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Multi-beam X-ray Sources with Carbon Nanotube Emitter for Tomosynthesis System

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ABSTRACT

Digital chest tomosynthesis that provides a reconstructed 3D chest image is a superior technique to detect chest diseases. As it is difficult to detect diseases like lung cancer with conventional 2D digital chest X-ray technology (CXT), digital chest tomosynthesis improves upon the many of the limitations inherent in the 2D digital CXT. In this study, we report a digital chest tomosynthesis system (D-CTS) that can generate multi X-ray information for the reconstruction of a 3D X-ray chest image. The D-CTS reported herein employs an array of carbon nanotube (CNT) emitter-based cold cathode electron-guns that are triggered in sequence to provide a gantry-less system (Figure 1). The CNTs are achieved by direct growth on a metal substrate and have a spaghetti-like structure (Figure 2) with fast response to electrical bias under vacuum conditions. Unlike conventional rotating type systems with gantries, our CTS has the advantage of less motion blur in image acquisition, given its stationary position. Additionally, the switching from one electron-gun (e-gun) to the next is much faster than the speed of conventional gantries, allowing faster acquisition time t required for digital operation. This system shows outstanding field emission property for taking X-ray images. The design, fabrication process and imaging processing of the multi-beam CNT X-ray system will be discussed during the presentation.

Keywords: Chest Tomosynthesis System, Field Emission X-ray, Carbon Nanotube

1. INTRODUCTION

Digital chest tomosynthesis is a superior technique in medical imaging to diagnose chest diseases by furnishing a reconstructed 3D X-ray chest image [1]. Fast response speed and the generation of the required amount of current within a short period of time are necessary to produce high resolution X-ray images, and a CNT-based X-ray tube is a significant key factor in this regard [2]. CNTs are promising field emission materials due to their good conductivity, unique structure, and excellent physical, chemical and thermal properties [3-6]. Compared to conventional gantries, the use of an array of X-ray sources that can be sequentially switched enables fast image acquisition required for digital imaging [2]. Additionally, stationary systems make it possible to obtain high resolution images without motion blur. Gantry-based scanners rotate a single X-ray source while shooting 2D X-ray images sequentially at different projection angles, which may result in motion blur [7]. In contrast, multiple X-ray sources produce less motion blur as they are triggered sequentially and fixed at different projection angles.

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2. METHODS

2.1 X-Ray Source Array for Stationary Tomosynthesis System

Our digital chest tomosynthesis system (D-CTS) has an array of X-ray emitters arranged in a line and operates in a stationary position. To obtain X-ray images with different angles, we can switch the multiple X-ray sources sequentially using driving circuitry involving field-effect transistors (FETs), a deMUX and a control unit (GenSync). Figure 1a shows a prototype of our full D-CTS. The D-CTS consists of 85 X-ray sources based on CNT field emitters (Figure 1b). The gap between the x-ray sources is 8 mm and the total length of the multi X-ray source array is 672 mm. The distance from the center of the X-ray source array to the detector is 1100 mm. Each source is placed at an angle in order to project to the center of the detector and the sources at the two far ends make an angle of 34 degrees from the center of the detector (Figure 1b). The chamber containing the X-ray sources maintains a vacuum at a pressure below 10^{-7} Torr and the X-ray beams emitted from the X-ray sources are radiated through an aluminum window to the detector (Figure 1c).

