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X-ray Sources for High Throughput and Extreme Resolution Imaging

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The liquid-metal-jet technology has developed from prototypes into fully operational and stable X-ray tubes running in many labs over the world. As illustrated in Figure. 1a, a 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 liquid-metal-jet anode (MetalJet) technology solves this thermal limit by replacing the traditional anode by a thin high-speed jet of liquid metal (see Figure. 1b). Melting of the anode is therefore no longer a problem as it is already molten, and significantly (currently about 10x) higher e-beam power densities can therefore by used.

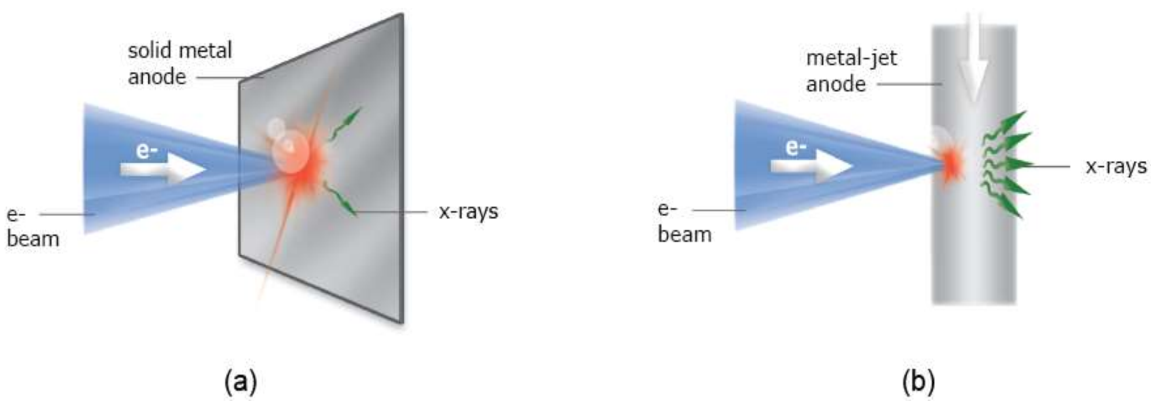

Figure. 1. The principle of a solid anode X-ray tube (a) and a liquid-metal-jet X-ray tube (b).

The assembly of a MetalJet source consists of an upper part that is the source head with the electron gun and the vacuum pump. This is like an open-type X-ray tube apart from the metal-jet anode that is formed by ejecting a ~200 µm diameter metal jet through a nozzle. To achieve 24/7 operation the100 % of the liquid-metal-alloy can be recirculated. This pump pressurizes the metal alloy to approximately 200 bar to allow the jet to reach a speed of ~75 m/s. The applications include X-ray diffraction and scattering, but recently several publications [1-5] have also shown very impressive imaging results using liquid-metal-jet anode technology, especially in 2-D or 3-D phase-contrast imaging and X-ray microscopy. MetalJet source also shows its applicability extending to industrial imaging applications..

Phase-contrast imaging achieves a significant improvement on the contrast and resolution of soft-issue with hard X-rays, however, the imaging quality, has been compromised by the low flux and brilliance using traditional microfocus tubes or adding optical elements. Therefore, the high brilliance liquid-metal-jet technology paves the way for the development of laboratory-scale phase-contrast imaging, especially its biomedical applications (Figure 2), 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 phase-contrast imaging techniques.

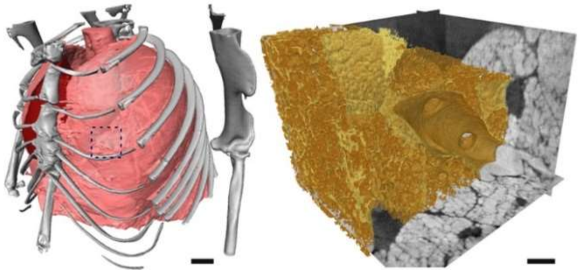

Figure. 2. 3D rendering of the “large FOV” volume (left) showing the thorax, containing automatically segmented bones (gray), the heart (red) and lung tissue (pink), and of the “zoom-move” dataset (right), obtained by the high-resolution propagation-based phase-contrast tomography of lung [4]

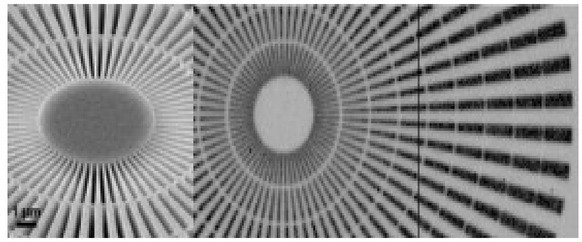

Figure. 3. SEM micrograph of a siemens star on the left and a projection radiograph captured using Nanotube on the right. The innermost features are 150 nm. From experiment in collaboration with Fraunhofer IIS (NanoCT systems) using a Dectris

Sharp characteristic line of Gallium, one of the main components in the liquid metal alloy, MetalJet fits well in the optics-based, i.e. X-ray zone plate, X-ray microscopy, while at the same time, reducing the exposure time and maintaining the ultimate resolution. Several application examples will be given during the conference, illustrating the capability of Metaljet in commercial or in-house built X-ray microscopy system. The Kα line of gallium, which is just above the absorption edge of copper, makes MetalJet beneficial for imaging copper with high contrast. Therefore, its advantage in electronic imaging, i.e., imaging copper in obsolete silicon materials, has also been shown [6].

Besides the high brightness microfocus Metaljet tube, based on the advanced electron beam technology, a new nanofocus x-ray tube, with tungsten-coated diamond-transmission target, has been published and reached an extreme resolution of 150 nm line-spacing (Figure 3). Additionally, the unique features of the nanofocus tube also consists in the internal calibration of the current focal spot size before each scan and the high stability for long-time, comparative investigations. The extreme small, true round focal spot of the Nanotube can be used for non-destructive, sub-µm resolution 2-D and 3-D imaging investigation.

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