Using cold atoms as a bright CW source for monochromatic ion and electron beams

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Introduction

State-of-the-art thermal ion and electrons sources have reached a level of performance primarily limited by a high source temperature. Here we report progress in using ionized ultra-cold atoms to create continuous ion and electrons sources. Strong focusing of low energy beams are shown to be possible using SIMION and General Particle Tracer (GPT) charged particle optics software products. simulations.

Traditional hot ion and electron sources have reached achievable limits in terms of source brightness and energy spread. Here we define brightness as,

$$\text{Brightness} : B = \frac{I}{8\pi^2 \epsilon_x \epsilon_y} = \frac{I}{A\Omega U} \quad (1)$$

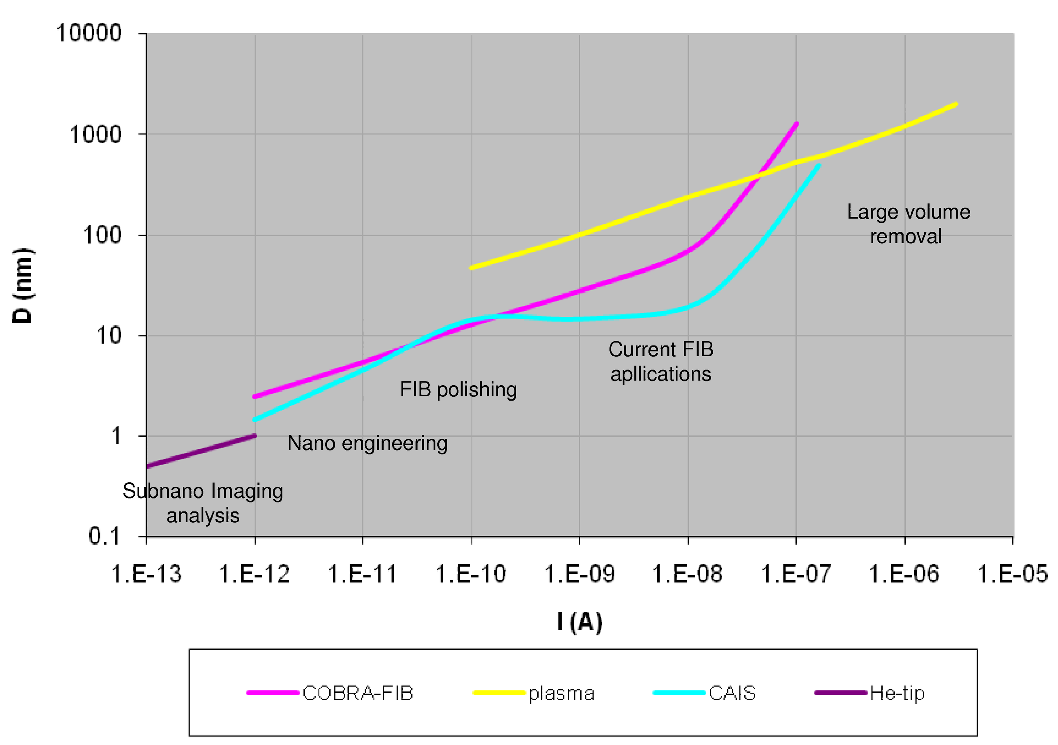
$$\text{Emittance} : \epsilon_i = \sigma_i \sigma_{v_i} \sqrt{m/2} \quad (2)$$

The energy spread, ΔE, limits the energy resolution and achievable focusing properties:

