PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

Stationary multi x-ray source system with carbon nanotube emitters for digital tomosynthesis

Park, Junyoung, Gupta, Amar Prasad, Kim, Wooseob, Lim, Jongmin, Yeo, Seungjun, et al.

Junyoung Park, Amar Prasad Gupta, Wooseob Kim, Jongmin Lim, Seungjun Yeo, Dongkeun Kim, Changwon Jeong, Kwon-Ha Yoon, Seungryong Cho, Jeung Sun Ahn, Mallory Mativenga, Jehwang Ryu, "Stationary multi x-ray source system with carbon nanotube emitters for digital tomosynthesis," Proc. SPIE 11595, Medical Imaging 2021: Physics of Medical Imaging, 115953G (15 February 2021); doi: 10.1117/12.2582280

Event: SPIE Medical Imaging, 2021, Online Only

Stationary Multi X-ray Source System with Carbon Nanotube Emitters for Digital Tomosynthesis

Junyoung Park[1], Amar Prasad Gupta[1], Wooseob Kim[1], Jongmin Lim[1], Seungjun Yeo[1], Dongkeun Kim[2], Changwon Jeong[3], Kwon-Ha Yoon[3], Seungryong Cho[5], Jeung Sun Ahn[1], Mallory Mativenga[4]*, Jehwang Ryu[1]*

[1]Department of Physics, Kyung Hee University, Seoul, 02447, Republic of Korea;
[2]Department of Hardware Investigation, ASTEL, Daejeon, 34111, Republic of Korea;
[3]Medical Convergence Research Center, Wonkwang University Hospital, Iksan, Jeollabuk-do, 54538 Republic of Korea;
[4]Department of Information Display, Kyung Hee University, Seoul, 02447, Republic of Korea;
[5]Department of Nuclear & Quantum Engineering, KAIST, Daejeon 34141, Republic of Korea

ABSTRACT

In order to diagnose diseases in complex areas such as the chest, an X-ray system of a suitable type is required. Chest tomosynthesis, which acquires a reconstructed 3D image by taking X-ray images from various angles, is one of the best image acquisition technologies in use. However, one major disadvantage of tomosynthesis systems with a single X-ray source is the motion blur which occurs when the source moves or rotates to change the acquisition angle. To overcome this, we report a stationary digital tomosynthesis system, which uses 85 field-emission type X-ray sources based on carbon nanotubes (CNTs). By using CNT-based electronic emitters, it is possible to miniaturize and digitize the X-ray system. This system is designed such that a maximum of 120 kV can be applied to the anode to obtain chest X-ray images. The field emission characteristics of the CNT-based emitters are measured, and X-ray images were obtained using the stationary multi X-ray source system, confirming its applicability to chest Tomosynthesis.

Keywords: Tomosynthesis, 3d imaging, Carbon nanotube, Multi X-ray source

1. INTRODUCTION

Digital chest tomosynthesis (DCT) is very suitable for effectively diagnosing a disease of the chest with a complex structure of soft tissues and hard bones [1]. Tomosynthesis provides 3D imaging by reconstructing X-ray projections taken from multiple directions [2]. However, conventional tomosynthesis systems have several disadvantages because they use one X-ray source which has to be rotated or moved around the subject to acquire images from different angles. Figure 1 shows the operation mechanism of the conventional tomosynthesis system. Given that X-ray emission continues while the X-ray source moves, motion blur associated with the movement occurs in the image acquired by the detector [3]. Conversely, if the movement speed of the X-ray source is reduced, motion blur due to the movement of the source decreases, but the shooting time increases and motion blur due to the movement of the subject increases. In this respect, it is possible to overcome these problems by creating a stationary system with multiple X-ray sources – each dedicated to a specific acquisition angle [4][6].

In this paper, a digital multi X-ray source system (D-MXSS) which uses an array of 85 carbon nanotube (CNT)-based electron emitters is investigated for chest tomosynthesis. As the CNT-based electron sources are field emitter, they can be miniaturized and digitally operated. Figure 2 shows the final designs of the D-MXSS with the patient in the (A) standing and (B) lying down position. The X-ray source array used in D-MXSS is designed such that 85 X-ray sources can be arranged in a row. The field emission characteristics of the CNT-based emitters were measured and X-ray images were obtained using the system. These results show the possibility of obtaining reconstructed 3D images by applying field emission emitters to a stationary X-ray system for chest tomosynthesis.

