Optimization of Focused Ion Beam performance.

C.W. Hagen and P. Kruit.
Delft University of Technology, Fac. Applied Sciences, Particle Optics Group, Lorentzweg 1, 2628CJ Delft, The Netherlands.

In the rapidly expanding field of nanoscience and nanotechnology one needs tools capable of fabricating structures of sub-10 nm size. Focused Ion Beam (FIB) systems have that potential. However, it will be necessary to improve the design of the ion beam column such that the optimum performance is achieved.

We first consider a two-lens system based on a Gallium Liquid Metal Ion Source (LMIS), which is the most frequently used ion source in FIB's. The smaller the spot into which a particle beam is focused, the smaller the probe current will be. For relatively large ion probes the current in the probe is determined by the chromatic aberration of both lenses and the angular current density at the current limiting aperture. This is a well known fact and it has been described by many workers[1]. However, going to smaller spot sizes the probe current is no longer determined by the angular current density but it is limited by the source brightness, and the chromatic aberration of the probe forming lens. This fact apparently has been overlooked by many FIB designers, e.g.[2]. In fig. 1 we show the current versus probe size for a two lens system with ion energy 30 keV, chromatic aberration coefficients of both lenses 30 mm, energy spread 5 eV, reduced brightness 10^6 A/(m^2srV), and angular current density 20 μA/sr, for the two extreme cases: brightness limited at small spot sizes and low currents, and angular current density limited at large probe sizes and high currents. The maximum current in a probe is always the one given by the lowest of the two lines in fig. 1. It demonstrates the importance of the source brightness as the probe current determining parameter in FIB's with a sub-10 nm probe size.

The same can be done for a two-lens system based on a Helium Gas Field Ion Source (GFIS), such as the recently introduced Orion He-ion microscope[3]. In figure 2 the probe current versus probe size relation is shown for ions of 20 keV, with 1 eV energy spread, reduced brightness of $2\cdot10^9$ A/(m^2srV), and angular current density 2.5 μA/sr (data taken from[3]). Assuming the chromatic aberration coefficients of fig. 1, it is seen that in such a point-source system the probe current is limited by the angular current density, for probes larger than 0.3 nm. Please note that we neglected diffraction and the spherical aberration contribution, which, however, only contributes to the probe size at higher currents.

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[1] K. Sakaguchi and T. Sekine, J. Vac. Sci. Technol. B16, 2462-2468 (1998), and refs. in there.
[2] J. Gierak, A. Septier, and C. Vieu, Nucl. Instrum. Methods Phys. Res. A427, 91-98 (1999).
[3] B.W. Ward, J.A. Notte, and N.P. Economou, J. Vac. Sci. Technol. B24, 2871-2874 (2006).

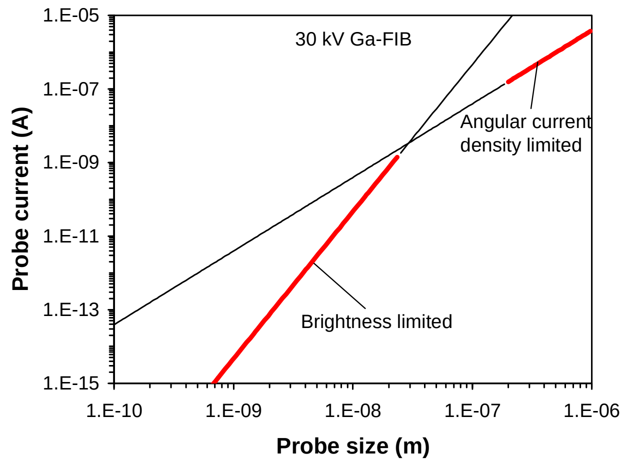

Figure 1. Probe current versus probe size in a two-lens system with a Ga-LMIS. The two lines indicate the extreme cases: brightness limited and angular current density limited. The thick solid parts of the lines indicate the regions where the extreme cases are approximately valid. The intermediate probe sizes will have to follow from a more exact theory. For nano-probes the current is brightness-limited.

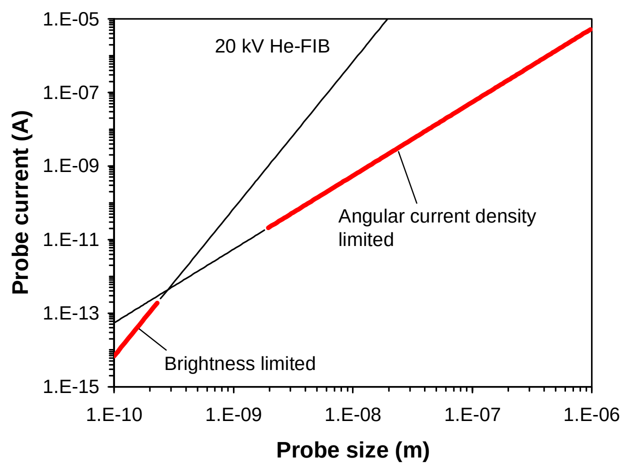

Figure 2. Same as in figure 1 but now for a two lens system with a He-GFIS, such as in the Orion He-ion microscope[3]. For the assumed values of the chromatic aberation coefficients the current is limited by the angular current density for probes larger than 0.3 nm.