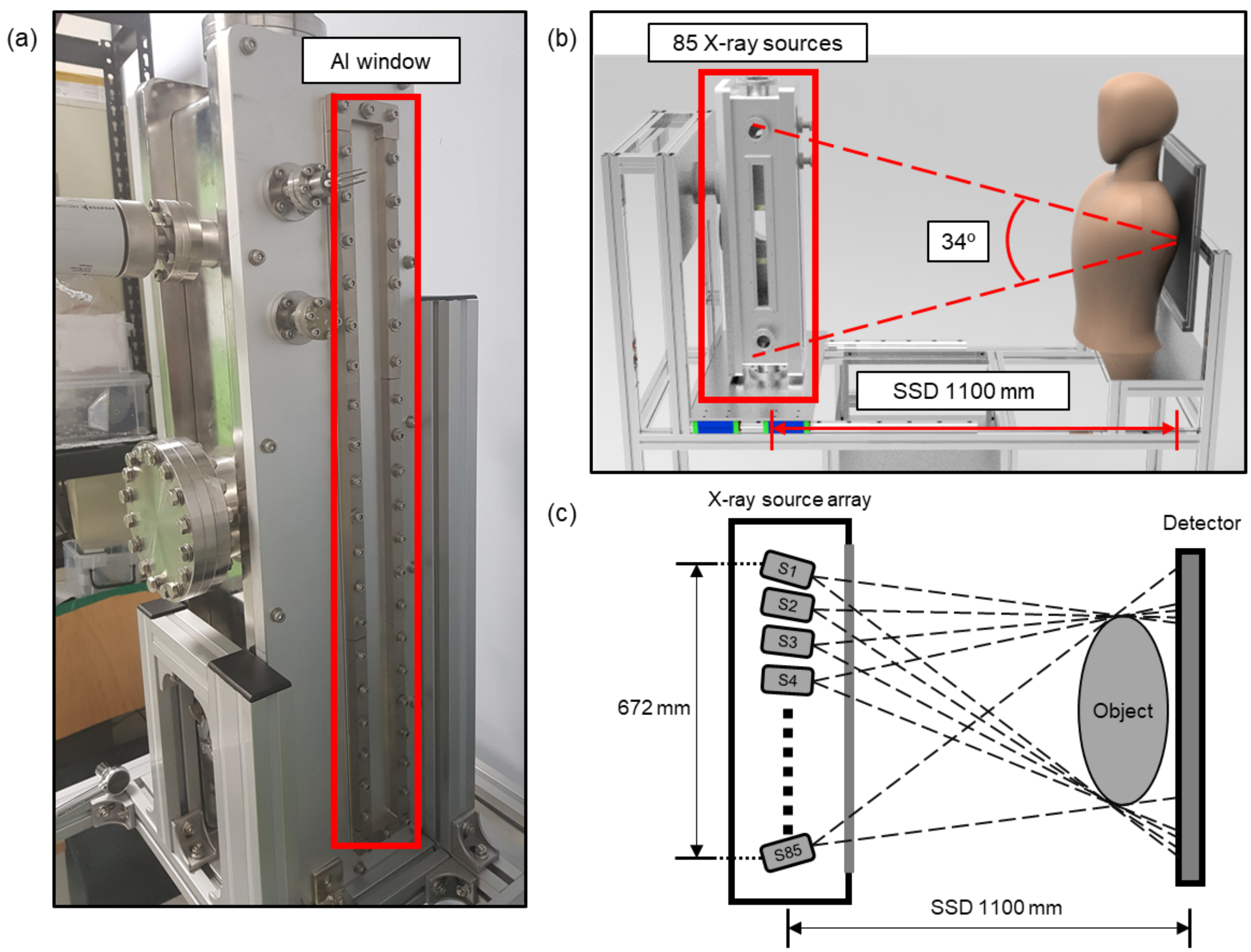

Figure 1. Structure of the digital chest tomosynthesis system (D-CTS). (a) Optical micrograph of completed prototype. (b) Simulated system showing multi-beam X-ray source and detector. (c) Multi X-ray source projection angles.

2.2 Multi X-Ray Source Driving and System Control

The D-CTS is controlled by driving circuitry imbedded into a console we call “GenSync”. It is connected to a computer and a display station as shown in Figure 2. Main controls of the GenSync include: (1) Control of the anode and gate power. (2) Reading the anode current and modulation of the gate and anode power accordingly. (3) Timing of X-ray emission and detection. Direct control of the X-ray source array is done by the emitter control circuitry, which consists of a DeMUX and 85 FETs connected to each X-ray source. For every scan line, 85 X-ray images are thus acquired from the detector. The 2D X-ray images acquired by the detector are reconstructed into 3D X-ray images by the PC.

