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Seung Jun Yeo, Amar Prasad Gupta, Jaeik Jung, Jung Sun Ahn, Hunkuk Park, Sanghyun Paik, Seung Hoon Kim, Nam Guk Kim, Beos-seok Ko, Jehwang Ryu, "Breast imaging using micro-resolution field emission x-ray system with carbon nanotube emitter
," Proc. SPIE 10573, Medical Imaging 2018: Physics of Medical Imaging, 105735J (9 March 2018); doi: 10.1117/12.2293981

Event: SPIE Medical Imaging, 2018, Houston, Texas, United States

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ABSTRACT

We report the design and fabrication of a carbon nanotube (CNT) based micro-resolution field emission mobile open type x-ray system for mammography. It can be used efficiently during the surgery of breast cancer removal to obtain accurate resection margin in partial resection of breast specimen. The obtained x-ray image of breast specimen with the proposed system shows the clear detection of microcalcifications.

Keywords: Open-type x-ray system, Breast imaging, microcalcification, CNT, field emission x-ray

1. INTRODUCTION

Breast cancer is frequently associated with microcalcification.[1] Surgery is considered to be the main treatment for the removal of microcalcifications. After the confirmation of locations of microcalcification on breast tissues through mammogram, patients usually undergo partial or complete resection of breast tissue with a rim of normal tissue around it depending on the size and distribution of lesion. One of the main goals of surgeon during the surgery is to completely remove the lesion to avoid the possible risk of local recurrences. Thus, during the surgery, it is important to identify the extent of malignant microcalcifications. The usual procedure to determine the surgical margin is to examine the rim of tissue pathologically.[2] However, pathological examination could be time consuming and surgeons along with patient have to wait for the results to confirm whether the patient should undergo further surgery or not.

We think that this time consuming process could be avoided, if we take the x-ray image of surgically removed tissue during the surgery. This could be done easily with existing x-ray technology. However, the present x-ray technology being filament emitter based is analog and inefficient compare to CNT field emitter based x-ray system.[3] CNT, as an electron field emitter has superior properties such as compact structure, reduction of power consumption, robustness, and active control function. A minimum focal spot size and the high anode current of the electron beam in the anode target by the digital switching operation can obtain a high-resolution image with a low dose.

In this study, we have discuss the development of the CNT based micro-resolution field emission open type x-ray system with a 4.5-inch spherical body consisting of a downward x-ray aperture, a vacuum part, an anode high voltage part, and a field emission triode electron gun. The system was used to obtain the x-ray image of surgically removed tissues to detect microcalcification on surgical margin.

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Medical Imaging 2018: Physics of Medical Imaging, edited by Joseph Y. Lo,
Taly Gilat Schmidt, Guang-Hong Chen, Proc. of SPIE Vol. 10573, 105735J

2. MATERIALS AND METHODS

2.1 Description of the x-ray system based on CNT field emitter

The x-ray system, shown in figure 1, is placed on and connected to a circular slab held by 4 rods connected to a rectangular slab, which in turn is mounted on an optical breadboard. It consists of a 4.5-inch circle shaped vacuum chamber with 723.83 cm^3 of internal volume. The circular body consists of following sub-system: (i) a customized high voltage electrical feedthrough connected to the reflection anode, i.e. a 5.5 mm radius tungsten brazed onto a Cu anode with a diameter of 19 mm, sliced at 170 angle; (ii) a 4 pins electrical feedthrough connected to an electron gun and a vent line at the top of interface to fill the chamber with air; (iii) a beryllium window of thickness 0.254 mm for x-rays transmission facing downward (iv) a molecular turbopump (TMU 071P) connected to a rotary pump; (v) a full range gauge (PKR251) at the top to measure the pressure inside the chamber.

The electron gun connected to cathode feedthrough, has a diameter of 16mm and consists of focusing, gate and cathode electrodes. The cathode is connected to a rectangular rounded metal substrate with an area of 0.1377 cm^2 and width of 1.5 mm. The gate mesh is a regular hexagon whose side is 360 µm, has an area of 0.00336 cm^2 and aperture ratio of 89.7 %. The focusing electrode has length of 10 mm, open width of 3 mm and thickness of 2.5 mm. The distance between gate and cathode is maintained at 370 µm. The three different electrodes of electron gun are connected to 3 different pins of cathode feedthrough. The cathode and the anode are installed opposite to each other, in such a way that x-ray emissions are transmitted toward downward through Be window.

