X-ray sources for high throughput and extreme resolution tomography of materials and structure

F. Yang*[1], E. Espes[1], U. Lundström[1], J. Hållstedt[1], B. Hansson[1], O. Hemberg[1], M. Otendal[1], P. Takman[1], T. Tuohimaa[1], A. Sofiienko[1]

[1]Excillum AB, Torshamnsgatan 35, Kista, Sweden

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Summary: Microfocus MetalJet D2+ benefits for X-ray imaging with its high brightness, which has been used for different applications of biology, medicine and materials science. The Excillum NanoTube N1 is the most advanced nanofocus X-ray tube on the market enabling unprecedented high resolution in Nano-imaging applications.

1. INTRODUCTION

X-ray tomography has been widely used to characterize 3D structure and process inside the object in different fields of scientific research, medical treatment and industry. Driven by the huge needs, the main advances are the increase in spatial and temporal resolution, alternative contrast modalities. As the critical element in the X-ray imaging system, the feature of X-ray source strongly influences the imaging quality.
The liquid-metal-jet anode (Metaljet) technology [1] has developed from prototypes into fully operational and stable X-ray tubes running in many labs among the world. Key applications include X-ray diffraction and scattering, but recently several publications have also shown very impressive X-ray computed tomography results using the Metaljet technology, especially in phase contrast imaging and X-ray microscopy [2][3].
To visualize fine details of the microstructure in the object, the imaging can be done either by using X-ray source with small spot size, or by using X-ray optics to build a microscope. Therefore, based on the advanced electron beam and target technologies, a new sub- microfocus x-ray tube has been commissioned and it reached an isotropic, extreme resolution of 150 nm line-spacing.

2. EXPERIMENTAL METHOD

The conventional X-ray tube generates X-rays when highly energetic electrons are stopped in a solid metal anode. The fundamental limit for the X-ray power generated from a given spot size is when the electron beam power is so high that it locally melts the anode. The MetalJet technology solves this thermal limit by replacing the traditional anode by a thin high-speed jet of liquid metal. Melting of the anode is therefore no longer a problem as it is already molten, and significantly (currently about 10x) higher e-beam power density can therefore by used.
Phase-contrast imaging (XPCI) achieves a significant improvement on the contrast and resolution of weakly absorbing materials with hard X-rays, however, the imaging quality, has been compromised by the low flux using conventional microfocus tubes or adding optical elements in order to gain contrast. Therefore, the high brightness MetalJet source paves the way for the development of laboratory-scale XPCI, by enabling shorter exposure time, higher imaging resolution and contrast. Besides, the high stability of the source at its top performance perfectly matches the requirement of the associated XPCI techniques.
MetalJet also fits well in the optics-based X-ray microscopy by reducing significantly the exposure time, thanks to the high brilliance Kα line of gallium, one of the main components in the liquid metal alloy. This sharp characteristic line, which is just above the absorption edge of copper, makes MetalJet beneficial for imaging copper with high contrast. Therefore, its advantage in imaging of electronics, i.e., copper in obsolete silicon materials.
To be able to benefit from the higher power-loading capability of the liquid-metal-jet anode, advanced electron optics had to be developed. The Excillum NanoTube is based on this advanced electron optics and the decent tungsten-coated diamond-transmission target. It has been experimentally proven to reach an extreme, isotropic resolution of 150 nm line-spacing. Additionally, its unique features also consist in the high stability for long-time imaging investigations, internal calibration of the current focal spot size before each scan. Till now it has been integrated into different Nano-CT systems and the publications [4] [5].

3. RESULTS

Fig. 1(a)) shows the quantitative analysis on the attention- and phase-contrast tomograms on multi- material phantoms, which were acquired by X-ray speckle-based (SBI) phase-contrast tomography based on MetalJet source [6]. MetalJet enables SBI at laboratory, given the high spatial coherence to resolve the µm-sized speckles and the high brightness to reduce exposure time while maintaining a sufficiently high image quality. Combing the multi-contrast modality information, the distinction and quantification among different material phases in the polymer colloidal suspension is possible, as shown in 2D-histogram of the tomograms (inset A). The 3D rendering of the segmentation in the volume is shown in inset B. Fig. 1(b)) shows one horizontal slice of the phase-contrast tomogram on Alder wooden sample, which was acquired by the NanoCT system with Excillum NanoTube at Fraunhofer IIS in Germany. The zoom-in window at the bottom-right corner clearly shows the sub-/-µm lumen structure within the fiber, as indicted by the yellow arrow.