Medical Imaging 2021: Physics of Medical Imaging, edited by Hilde Bosmans, Wei Zhao, Lifeng Yu, Proceedings of SPIE Vol. 11595, 115953G · © 2021 SPIE
CCC code: 1605-7422/21/$21 · doi: 10.1117/12.2582280

2. METHODS AND MATERIALS

2.1 Stationary multi X-ray source system for digital tomosynthesis

A picture of the D-MXSS is shown in Fig 3(A). Inside the system, X-ray sources are arranged vertically in an array, and X-rays are emitted toward the detector through an aluminum window. For efficient X-ray emission, the pressure in the system's chamber is kept below 10^{-7} Torr. The multi X-ray source array consists of two parts, an anode array and an emitter array, and has a total of 85 X-ray sources [Fig. 3(B)]. Fig. 3(C) shows the emission geometry of X-rays emitted from the multi X-ray source array. The 85 X-ray sources in the X-ray source array are arranged at equal intervals and form a total length of 672 mm. The detector is located 1100 mm away from the center of the X-ray source array, and the directions of each anode are tilted so that X-rays generated from the X-ray source array are directed toward the center of the detector. The angle formed by the two ends of the X-ray source array from the center of the detector is 34 degrees.

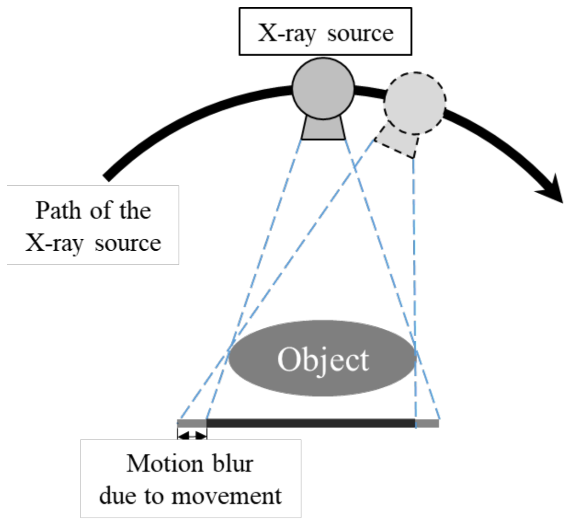

Figure 1. Schematic structure and operation mechanism of conventional tomosynthesis systems.

