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Operating high-current field emitters in a commercial X-ray source

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***Abstract*— The need for a low-cost, low-dose 3D imaging capability, as an alternative to CT and MRI scanners, has driven the development of a multi-cathode, stationary Digital Tomosynthesis (s-DT) scanner. Demonstration experiments with an array of cold cathodes as electron sources have been reported by multiple groups. We report the operation of a device with a different field emitter geometry, at 60kV, to obtain images of a dental phantom, and the subsequent reconstruction of the raw images to obtain 3D slices. Failure mechanisms of the emitters, possible mitigation options, and the future outlook of emitter array devices are also discussed.**

Keywords*— *X-ray; digital tomosynthesis; field emitters; thermal management

I. Motivation

Diagnostic imaging in hospitals using CT and MRI is expensive and is often constrained by long waiting times. In addition, CT scans give a relatively high radiation dose. There is therefore a need for a lower-cost, lower-dose 3D scanner, especially in low and middle-income countries. The only current alternatives use 'Digital Tomosynthesis' (DT) and precisely move a heavy X-ray tube over a limited angle, but are expensive (~$450,000) and not portable (see Fig. 1 for the operating principle of DT). Also, a rotating stage increases the total scan time (the average duration of a DT chest scan is 10 sec), and the images can suffer from motion blur. One approach to reduce scan time and the costs associated with a precision motorized stage is to build a stationary, spatially distributed source which consists of multiple tubes [1]. Another approach to stationary Digital Tomosynthesis (s-DT) is to electronically steer a single beam over different angles [2-3]. Both these approaches were abandoned early-on because of the significant technical hurdles and apparent lack of cost reduction.

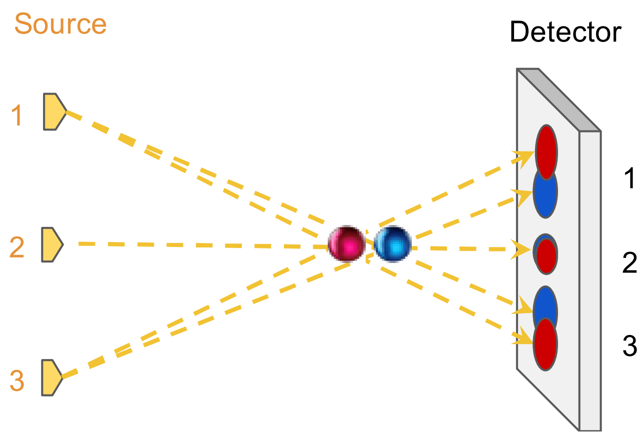

Fig. 1. Operating principle of conventional digital tomosynthesis: multiple scans are acquired by moving a single X-ray tube along an arc or a line. Shown are three source positions along with the resulting shadows projected onto three areas of the detector. Partial 3D information ('slices') are calculated using reconstruction algorythims.

II. Review of Field

Since having multiple thermionic X-ray tubes is not cost or space effective, several groups have reported demonstration experiments in which cold cathodes or field emitters were used as electron sources instead, with reported X-rays energies between 35-50 keV [1-3]. Each cathode (~1mm^2 in size) contained a large number (between 50,000 to 62,500) of micron-sized metal, or silicon tips or a forest of carbon nanotubes. The large density of emitters reduced the current per emitter to between 20-300nA. Not well reported in the literature are the effects of these extended-area sources on the resultant image resolution.

III. Geometry & Results

Our geometry is significantly different from the work reviewed above: we have replaced each multi-emitter cathode by one large emitter capable of delivering the required current (~100 µA). This low-density geometry simplifies the fabrication requirement by eliminating the need for focusing or gate layers, and also potentially improves cathode to cathode uniformity. The single-emitter per cathode approach also ameliorates image resolution degradation caused by large area sources.

A. Device Geometry

The emitter arrays tested here have a large pitch (1cm) between tall (>100µm) silicon emitters. The arrays (typically arranged along a 7x7 square grid) are fabricated using a wet-etch process and hence have a geometry characteristic of the crystal planes (Fig. 2).

These arrays (cathodes) are spaced from the anode from a few mm to a more typical 10 mm. A negative high voltage is applied to the cathode (0-60kV) while the anode is kept at ground (0V). Various configurations are used depending on the specific testing, and can include scintillator measurements, high-Z targets on the anode, and isolated anodes (i.e. a Faraday cup).

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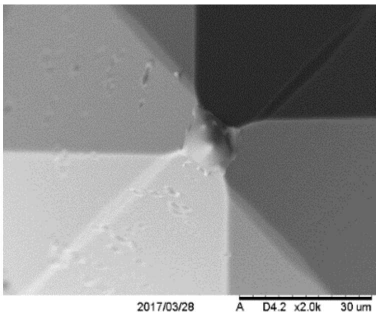

Fig. 2. Scanning Electron Microscope (SEM) image of a single emitter tip. Suspected thermal melting after sourcing ~100 µA of current is evident.

