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## Nanofabrication at the sub 10 nm length scale using helium ions

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The helium ion microscope (HIM)) takes advantage of an anatomically sharp source to emit a beam of focused He ions so the microscopist today can go beyond imaging resolutions achieved in the Scanning Electron Microscope (SEM). Imaging with ions rather than electrons offers many advantages including the ability to image uncoated non conducting samples at high resolution without damage. Additionally, helium ions can be used to sputter material for nanolithography and nanopatterning applications where sub 10 nm structures are desired<sup>1</sup>.

A gallery of helium ion microscopy results will be presented to showcase the capability and performance of this novel microscope. While the HIM has proven invaluable at characterizing uncoated biological samples as well as other soft materials,, the focus off this paper is to highlight nanofabrication capabilities at sub 100 nm length scales. Features size and material removal via conventional Ga focused ion beam (FFIB) systems is now surpassed using HHIM. One emerging research area is in the fabrication of nanophotonic and plasmonic devices. Increased near-field resolution and enhanced transmission is achieved using complex fractal shapes and reduced aperture sizes<sup>2</sup>. Figure 1 shows the third iteration of the Hilbert curve milled through 40 nm thick Al using A) Ga ((liquid metal ion source or conventional FIB technology). The insets, B) and C), represent the same structure patterned using He from the gas field ion source technology found in the HIM. The features in B) and C) were milled adjacent to the Ga milled structure in order to demonstrate the ability to pattern smaller structures of higher fidelity using the HIM-FIBB. Edge structures are sharper and well defined in the smaller fractal aperture using helium while material redistribution and rounded features result in the larger aperture milled with gallium.

In addition to fabricating resonant nanostructures, the HIM-FIB has touched a wide array of other nanopatterning applications. HIM-FIB has been used to nanomachine 5 nm pores through 100 nm thick Au films for single molecule detection in microfluidic applications. Current efforts use time consuming TEM with irreproducible results. Ion beam lithography is another application where HIM has emerged as an advanced tool compared to traditional electron beam techniques<sup>3-4</sup>. Combined with higher sensitivity, lower proximity effects and a sub nanometre probe size, HIM lithography provides the highest resolution for lithography. Helium has also proven a key technology for advancing graphene research. Suspended graphene nanoribbons only 5 nm wide with high aspect ratios have been achieved by varying the He ion dose in the HIM<sup>5</sup>. In summary, the application front has reached new levels using helium ions and the Orion Nanofab is now presented as the next generation microscope for nanopatterning technology.

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