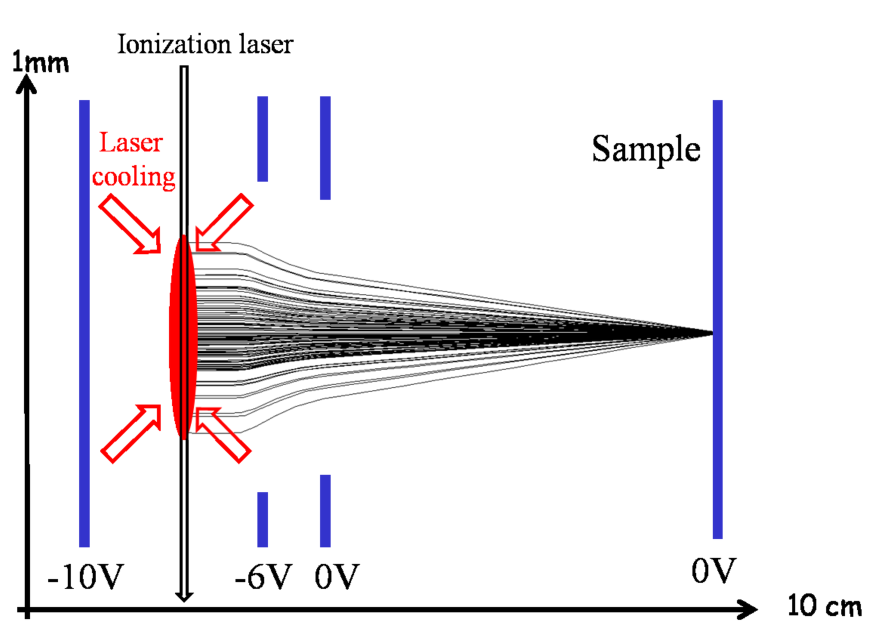
$$d_{chr} = C_{chr} \alpha_i \frac{\Delta E}{E} \qquad d_{sph} = \frac{C_{sph}}{2} \alpha_i^3, \quad (3)$$

where α is the half-angle subtended by the beam acceptance aperture at the emitter[1]. Brightness is a conserved quantity useful for source characterization.

Previous work on ultracold electron sources by Bömmels *et al.* produce low currents ($I < 180\,\text{pA}$) and low beam enegies ($E < 180\,\text{meV}$)[2]. Previous work on ultracold sources at Eindhoven have created ion and electron bunches with 100 nA currents suitable for single-shot diffraction studies.[3–5] Work on cold ion sources has also been undertaken by the McClelland group at NIST, using Cr and Li[6–8]. They have recently achieved coupling of a cold ion source to a commercial ion microscope assembly for pA currents and imaging resolution up to 27 nm[9].