The molecular turbopump is maintained at a base vacuum level of 1.2 X 10^{-7} Torr. The weight of the system is 20 kg without the turbopump weight. Two power sources were used for x-rays generation, i.e. the anode voltage was supplied by SHV700 power supply capable of delivering 1 - 70 kV, the gate voltage was supplied by Spellman High Voltage SL40P60/NSS/100 power supply capable of delivering 0 - 40 kV and cathode electrode was grounded.

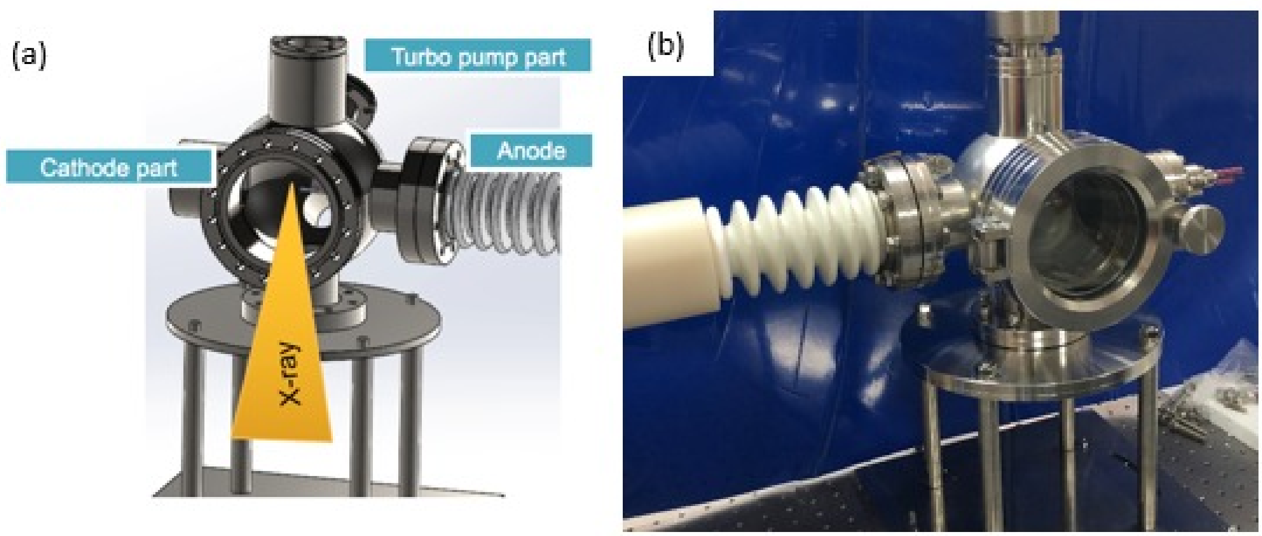

Figure 1: a) 3D design of the open type x-ray system; b) optical image of the open type x-ray system.

2.2 Obtaining of breast specimen from operation theatre

The breast specimen in figure 2 (b) was obtained by the partial surgical resection. Before the surgery, mcirocalcifications in breast tissues were confirmed by the professional radiologist through 3D tomosynthesis mammogram, as shown in figure 2 (a). This specimen was obtained at Department of Breast Surgery, Asan Medical Center and the pathological examination was done before the x-ray image was taken.

