A miniature X-ray tube based on carbon nanotube for an intraoral dental radiography

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1. Introduction

In conventional dental radiography system, X-ray tube is placed outside of the mouth and X-ray detector is inserted into the mouth [1, 4]. As a consequence, small-sized X-ray detector is needed for insertion into the mouth. The number of human teeth that can be radiographically taken is limited. Moreover, at least two X-ray shots are required to get images of teeth from both sides of the mouth. In order to overcome the disadvantages of conventional dental radiography, a dental radiograph has been proposed in which an X-ray tube is inserted into the mouth while an X-ray detector is placed outside the mouth [2.3]. The miniature X-ray tube is required small size to insert into the mouth.

Recently, we have fabricated a miniature x-ray tube with the diameter of 7 mm using a carbon nanotube (CNT) field. But, commercialized miniature X-ray tube were adopted a thermionic type using tungsten filament. The X-ray tubes adopted thermionic emission has a disadvantage of increasing temperature of x-ray tube. So it need to cooling system to cool x-ray tube. On the other hands, X-ray tubes adopted CNT field emitters don't need cooling systems because electrons are emitted from CNT by applying high voltage without heating. Therefore, the CNT-based miniature X-ray tube can be a good intra-oral X-ray source for the new dental radiography system. The propose of this study is to demonstrate to intraoral dental radiography system

2. Methods and Results

A miniature X-ray tube based on carbon nanotube (CNT) was consisted of x-ray target, ceramic tube (alumina), CNT emitter, getter and focusing electrode. The diameter of designed miniature x-ray tube 7mm, the length is below 50mm, and no vacuum pump is required for the stable operation. A conical shaped transmission-type tungsten (W) target with a thickness of 1.5 μm is used in the vacuum-sealed miniature x-ray tube to produce x-ray with uniform spatial distribution. A getter is used to maintain high level vacuum and ceramic tube is applied for electrical insulation of vacuum sealed miniature x-ray tube. CNTs are used as electrons source of the production of x-ray.

Brazing is a joining process between x-ray tube components whereby a brazing filler metal is heated above melting point and distributed between two or more close-fitting parts by capillary action. It is similar to soldering, except the temperatures used to melt the filler metal are higher. In this study, brazing is used to assembly to all components of x-ray tube such as x-ray target, CNT emitters and focusing electrode with high vacuum levels. Brazing is conducted in accordance with optimized brazing process temperature. Fig. 1 represents developed miniature X-ray tube.

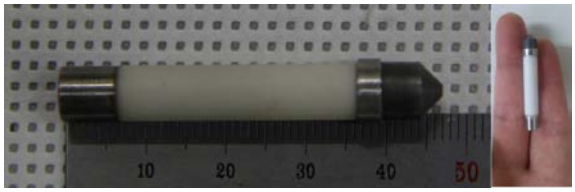

Fig.1. The developed miniature X-ray tube

The developed miniature X-ray tube was stably operated at 50 kV without any high-voltage breakdown or discharge. The x-ray tube was operated in a negative mode: the CNT emitter and the focusing electrode were floated in negatively high voltage while the X-ray target was grounded because fabricated miniature X-ray tube can be applied for intraoral dental X-ray image. When the tube voltage was increased to 50 kV, the current at the x-ray target came to 140 ㎂. And X-ray dose rate at 3.0 cm apart from surface of miniature X-ray tube was 8.19 Gy/min.

An X-ray image of a 0.1 mm thickness of tungsten cross phantom was obtained with the magnification factor of 1.02 to get the X-ray focal spot size. The X-ray intensity profiles of the horizontal and vertical direction have been analyzed by following the European standard EN 12543-5 (Fig 2). The x-ray focal spot size is 0.67mm in the horizontal direction and 0.48mm in the vertical direction, respectively.

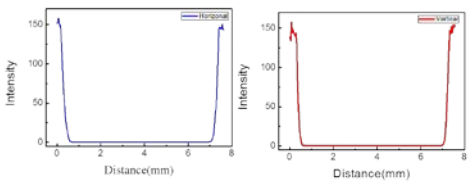

Fig. 2. The X-ray intensity profiles along the horizontal and vertical direction

Fig. 3 shows the X-ray image of human teeth phantom obtained using the developed miniature X-ray tube with the magnification factor of 1.02. The operational voltage of miniature X-ray tube was 50kV

and the X-ray exposure time was around 0.2 s. We can clearly see the X-ray image of human teeth phantom. The quality of human teeth phantom X-ray image is very good with high resolution. So we can recognize enamel, dentin and pulp of teeth in human teeth phantom X-ray image.

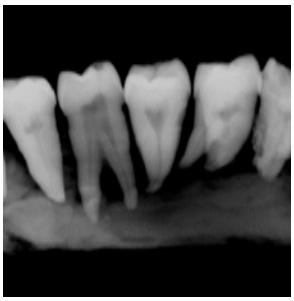

Fig. 3. X-ray image of a teeth phantom

Fig 4 (a). Shows experimental platform to get X-ray images of the pig teeth specimen. To demonstrate intraoral dental radiography system, a pig teeth specimen extracted from a lower jaw bone was used for the X-ray radiography. The miniature X-ray tube was placed (or inserted) into the pig teeth specimen and two X-ray detectors were placed outside of the left and right molars. The miniature X-ray tube was operated at 50 kV and the exposure time was 0.1 seconds. Figs. 4b and 4c show X-ray images of left and right of the pig teeth specimen, respectively by single X-ray shot. The teeth, root canals, and jaw bones at both sides are clearly observed in the X-ray images.

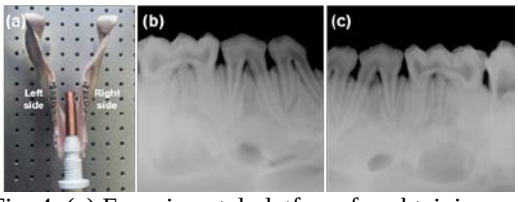

Fig. 4. (a) Experimental platform for obtaining an X-ray image of pig teeth specimen. (b),(c) X-ray images of a left and right pig teeth specimen.

3. Conclusions

We have developed the miniature x-ray tube that produce x-ray with uniform spatial distribution based on carbon nanotube field emitters. The fabricated miniature x-ray tube can be stably and reliably operated at 50kV without any vacuum pump. The developed miniature X-ray tube was applied for intraoral dental radiography that employs an intra-oral CNT-based miniature X-ray tube and extra-oral X-ray detectors. The x-ray focal spot size of developed miniature X-ray tube is 0.67mm in the horizontal direction and 0.48mm in the vertical direction, respectively. An X-ray image of many teeth was successfully obtained by a single X-ray shot using the intra-oral miniature X-ray tube system. Furthermore, images of both molar teeth of pig were simultaneously obtained by a single X-ray shot. These results show that the intraoral dental radiography, which employs an intraoral miniature X-ray tube and an extraoral X-ray detector, performs better than conventional dental radiography.

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