Application of laser-cooling and compression to create a high resolution focused ion beam

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Ultra-low temperature (1 mK) ion beams can be created by photo-ionization of a laser cooled and compressed thermal atomic beam. When such an ion beam is introduced to a lens system, a focused ion beam (FIB) is formed which can be used to image, etch and deposit structures on the nanometer scale. Calculations and simulations have shown that for rubidium-85 an atomic beam brightness of 10^7 A/m^2 sr eV can be achieved within a compact 7 cm long magneto-optical compressor [1]. Particle tracer simulations taking all lens aberrations into account indicate[2] that such an atomic beam, once fully photo-ionized, can be focused to a spot of 1 nm at a current of 1 pA or 5 nm at currents up to 20 pA, surpassing the industry standard for milling and deposition: the gallium liquid metal ion source.

Figure 1 shows a schematic overview of the new ion source under development: the starting point is a high-flux atom source which consists of a Knudsen cell connected to a collimating tube. The brightness of the atomic beam is increased by laser cooling and compression in the transverse direction by means of a magneto-optical compressor. The resulting cold beam of atoms is photo-ionized inside an electric field to suppress disorder-induced heating caused by the non-uniform Coulomb interactions between the ions. The ion beam is then focussed to a nanometer-sized spot by means of a an electrostatic lens column.

This contribution reports on the experimental realization of the proposed device by means of the development of the high-flux collimated atom source and the 3 T/m magnetic quadrupole required for laser cooling and compression. Also the results of laser cooling and compression experiments are presented.

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[1] S. H. W. Wouters, G. ten Haaf, R. P. M. J. W. Notermans, N. Debernardi, P. H. A. Mutsaers, O. J. Luiten, and E. J. D. Vredenbregt, Phys. Rev. A 90, 063817 (2014).

[2] G. ten Haaf, S. H. W. Wouters, S. B. van der Geer, E. J. D. Vredenbregt, and P. H. A. Mutsaers, J. Appl. Phys. 116, 244301 (2014).

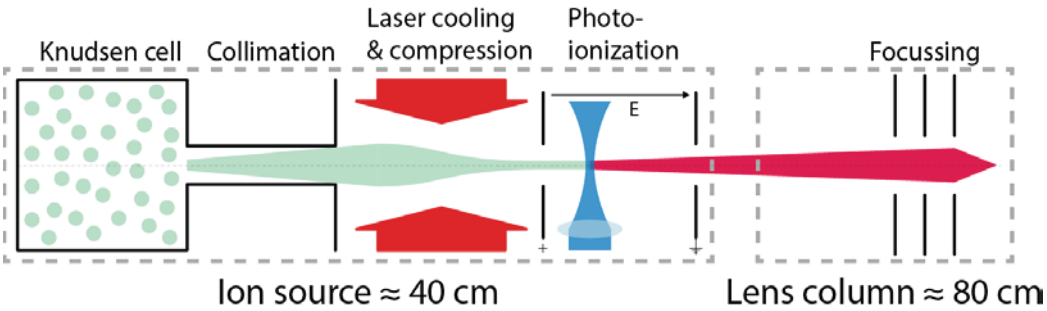

Figure 1: Schematic overview of the Atomic Beam Laser-cooled Ion Source.