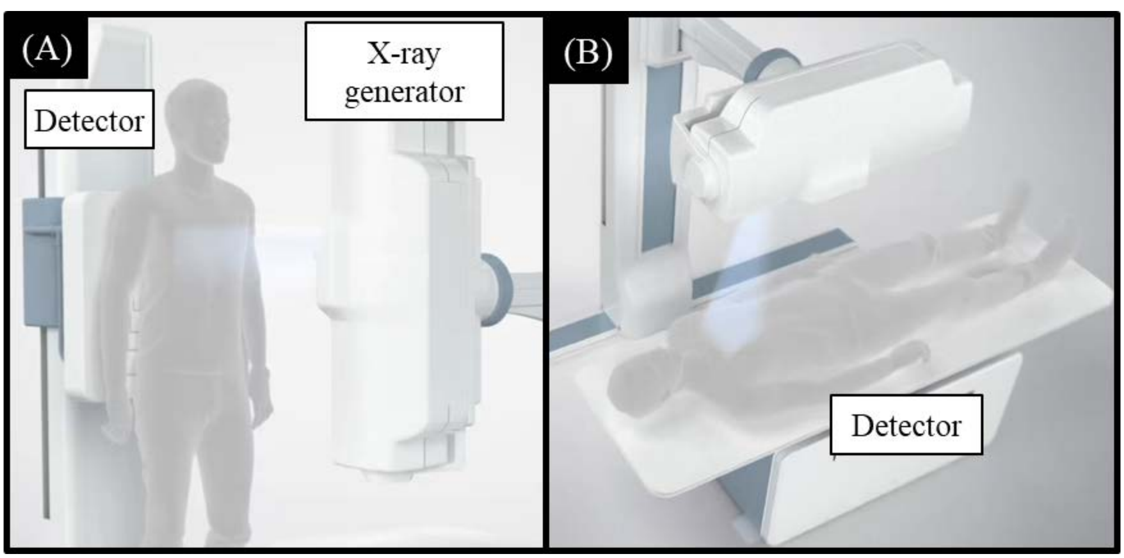

Figure 2. Computer Aided Design image of the final digital multi X-ray source system. (A) Patient in standing position; (B) Patient in lying-down position.

