Photoionization of a laser-intensified atomic beam: prospects for high resolution focused ion beams

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Focused ion beams (FIBs) are indispensable tools in the semiconductor industry because of their ability to image and modify structures on the nanometer length scale. In present days the liquid metal ion source (LMIS) and the gas field ionization source (GFIS) are the foremost sources in high resolution focused ion beams. The extremely high resolution of the GFIS makes it the preferred source for imaging. However, since its application is currently limited to helium or neon ions it is not suitable for milling applications, due to its low sputter yield and the appearance of subsurface damage. Therefore the LMIS, with a resolution of 5-10 nm, is the industry standard when it comes to FIB milling. With the ongoing drive towards smaller features on integrated circuits this means there is a need for new types of ion sources for high resolution milling applications.

A good candidate for the outlined task is an ion source based upon photoionization of a laser-intensified atomic beam, which is the topic of the work presented here. Such a beam is created by means of laser cooling and compression of a thermal atomic beam (^{85}Rb in our case) which is created by a collimated Knudsen source. This process is expected to give an atomic beam with an equivalent reduced brightness of 10^7 A $m^{-2}sr^{-1}eV^{-1}$.[1]

Here we will report on the strategy that will be followed in order to transfer this atomic beam in a high brightness ion beam by means of photoionization. By numerically solving the so called optical Bloch equations, which were adapted to include the ionization process, it was found that complete ionization of the atomic beam is possible when an ionization laser (480 nm) is applied with an intensity of 10^{11} W m^{-2}. In order to reach this high intensity the use of a build-up cavity will be necessary.

An additional problem in maintaining the high brightness is disorder-induced heating. Due to the disorder in the positioning of the ions within the beam, the beam will heat up which will have disastrous effects on the beams brightness. This problem was investigated with particle tracing simulations, which revealed a strategy to suppress the heating by creating a so called pencil beam[2]. Analytical calculations which included the limited brightness of the beam and chromatic and spherical aberrations of a realistic lens system showed that by following this strategy a spot size of 1 nm is possible with a 30 keV beam containing 1 pA.

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[1] S.H.W. Wouters et al., Phys. Rev. A 90, 063817 (2014)
[2] G. ten Haaf et al., J. Appl. Phys. 116, 244301 (2014)