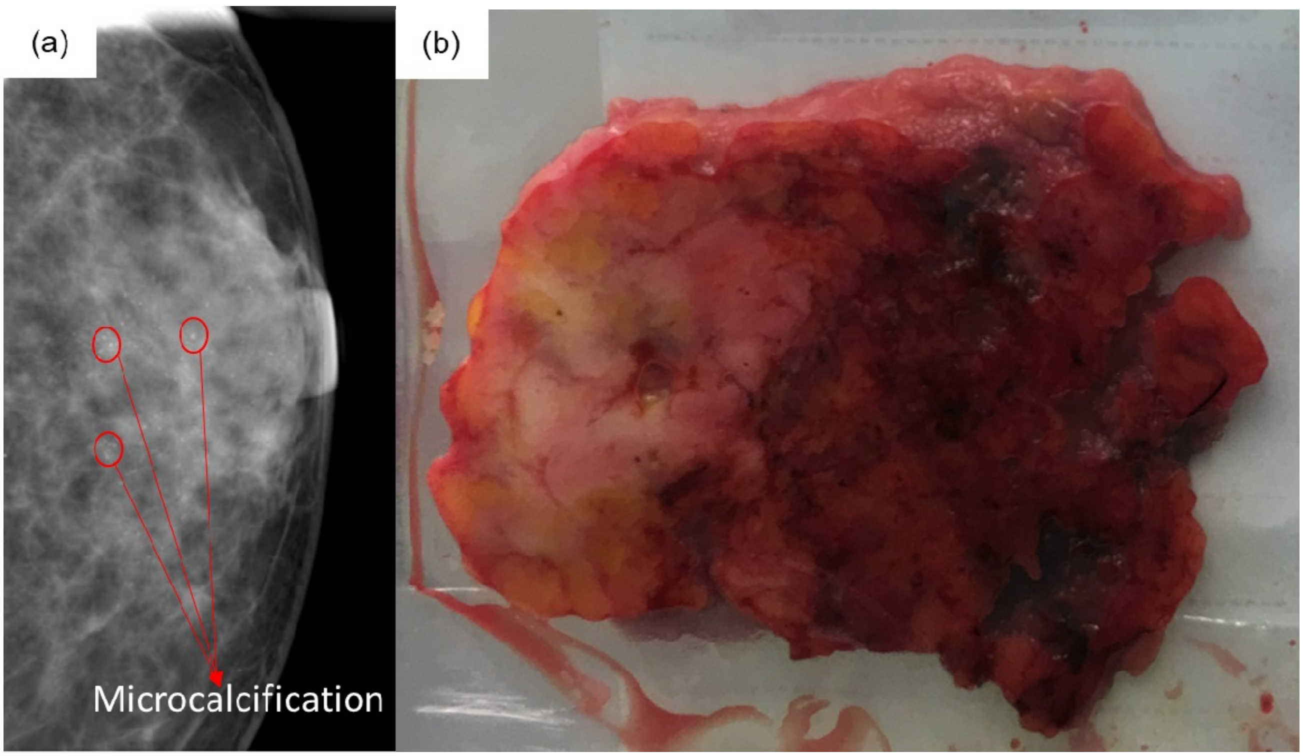

Figure 2: a) 3D mammogram of the breast tissue with microcalcification; b) optical image of surgically removed tissue

2.2 Image Acquisition

The specimen was placed between detector and x-ray source. As mentioned earlier, the x-ray emissions were transmitted through downward aperture.. The x-ray image was obtained by accelerating the anode voltage at 30 kV with anode current of 0.1 mA. The gate voltage was maintained at 5.9 kV in 50 % duty pulse mode and exposition time was 3 sec. We got this optimized condition from the o experiment described elsewhere.[4] A commercially available flat-panel detector (C7943, Hamamatsu, Japan) has been used as the 2D digital x-ray imager in the x-ray tube. The flat-panel detector consists of a 1216 × 1216 active matrix of transistors and photodiodes with a pixel pitch of 100 m and a CsI:Tl scintillator. The optical photons, emitted from CsI:Tl when irradiated by x-rays, have a peak spectrum at about 560 nm (or 2.2 eV in equivalent energy), and they are converted to electrical charges in the readout photodiode array. The detector was fabricated with the CMOS process capable of a submicron line width resolution. The pixel fill factor is 87%, in spite of the small pixel size of 100 m, which would be hardly achievable with a-Si technology.