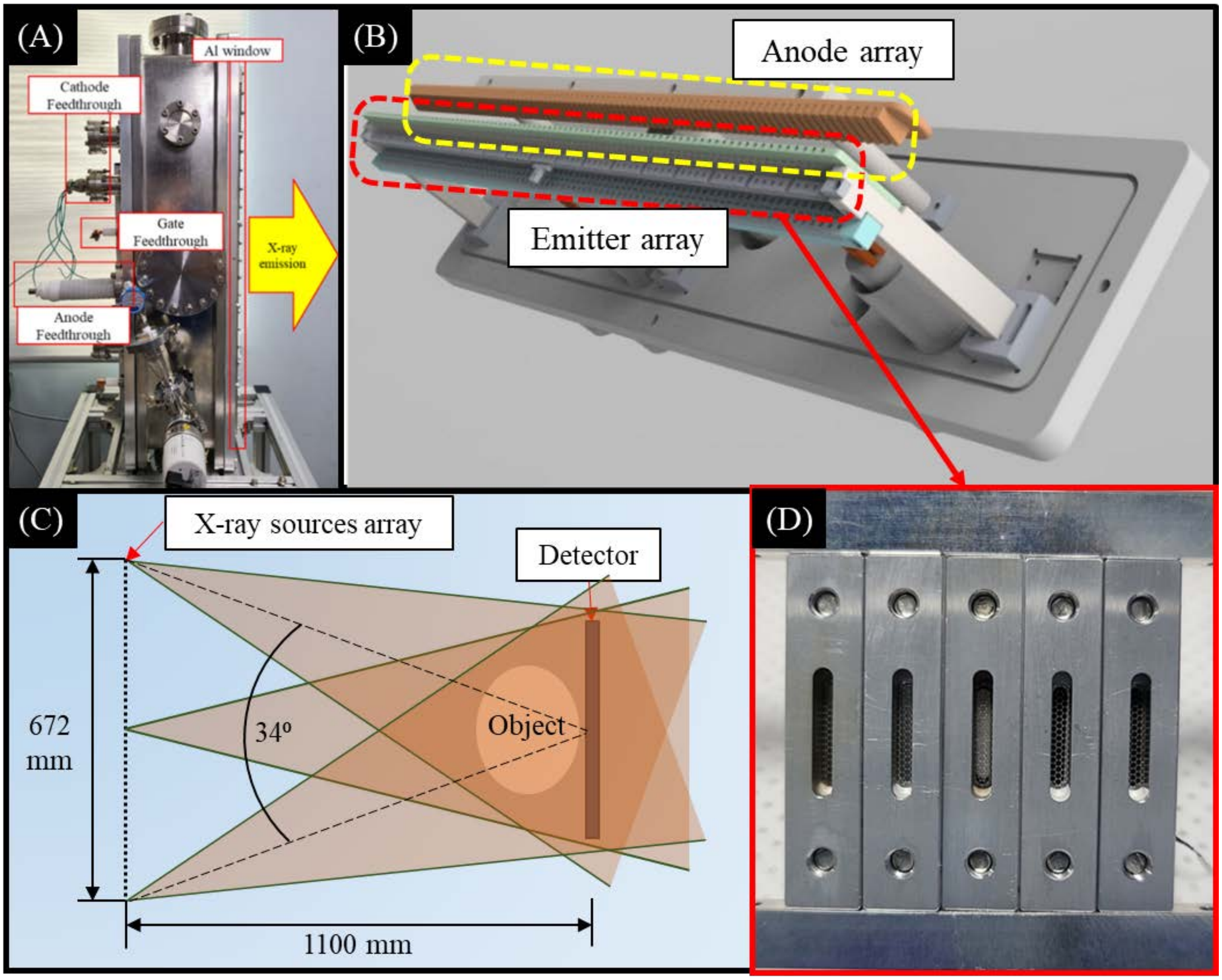

Figure 3. Digital multi X-ray source system. (A) Picture of the digital multi X-ray source system (D-MXSS); (B) . Computer Aided Design drawing of the multi X-ray source array. It consists of an emitter array and an anode array; (C) Geometry of the D-MXSS; (D) Top view of the emitter array.

2.2 CNT-based electron emitter

For the digital drive of the D-MXSS, a CNT-based field emission emitter was used as an X-ray source. Fig. 4(A) shows a photograph of the process of synthesizing CNTs on a metal alloy (Fe-Ni-Cr) substrate as the cathode of the emitter. The synthesis of CNTs was performed by chemical-vapor-deposition (CVD) at a high temperature of 900 degrees or higher using ethylene as a precursor. The CNTs synthesized on the metal substrate could be confirmed through a scanning electron microscope (SEM). The CNTs grew in random directions with diameters ranging from 40 to 150 nm and a maximum length of 10 μm.

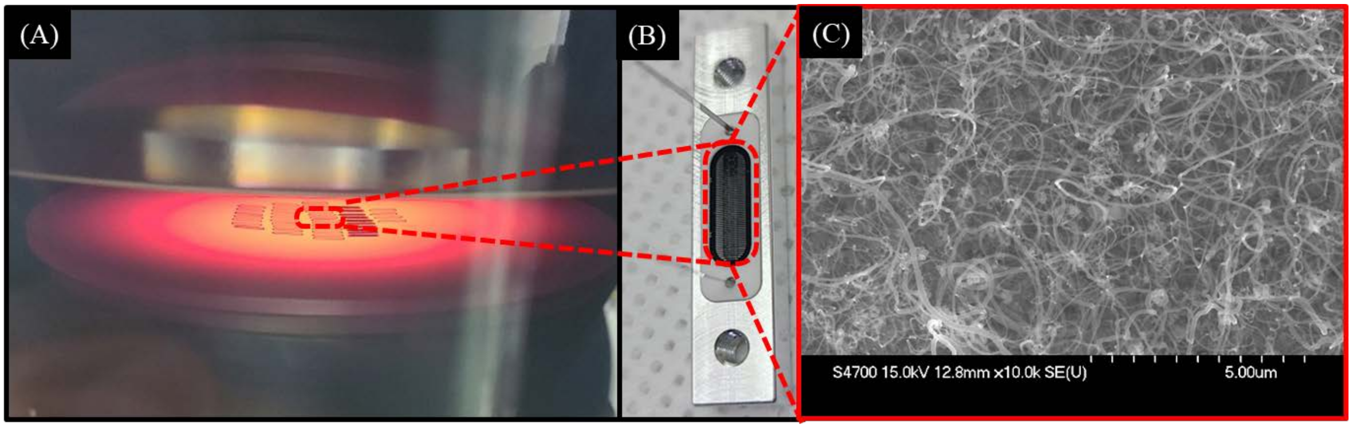

Figure 4. CNT-based field emitters for X-ray source. (A) CVD process; (B) CNT-based cathode in emitter; (C) SEM image showing CNTs on cathode.

2.3 X-ray source

Figure 5(A) is a schematic diagram showing the X-ray generation process of a single X-ray source consisting of an anode target, a cathode, and a gate. The gate is an electrode having a mesh shape, and a voltage of up to 3 kV is applied to extract electrons from the CNT cathode. The distance between the cathode and the gate is 370 mm, and the size of the emitter's emission area is 0.1377 cm^2. The distance between the emitter and the anode is approximately 10 mm, and it was manufactured to be changed according to conditions. Fig. 5(B) shows a picture of an emitter array with only one emitter installed and an array of anodes.

