MOTIS: Focused Ion Beams from Laser-Cooled Atoms

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Focused ion beams (FIBs) are an invaluable tool for the creation and observation of materials with nanoscale feature sizes. However, ion sources capable of both high brightness and low emittance operation are difficult to realize, with practical sources limited to very few atomic species. Recently, we have developed a new type of low-emittance, high-brightness ion source based on the ionization of magneto-optically trapped atoms.[1] Using this source, known as a magneto-optical trap ion source (MOTIS), we have demonstrated nanoscale-focused ion beams of both lithium and chromium.

The MOTIS uses laser-cooled neutral atoms that are photoionized to create an isotopically pure beam of ions whose ion optical properties are comparable to those of liquid metal ion sources. The MOTIS paradigm can be extended to create ion sources from any atomic species that can be laser-cooled, a list that currently consists of over 22 species, including alkalis, alkaline earths, noble gases, plus several metals and rare earths. This flexibility allows the atomic species of the source to be tailored to the specific application, e.g., microscopy with light ions, milling with heavy ions, and nanoscale implantation of a variety of elements. In addition, the inherently low energy spread enables the creation of high-resolution focused ion beams at low energy.

We report on the construction and performance of MOTIS-technology-based lithium and chromium FIBs. Each FIB platform consists of a chromium or lithium MOTIS that is integrated with a conventional ion optical column. We will present results of microscopy using chromium and lithium beams and a characterization of focal spot sizes. We will also examine applications of this technology, such as beam-activated surface chemistry, direct deposition and removal of materials, and deterministic single ion implantation.

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[1] J. L. Hanssen, S. B. Hill, J. Orloff, and J. J. McClelland, *Nano Letters* **8**, 2844 (2008).

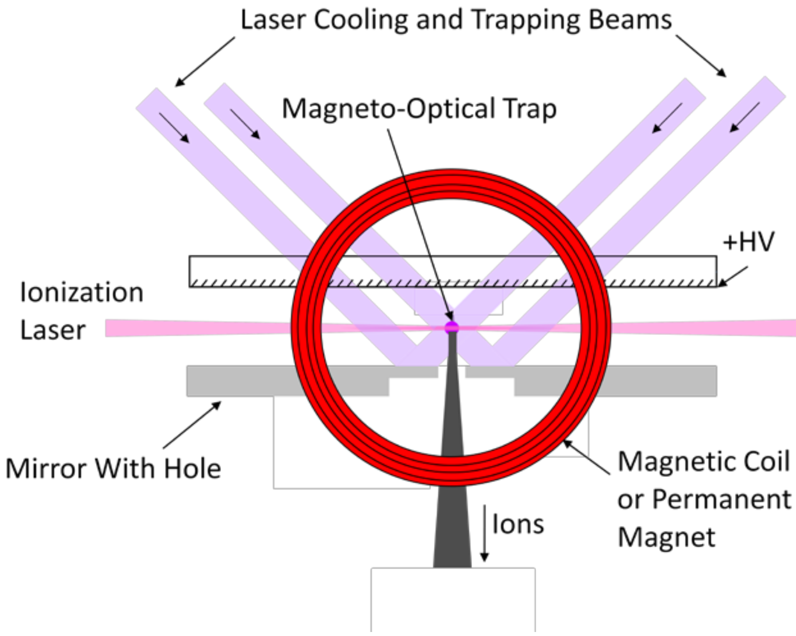

Figure 1. Schematic of the Magneto-Optical Trap Ion Source. Neutral atoms from an atomic beam are trapped and cooled to a few hundred microkelvin in a magneto-optical trap, where they are ionized and extracted. Six counterpropagating laser beams (two perpendicular to the page, not shown), together with a quadrupole magnetic field form the trap. An additional laser beam performs the ionization. A mirror with a hole and a fused silica window coated with indium tin oxide form the extraction electrodes.

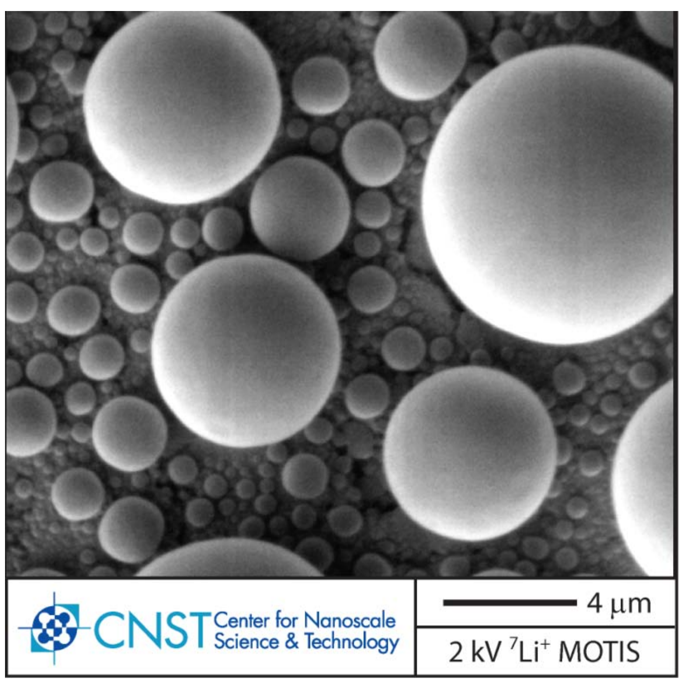

Figure 2, Image of Sn balls acquired with a 2 kV, 2 pA $^{7}Li^{+}$ beam.