3. RESULTS

3.1 Fabrication and Field Emission of CNT emitters

As shown in figure 3 (a) the CNTs were grown on metal substrate through plasma enhanced chemical vapor deposition process described elsewhere.[5] The SEM image of CNTs confirms that it was spiral in shape and distributed uniformly throughout the substrate. Before the electron gun with CNT emitter was inserted in the open type x-ray system, the field emission was measured in triode system. Figure 3 (b) depicts the field emission characteristic of CNT emitters on metal substrate. After the electrical aging process i.e. the 100^{th} emission, the emitter produced the 0.8 mA of cathode current at electric field of 7.5 V/μm with gate leakage current of 0.14 mA. The transparency rate was as high as 82.5 %.

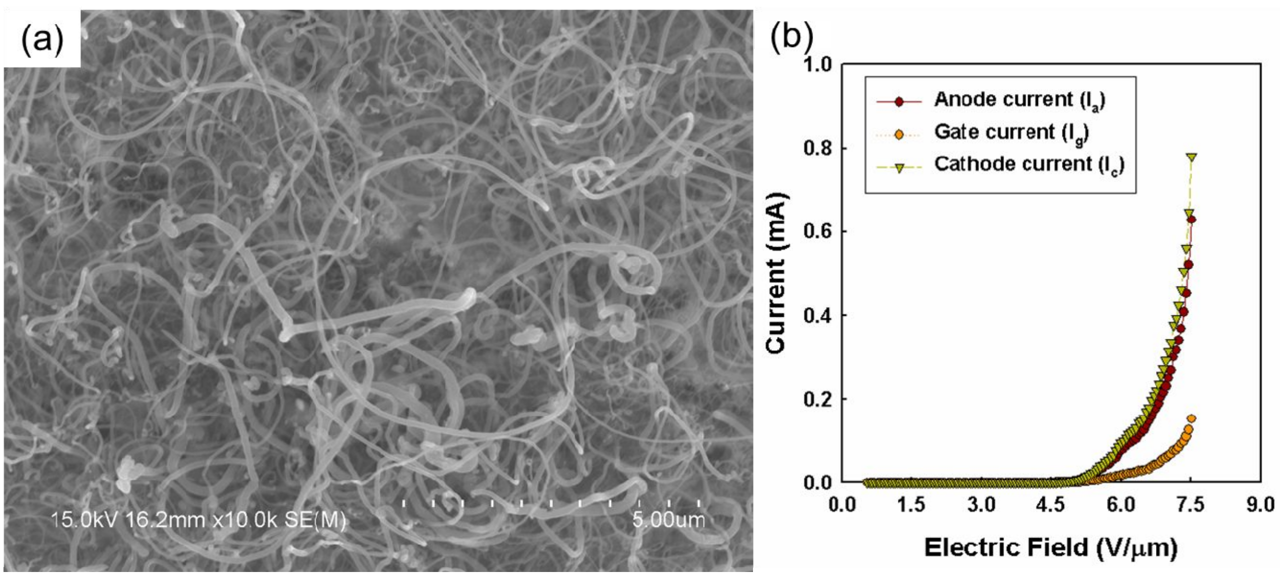

Figure 3: a) SEM image of grown CNT on metal substrate; b) field emission of triode type CNT emitter

3.2 X-ray image of breast specimen

Figure 4 shows the x-ray image of the surgically removed breast tissue. We can see that microcalfications are visible all over the breast tissue. However, white dots inside the red circles are much easier to detect than other dots on the x-ray image. It is because the level of calcification around these dots are higher and has more interference with x-rays. Although, the image was taken at 30 kV anode voltage with 0.1 mA anode current, the result shows the resolution of micro level was obtained.