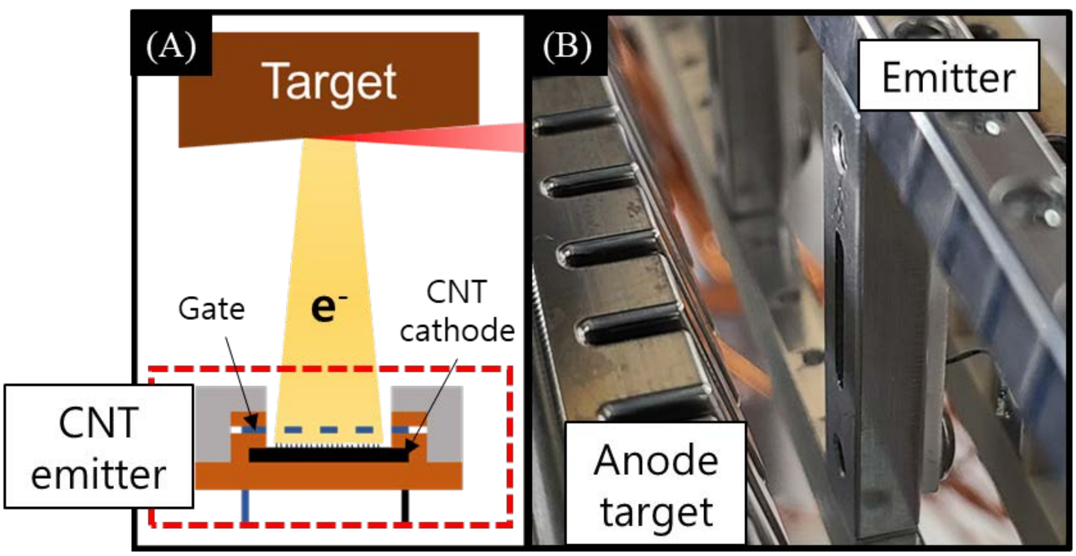

Figure 5. X-ray sources of the digital multi X-ray source system (D-MXSS). (A) A schematic of one X-ray source. X-ray source consists of a CNT cathode, a gate electrode, and an anode target; (B) Picture of X-ray sources in D-MXSS.

3. RESULTS

The field emission characteristics are measured with the same CNT-based emitter used in the D-MXSS, and the current-voltage (I-V) characteristics are presented in Fig. 6. At a gate voltage of 1.4 kV, the emitter current is 1.31 mA, which corresponds to a current density of 9.49mA/cm^2. Also, through the graph, it can be seen that the current increases rapidly near 0.8 kV, through which the field emission method shows the possibility of digitizing X-ray emission.

Fig. 6 shows an X-ray image of a chicken wing taken using the D-MXSS proposed herein. The X-ray image was taken for 2 s at an anode voltage of 45 kV and a current of 0.6 mA. A field emission X-ray source using CNTs as a cathode was sufficient to obtain an X-ray image.

