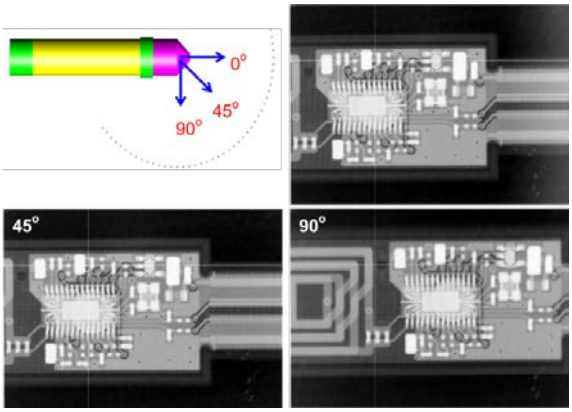

Fig. 6. X-ray images of USB flash drive acquired various directions.

3. Conclusions

In summary, we have fabricated the vacuum sealed miniature X-ray tube based on carbon nanotube as electron sources. The miniature X-ray tube can be stably and reliably operated up to 70keV without high voltage breakdown or discharge and produce X-ray with uniform spatial dose distribution. The fabricated miniature X-ray tube can be more miniaturized, and is expected to apply for various fields.

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