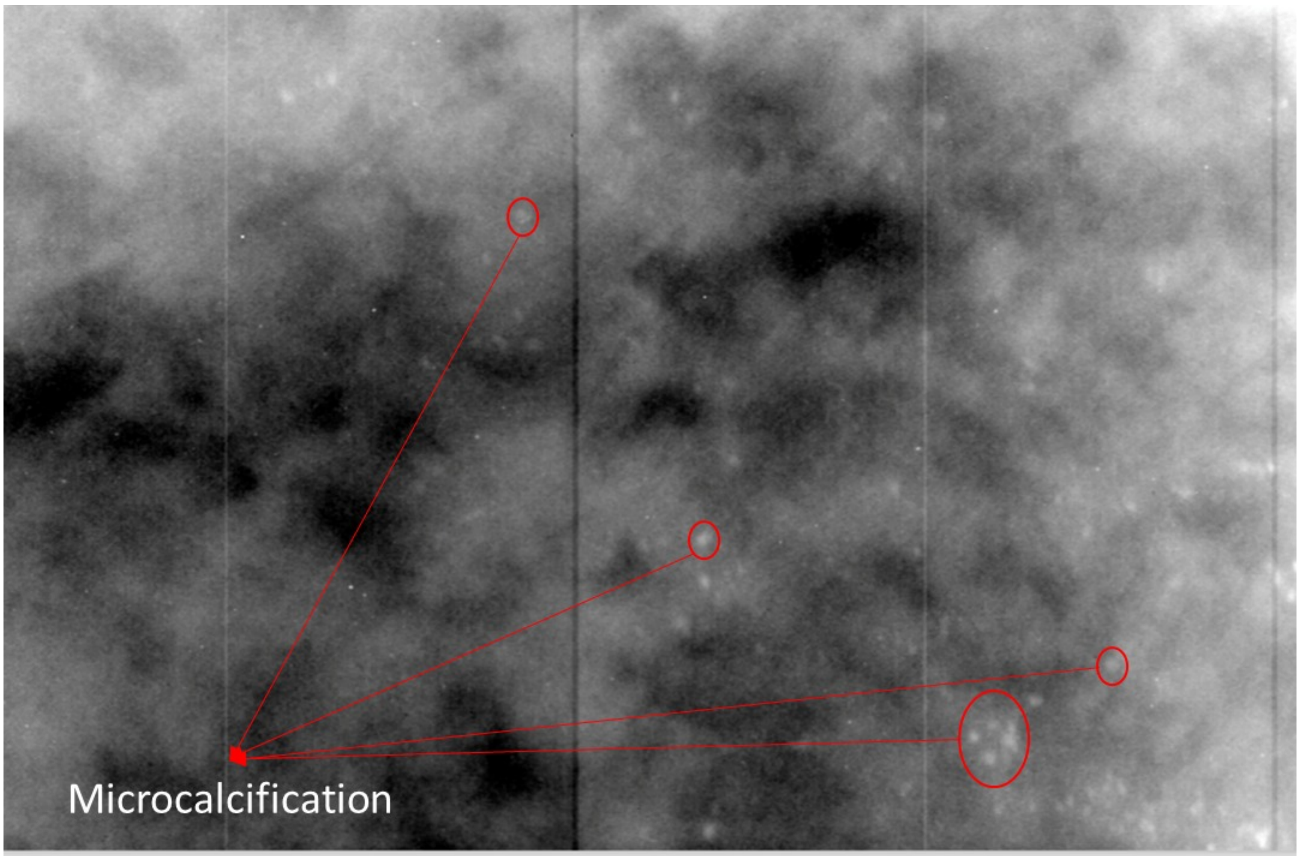

Figure 4: X-ray image of microcalcifications detected by proposed X-ray system based on CNT emitters

4. CONCLUSION AND DISCUSSION

In this study, we demonstrated the working of CNT based micro-resolution field emission open type x-ray system for the breast imaging. The system produced the high resolution able to detect the microcalcification on surgically removed tissue. This level of resolution was able because of the electron coming from the nano source and switching of CNTs digitally. Since the CNT enabled x-ray system is light and mobile, it can be operated easily at operation room and bears greater potential to be used for the identification of the extent of malignant microcalcification on surgical margin. With the more pre-clinical trials and development of CNT based small-CT scanner, the efficiency of screening test can be increased gradually. The small CT scanner will be able to take 3D images of removed tissue, which with image reconstruction software can provide better insight on the presence of microcalcifications around surgical margin.

ACKNOWLEDGEMENT

This research is supported and funded by Kyung Hee University (1345258970), Ministry of SMEs and Startups(1425112479), and Seoul R&BD Program(TB17013).

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