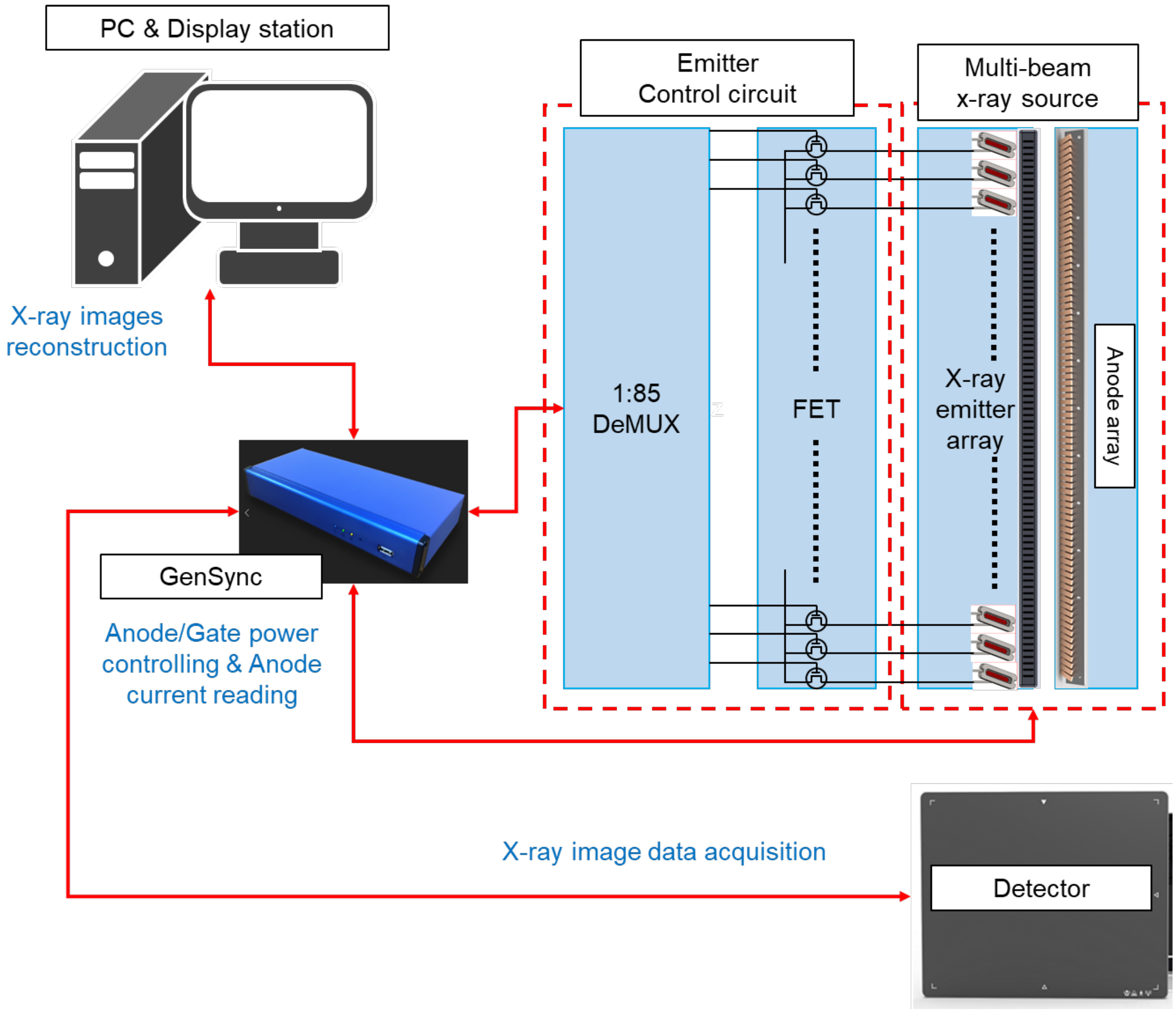

Figure 2. Multi X-Ray Source Driving and System Control

2.3 Fabrication of X-ray Source Array.

An X-ray source consists of an anode target and a CNT-based electron emitter (Figure 3a). A metal alloy substrate is used as the cathode in the emitter with an emission area of 0.1377 cm^2 and a width of 1.5 mm. The CNTs on the substrate are synthesized by the thermal chemical vapor deposition (TCVD) method [8]. The growth of the CNTs can be controlled via pre- or post-growth treatments [9]. Schematic diagrams of the anode and emitter arrays and a single emitter are shown in Figures 3b, 3c, and 3d respectively. The distance between the anode and the emitter is approximately 30 mm and can be adjusted depending on the conditions. The anode is made of copper or copper-tungsten. The gate of the emitter is meshed (with hexagonal holes) and made of kovar.

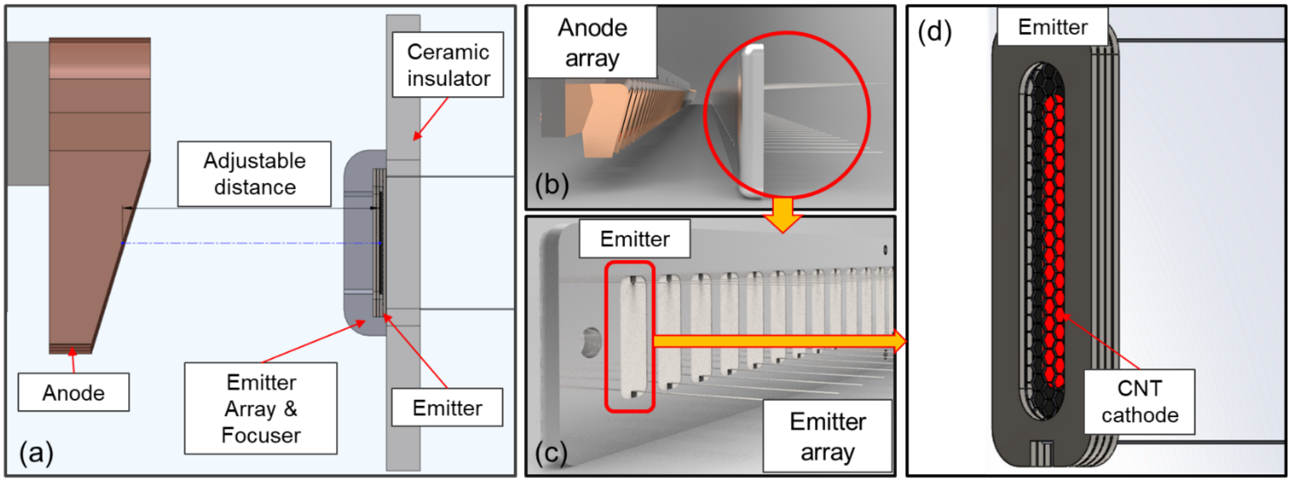

Figure 3. Structure of X-Ray Source Array. (a) Anode target and a CNT-based electron emitter. (b-d) Schematic diagrams of the anode array, (b) emitter array, (c) and a single emitter.

3. RESULTS

Figure 4a shows an optical micrograph of a fabricated emitter [11]. The emitter employs carbon nanotubes fabricated on a metal alloy (Fe-Ni-Cr) substrate (Figure 4b). The scanning electron microscope (SEM) image of the synthesized CNTs indicate a spaghetti-like orientation, with diameters ranging from 50–120 nm and an average length of about 5 µm (Figure 4b). Due to the random existent of the catalyst used on the metal surface, the CNTs are densely populated, non-uniform, and curved. The X-Ray source array is a core part of the D-CTS. X-rays for medical imaging are generated when electrons emitted from the cathode of the emitter are accelerated to the anode target (Figure 4c). A voltage of up to 3 kV is applied to the gate to extract the electrons and a voltage of up to 120 kV is applied to the anode to accelerate the electrons for X-ray generation. Ceramic spacers are used for electrical isolation between the gate and the cathode.