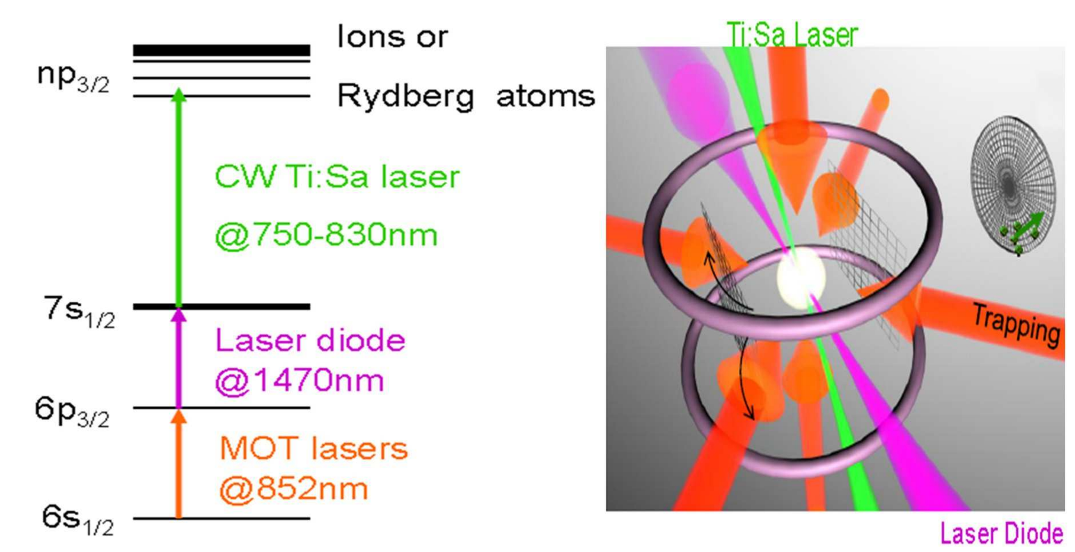


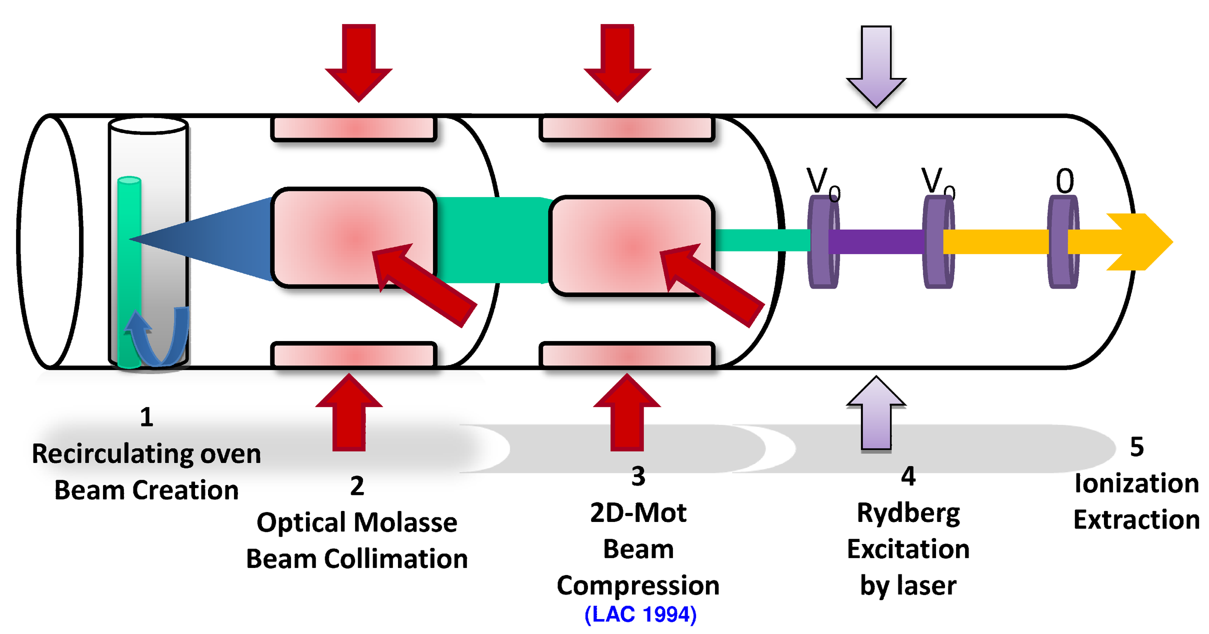
Ion Trajectory Simulation

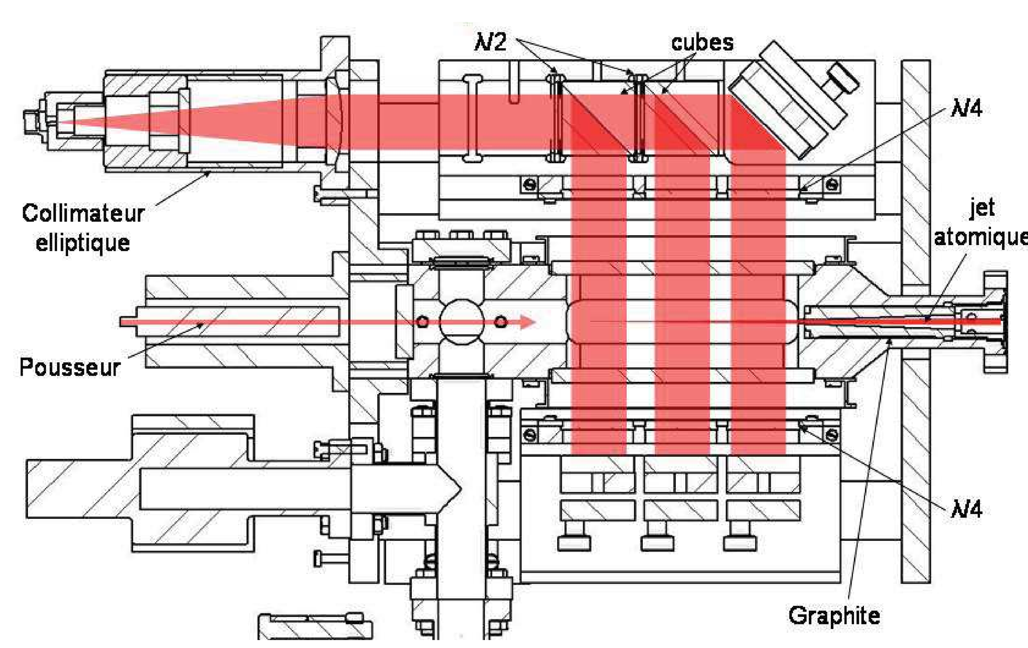


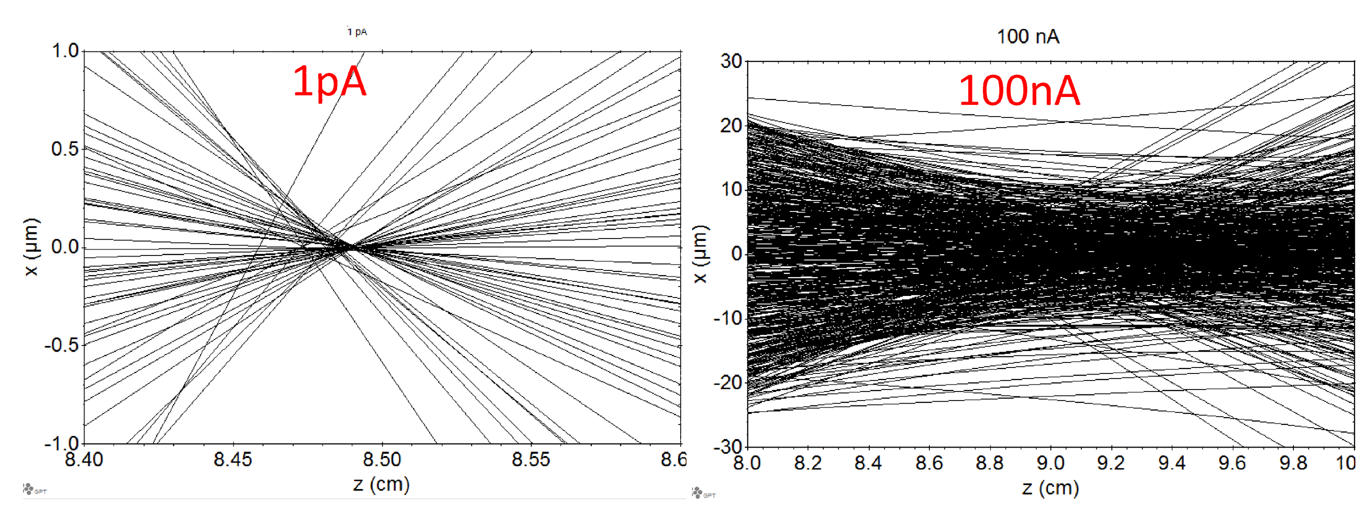
Experimental Setup

This new source uses a large laser cooled sample of Cs atoms, promoted to Rydberg states before undergoing field ionization. The low velocity dispersion and large sample size should allow for superior performance, in terms of both brightness and energy dispersion, ion and electron sources. The use of cold atoms should avoid aberrations due to Coulomb repulsion common to thermal sources. Two different cold atom sources are in progress, one for ions and the other for electrons.