B. *Measurements & Reconstruction*

Emitter arrays were tested in a variety of configurations and environments, including a vacuum chamber with outer walls large compared to the cathode and anode diameters and vacuum levels in the 10^{-9} mbar range. In other tests, the emitter arrays were placed in smaller housings, more closely resembling what a final product would contain, and with relatively poor vacuum levels in the 10^{-7} mbar range.

So-called Fowler-Nordheim curves typically found in field emission literature were generally found to be unhelpful in characterizing these arrays. Non-exponential behaviors and saturation effects were seen in most measurements. These deviations from conventional "exponential" current vs. voltage (I-V) curves appears to be due to different emitters switching on during the measurement (and hence the number of active emitters is a function of the applied voltage), and due to a current dependence of the emission parameters (perhaps the work function).

While in this work, we report sufficient yield at 60kV to calculate 3D slices through dental phantoms (Fig 3a), the overall array performance was highly variable. Some emitters did not switch on, even at voltages where other emitters would die. Of the emitters that functioned, the peak-to-peak variation was large (>20%) and not stable over time.

IV. Emitter Failure Mechanisms

The main challenge during product testing was found to be the sudden failure of emitters during operation. Several mechanisms can contribute to emitter failure including high voltage breakdown, ion back-bombardment, heat gradients, and crystal distortion. In our case, thermal effects were found to be the dominant cause (again see Fig. 2).

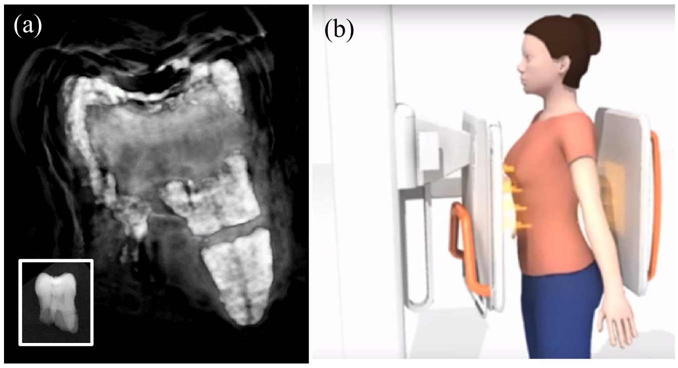

Fig. 3. (a) A single slice (calculated using DT) through a tooth (with a cracked root) imaged using the dental version of our source. The inset is a standard X-ray image. (b) Schematic of Adaptix flat panel source being used for a chest scan.

V. Summary & Outlook

The use of low-density, high current per emitter arrays offers the possibility of high-resolution, easy to control x-ray sources that enable stationary Digital Tomosynthesis, and hence portable 3D imaging in radiology. The drawback of our approach is the need for high yield and high uniformity across the emitter array. Both these potential problems can be resolved by a robust fabrication recipe. Ballast resistance [4], improved fabrication methods, and protective coatings should significantly improve device performance. The end goal is the realization of a stationary source, which will be highly portable (~20kg), low-cost (<$100,000), and 3D capable (Fig 3b).

References

[1] R. A. Robb, E. A. Hoffman, L. J. Sinak, L. D. Harris and E. L. Ritman, Proceedings of the IEEE, vol. 71, no. 3, pp. 308 (1983)

[2] M.J. Lipton, C.B. Higgins, D. Farmer, D.P Boyd, Radiology vol. 152(3), pp. 579 (1984)

[3] M.A. Speidel, B.P Wilfley, J.M. Star-Lack, J.A. Heanue, M.S. Van Lysel Med.Phys. vol. 33(8) (2006)

[4] X. Qian, A. Tucker, E. Gidcumb, J. Shan, G. Yang, X. Calderon-Colon, S. Sultana, J. Lu, O. Zhou, D. Spronk, F. Sprenger, Y. Zhang, D. Kennedy, T. Farbizio, Z. Jing, Med. Phys. Vol. 39 (4), pp. 2090 (2012)

[5] P.R. Schwoebel, J.M Boone, J. Shao, Phys. Med. Biol., Vol. 59, pp. 2393 (2014)

[6] A. Basu, M. E. Swanwick, A. A. Fomani, L. F. Velásquez-García, J. Phys. D: Appl. Phys., Vol. 48 pp. 225501 (2015)

[7] A. Ghis, R. Meyer, P. Rambaud, F. Levy, T. Leroux, IEEE Trans. Electron Devices Vol. 38, pp. 2320 (1991)

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