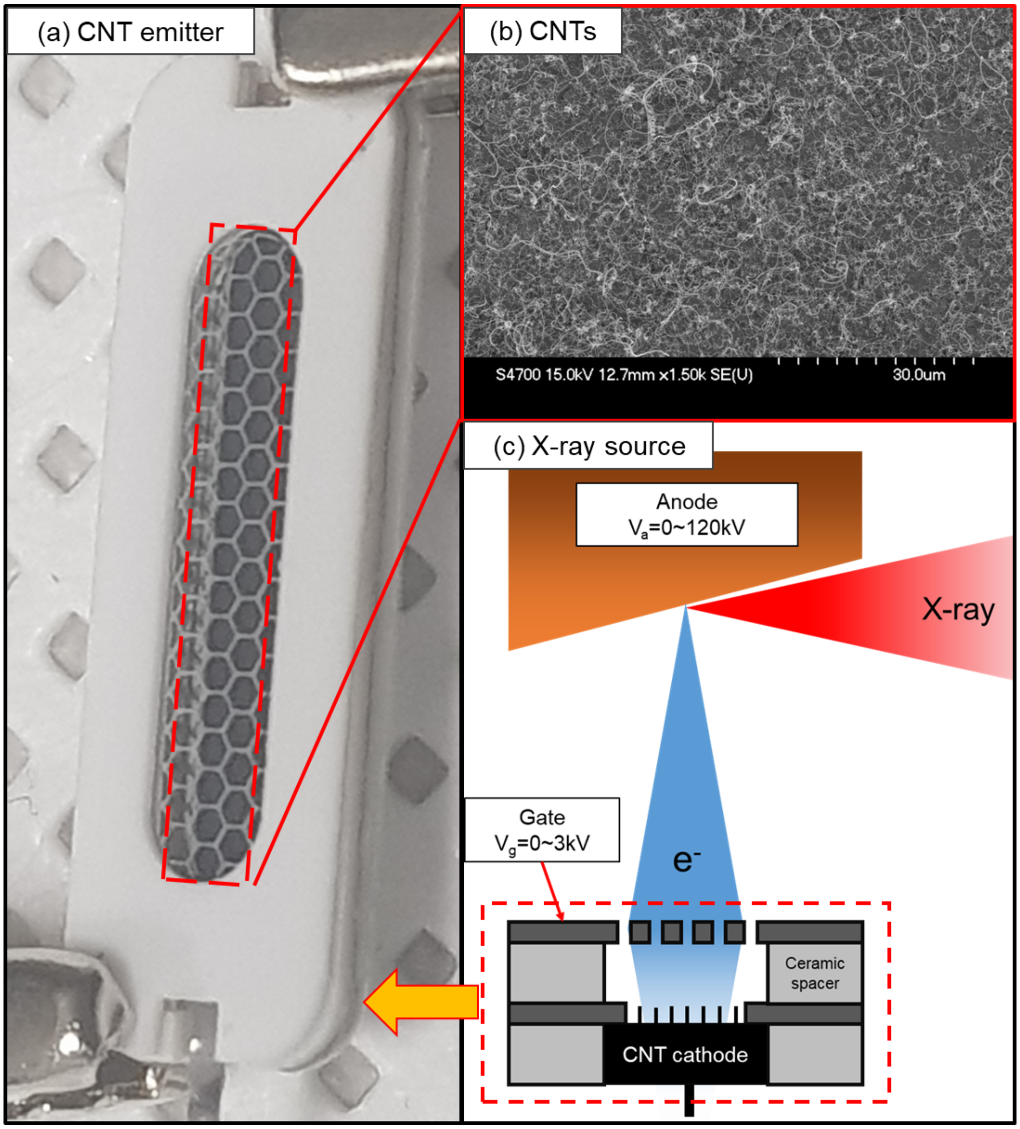

Figure 4. Structure of fabricated X-ray emitter. (a) Optical micrograph of a fabricated emitter. (b) Scanning electron microscope (SEM) image CNTs fabricated on a metal alloy (Fe-Ni-Cr) substrate with a spaghetti-like structure. (c) Working principle of X-ray source.