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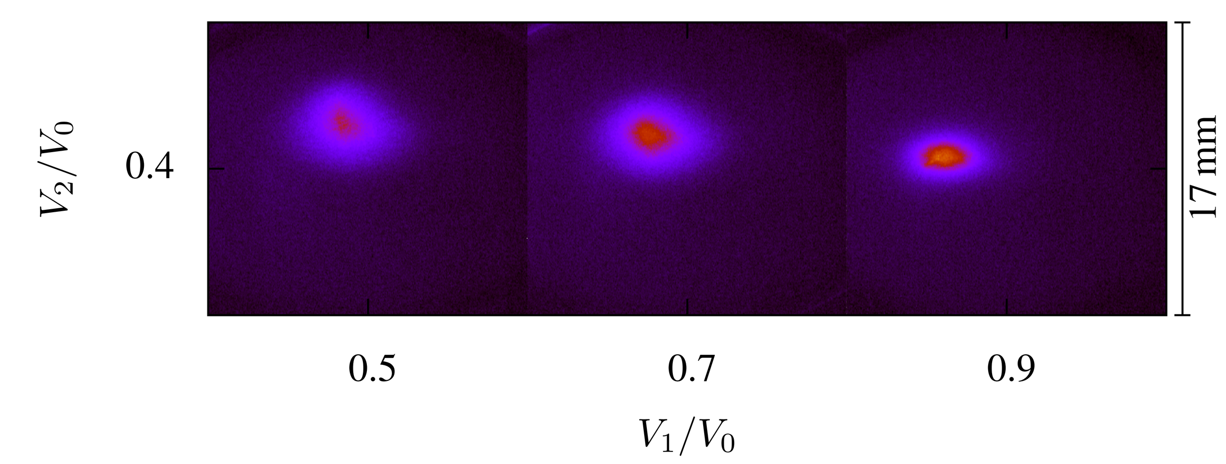
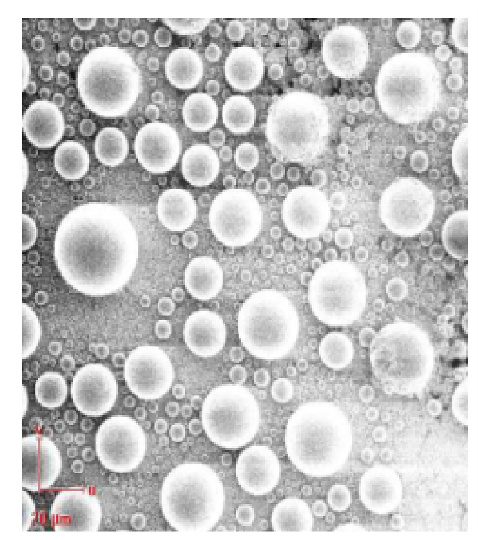
Ion focusing

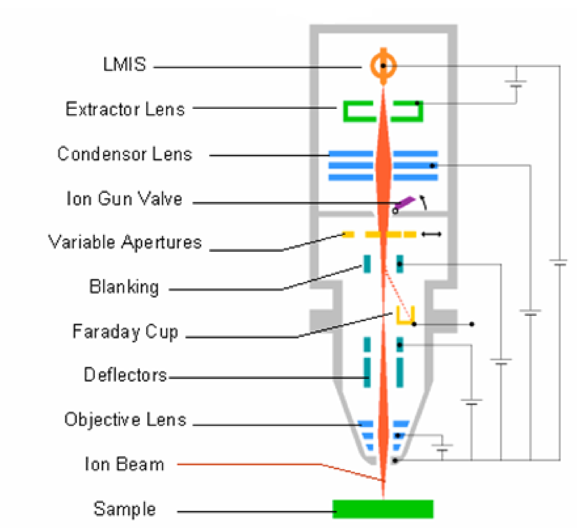
Preliminary focusing results are shown below, varying the voltage on the third grid from $0.5\,V_0$ to $0.9\,V_0$ in $0.2\,V_0$ steps, with the last grid at $0.4\,V_0$ and $V_0 = 500\,\text{V}$ to achieve more than a factor of two in focusing.



Future Directions

The cold atom ion source produces up to 10^{14} atoms/sec in a collimated beam and is currently undergoing characterization. Coupling the cold atom source to a commercial microscope column should allow for improved imaging. The cold electron source is under construction, with planned experiments involving electron controlled chemical lithography (ECCL), and STEM coupling for electron energy-loss spectroscopy (EELS) in the near-term.





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