References

[1] O. Hemberg, M. Otendal & H. M. Hertz, *Applied Physics Letter*, 83, 1483, 2003.

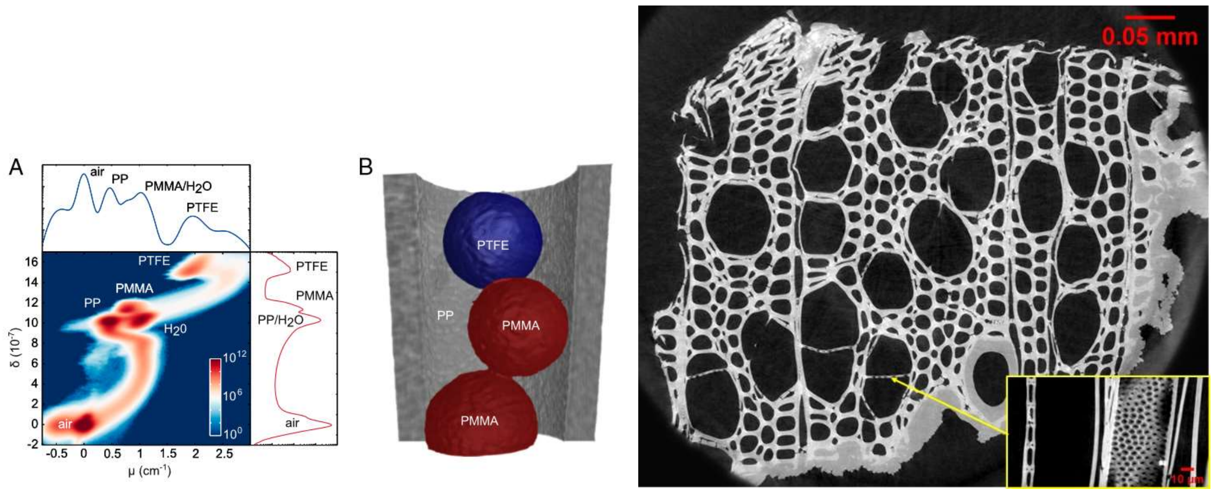
[2] J. Romell, W. Vågberg, M. Romell, S. Häggman, S. Ikram & H. M. Hertz, *Radiology*, 180945, 2018.

[3] A. Balles, C. Fella, J. Dittmann, W. Wiest, S. Zabler & R. Hanke, *AIP Conference Proc*, 1696, 020043, 2016.

[4] M. Müller, I. S. Oliveira, S. Allner, S. Ferstl, P. Bidola, K. Mechlem, A. Fehringer, L. Hehn, M. Dierolf, K. Achterhold, B. Gleich, J. U. Hammel, H. Jahn, G. Mayer & F. Pfeiffer, *PNAS* 114 (47), 12378-12383, 2017.

[5] C. Fella, J. Dittmann, D. Muller, T. Donath, D., Murer, T. Tuohimaa, A. Sofiienko, S. Zabler & R. Hanke, *Microscopy and Microanalysis,* 24(S2), 234-235, 2018.

[6] I. Zanette, M. C. Zdora, T. H. Zhou, A. Burvall, D. H. Larsson, P. Thibault, H. M.Hertz & F. Pfeiffer, *PNAS,* 112.41, 12569-12573, 2015.



(a) (b)

Figure 1: (a) Quantitative analysis using the 2-D histogram of the multi-contrast tomograms on multi-material phantoms (A), which were acquired by the SBI tomography based on MetalJet source, as well as the 3D rendering of the tomogram (B). (b) one horizontal phase-contrast nanoCT slice of Alder wooden sample and the zoom-in window on the fiber lumen of the vertical tomographic slice. Paganin single-distance based phase retrieval was applied to the raw data before FBP reconstruction. The effective pixel size is 300 nm. Image in courtesy by C. Fella from Fraunhofer IIS in Würzburg, Germany.

*e-mail: fei.yang@excillum.com