Figure 5 shows current-voltage (I-V) curves of emission currents versus gate voltage measured at the X-ray source of the D-CTS. At 1.38 kV, the emitter had an emission current of 3.4 mA. The corresponding current density is about 17.76 mA/cm2 for a gate field of 3.73 V/µm. For X-ray imaging, our target is to use an anode accelerating voltage of 120 kV and an anode current of about 12 mA achieved by applying a gate field of around 5 V/µm for 0.1 s (single scan). Our focal spot size is around 300 and 500 µm, respectively, for the vertical and horizontal axes [European Standard (EN 12543-5)] [12]. More details will be provided during the presentation.

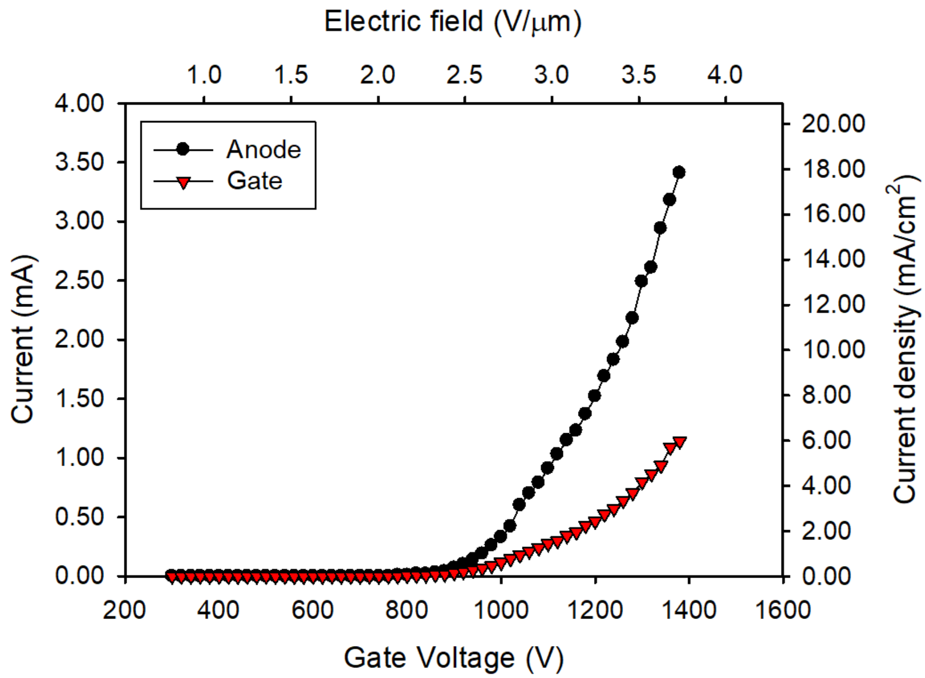

Fig. 5. The measured current-voltage (I-V) curves for the CNT based X-ray source. The maximum current density is 17.76 mA/cm^2 at about 3.73 V/μm. The threshold voltage, which is the voltage when the current density is 1 mA/cm^2, is measured to be about 2.84 V/μm.

4. CONCLUSION

We reported the design of a stationary tomosynthesis system employing an array of CNT-based X-ray sources that are triggered in sequence. By operating the multi X-ray source system, we can obtain many slices of X-ray images for the reconstruction of a 3D X-ray image within a short period of time, reducing patient X-ray dose. Getting digital high resolution 3D X-ray images without motion blur by this novel X-ray system will be a significant addition to medicine.

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