Focused ion beam based on laser cooling: towards sub-nm ion beam milling

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Focused ion beams (FIBs) are indispensable tools in the semiconductor industry and materials science, because they can create structures at the nanometer length scale without lithography. The current state of the art FIB for milling purposes is the liquid metal ion source, which can reach a spot size of 5 nm with a Ga^+ ion beam containing 1 pA. Recently, ideas have come up to create a FIB based on photo-ionization of a laser cooled and compressed atomic beam [1]. Here we present simulations and calculations on the formation and focusing of an ion beam created from such a laser-intensified atomic beam of rubidium which originated from a Knudsen cell.

In a FIB based on laser cooling, ions will be produced at random locations in the ionization region after the magneto optical compressor. Therefore, so-called disorder-induced heating will occur due to the mutual Coulomb interaction between the ions at random locations [2, 3]. This heating can be suppressed by a sufficiently large electric field, which lowers the ion density and creates a so called pencil beam. However, due to the photo-ionization process, the energy spread of the ions, and thus the amount of chromatic aberration of the downstream lens system, will be proportional to this electric field. Therefore an optimum value of this electric field will exist, which leads to the smallest spot size. The process of disorder-induced heating was investigated with particle tracing simulations. They were used to find a relation between the current and flux density of the ion beam and the electric field needed to suppress disorder-induced heating. This relation was used as input for analytical calculations of the minimum achievable spot size, which included the effects of the initial temperature and flux density achieved after the magneto optical compressor and chromatic and spherical aberration of a realistic electrostatic lens system. Figure shows the result of these calculations in terms of the spot size that can be reached with a 1 pA beam as a function of the initial temperature and flux density of the atomic beam.

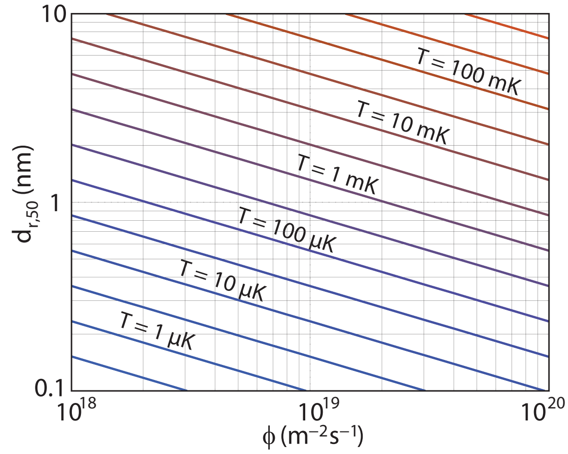

Figure 1: *The expected spot size (50% diameter) as a function of the initial flux density ϕ and temperature T, which are expected to be 5×10^{19} $m^{-2}s^{-1}$ and 1 mK.*

A very important part of the source discussed here is the Knudsen cell and especially the collimation tube connected to it. From this collimation tube, a thermal atomic beam of Rubidium will effuse that is laser cooled and compressed in the next stage. The properties of this atomic beam, such as the flux, transverse velocity distribution and brightness will influence the performance of the rest of the setup. We will show laser-induced fluorescence measurements of these properties and discuss their impact.

References

[1] B. Knuffman, A.V. Steele and J.J. McClelland, Journal of Applied Physics **114**, 044303 (2013)
[2] S.B. van der Geer *et al.*, Journal of Applied Physics **102**, 094312 (2007)
[3] L. Kime *et al.*, Physical Review A **88**, 033424 (2013)