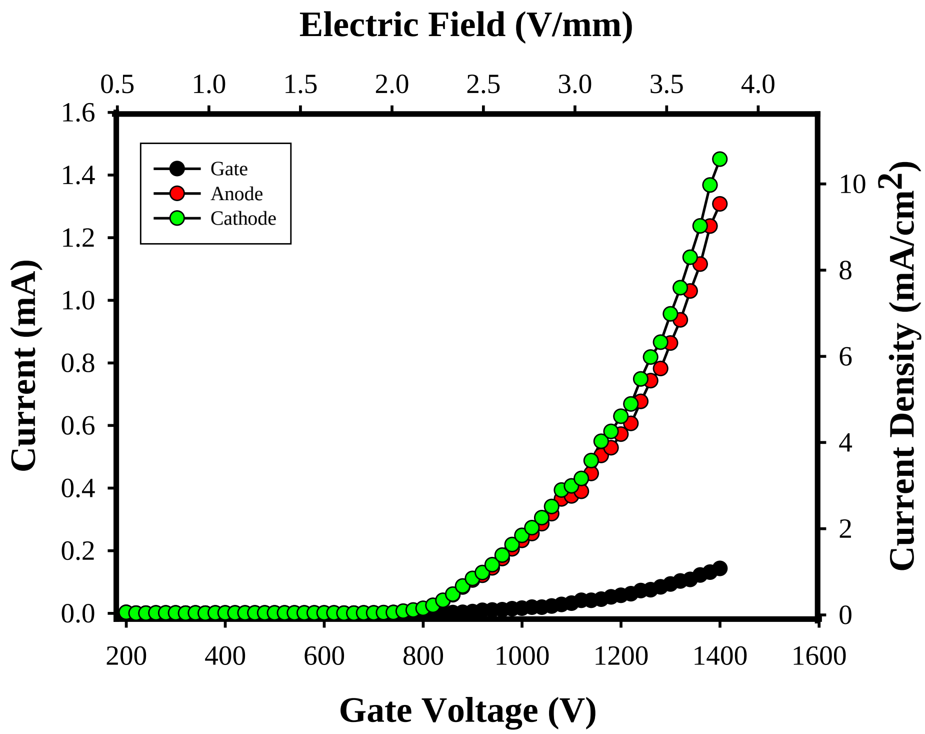

Figure 6. I-V curve of CNT-based field emission electron emitter.

Figure 7. X-ray image of a chicken wing taken using the CNT-based stationery multi X-ray system.

4. CONCLUSIONS

We report a new design of a stationary digital multi X-ray source system which uses CNT-based field emitters. The system consists of 85 CNT-based X-ray sources, each emitting X-rays from a different angle. An X-ray image of chicken wing was successfully acquired using the CNT-based X-ray system, confirming the possibility of obtaining an X-ray image with reduced motion blur, given that the sources are stationary. There are still points to be supplemented, but it will be of great help to medicine if high resolution reconstructed 3D images can be obtained through this new X-ray system.

5. ACKNOWLEDGEMENTS:

This work was supported by the Bio & Medical Technology Development Program of the National Research Foundation (NRF) funded by the Ministry of Science & ICT (NRF-2018M3A9E9024942, NRF-2016M3A9E9942010), the Creative Convergence Research Program funded by the National Research Council of Science & Technology (CAP-18-03-ETRI)

REFERENCES

[1] S. H. S. Chou, G. A. Kicska, S. N. Pipavath and G. P. Reddy, "Digital tomosynthesis of the chest: current and emerging applications", Radiographics, 34, 359-372 (2014).

[2] Vikgren J., Bath M., & Johnsson A., "Chest Tomosynthesis: Technical and Clinical Perspectives", Seminars in Respiratory and Critical Care Medicine, 35(01), 017–026 (2014)

[3] X. Qian, A. Tucker, E. Gidcumb, J. Shan, G. Yang, X.C. Colon, S. Sultana, J. Lu, O. Zhou, D. Spronk, F. Sprenger, Y. Zhang, D. Kennedy, T. Farbizio, Z. Jing, "High resolution stationary digital breast tomosynthesis using distributed carbon nanotube X-ray source array", Med. Phys., 39, 2090-2099 (2012)

[4] J. Shan, A. W. Tucker, Y. Z. Lee, M. D. Heath, X. Wang, D. H. Foos, J. Lu and O. Zhou, "Stationary chest tomosynthesis using a carbon nanotube X-ray source array: a feasibility study", Physics in Medicine and Biology, 60(1), 81–1005 (2014)

[5] W. Kim, A. P. Gupta, J. Jang, J, Jung and J. Ryu "Micro computed tomography system based on field emission X-ray source with carbon nanotube emitter", Proc. SPIE 11312, 113122V (2020).

[6] S. Park, JW. Jeong, JW. Kim, JT. Kang, K.N. Yun, JH. Yeon, S. Kim, H. Jeon, E. Go, JW. Lee and YH. Song, "A fully vacuum-sealed miniature x-ray tube with carbon nanotube field emitters for compact portable dental x-ray system", Proc. SPIE 10573, 105732G (2018)

[7] J. Park, J. Jung, A. P. Gupta, J. Soh, C. Jeong, J. S. Ahn, S. Cho, KH. Yoon, D. Kim, M. Mativenga, J. Ryu, "Multi-beam X-ray Sources with Carbon Nanotube Emitter for Tomosynthesis System", Proc. SPIE 11312, 113122E (2020)