doi:10.1017/S1431927622001751
Microsc. Microanal. 28 (Suppl 1), 2022

High throughput Imaging and Increasing Resolution of X-ray Imaging at High Acceleration Voltages

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Recently the interest in x-ray source technology has been intensified since several critical semiconductor metrology methods such as optical based scatterometry is starting to run out of steam [1]. Furthermore, with introduction of advanced strain engineering and 3D structures in manufacturing new challenges for semiconductor metrology are emerging. Proposed solutions involve a variety of techniques including x-ray-based methods, however a main problem with most of those is the very low throughput since conventional X-ray tubes are very limited in x-ray output such as flux or brightness.

As illustrated in Fig 1a, a conventional X-ray tube generates X-rays when highly energetic electrons are stopped by 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. This damage or destroys the anode which replacement of anode or sometimes the whole x-ray source. 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 thereby no longer a problem as it is already molten. Moreover, the high speed of the jet (in the range of 100 m/s) effectively transports the heat away and ensure an optimal surface constantly being regenerated for the electron impact. Thereby, significantly (currently about 70x) higher e-beam power densities can therefore be applied.

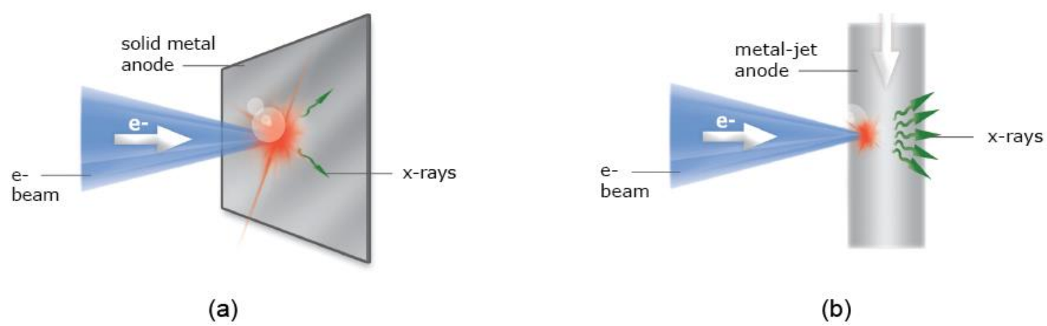

Figure 1. The principle of a solid anode X-ray tube (a) and a liquid-MetalJet X-ray tube (b).

We recently introduced two products that will improve the throughput and resolution needs of the semiconductor industry. MetalJet E1+ operates at 160kV and 1000W power on a 30 µm X-ray spot using 24keV energy alloy. Also, we introduced Nanotube N3 that operates at 160kV and provides a 150nm resolution for high resolution imaging needs.

The highest available resolution in lab-based X-ray microscopes is achieved with zone-plate based projection microscopes [7] Such microscopes, however, typically use Cu Kα radiation which is not so well suited to resolve copper structures in silicon due to poor contrast between copper and silicon. As illustrated by Fig. 2, the Kα of Ga used in MetalJet sources, is just above the K-absorption edge of Cu [8] and thus much better suited to create a sufficient contrast between copper and silicon. First x-ray microscopy instrument using the MetalJet for Cu interconnect inspection was recently presented [9].

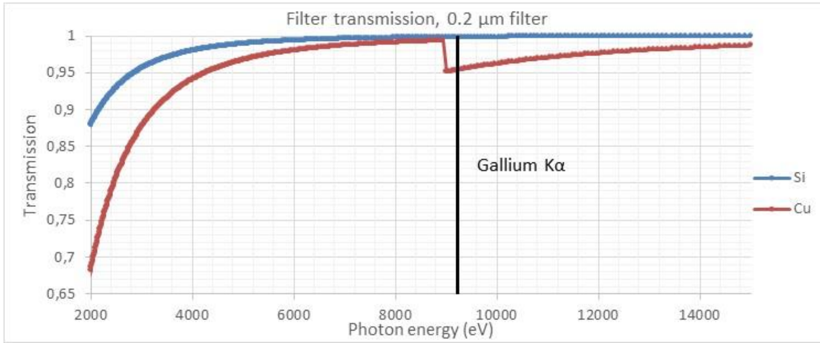

Figure 2. X-ray transmission trough a 0.2 μm filter of silicon and copper. The black line indicates the Kα of gallium [8].

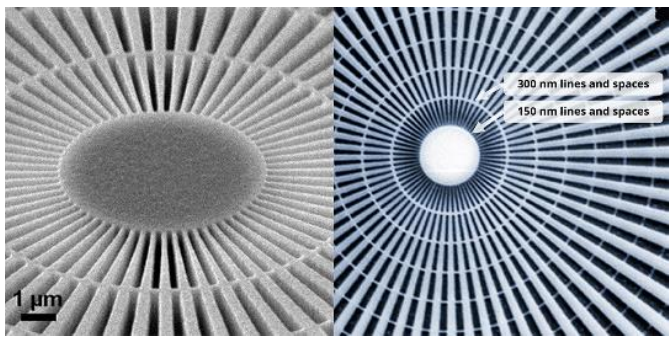

Figure 3. SEM micrograph of a Siemens star and an X-ray projection radiograph is shown on the right.

The Excillum NanoTube N3 enables industry-leading resolution and stability in geometric-magnification X-ray imaging systems with no need for manual tuning. The Excillum NanoTube N3 is based on advanced electron optics and the latest tungsten-diamond transmission target technology. Automatic e-beam focusing, and astigmatism correction ensures that the smallest possible, truly round spot is achieved every time, every day.

The NanoTube N3 also has the unique feature of internally measuring and reporting the current spot size. In addition, advanced cooling and thermal design results in extreme stability over long exposures. This enables an unprecedented true resolution of 150 nm lines and spaces. In the publication we will discuss how MetalJet based x-ray tubes are reliable, robust high-end alternative to other lab-based X-ray sources and we will discuss some results that our customers shared that show the value of these sources in X-ray labs and industry worldwide.

https://doi.org/10.1017/S1431927622001751 Published online by Cambridge University Press

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