Advanced Ion Microscopy and Ion Beam Nano-engineering Focus Topic
Room On Demand - Session HI-Contributed On Demand

Advanced Ion Microscopy & Nano-Engineering Contributed On Demand Session

HI-Contributed On Demand-1 Applications of the Cesium Low Temperature Ion Source*, **Adam Steele**, A. Schwarzkopf,* zeroK NanoTech Corporation*; B. Knuffman,* zeroK NanoTech Corporation

We present the latest results from FIB and FIB+SIMS systems featuring the Cs^+ Low Temperature Ion Source (LoTIS). When compared with other ion sources LoTIS can deliver very small spot sizes, high sputter rates, high yields of secondary ions, and a wide range of beam currents from pA to many nA.

We will review applications of LoTIS tested on a single beam FIB system. These include high resolution imaging, long depth-of-focus imaging, successful circuit edit operations on 10 nm node integrated circuits, high-precision machining of gold, and demonstration of the high grain-visibility imaging in copper and steel offered by LoTIS.

Previously we reported spot sizes as small as (2.1 ± 0.2) nm (one standard deviation) are observed with a 10 keV, 1.0 pA beam. Brightness values as high as (2.4 ± 0.1) × 107 A m-2 sr-1 eV-1 are observed near 8 pA [1]. The measured peak brightness is over 24 times higher than the highest brightness observed in a Ga liquid metal ion source (LMIS). This system has generated beam exceeding 11 nA. LoTIS is composed of a several discrete stages that collect, compress, cool and finally photoionize a cesium atomic beam [2].

The talk will conclude by reviewing our progress in the construction of a high resolution FIB/SIMS hybrid system called SIMS:ZERO; this system is being built in collaboration with the Luxembourg Institute of Science and Technology (LIST). SIMS:ZERO will be capable of high-resolution FIB operations while also providing a new material analysis information channel through the application of Secondary Ion Mass Spectrometry (SIMS). For many target materials Cs+ will generate orders or magnitude more secondary ions than other ion ions. In addition, LoTIS is can provide over 100x more current into a given spot than alternative Cs^+ ion sources.

[1] A. V. Steele, A. Schwarzkopf, J. J. McClelland, and B. Knuffman. Nano Futures. 1, 015005 (2017).[2] B Knuffman, AV Steele, and JJ McClelland. J. Appl. Phys. 114, 4 (2013).

HI-Contributed On Demand-7 Focused Nanoscale Machining via the Gas Field Ion Microscope with Laser and Reactive Ion Assist: Joint Experimental and Simulation Investigations*, **Jack Lasseter**, P. Rack,* University of Tennessee Knoxville

Focused ion beams utilizing light atoms like helium and neon are able to be used in materials processing providing nanoscale manipulation from milling, to reactive ion etching, to 3D nanomaterials deposition. However very light atoms like helium require high doses for milling applications and thus can suffer sub-surface implantation effects like substrate damage through bubbling, so nanofabrication can require extra care. Thus, reactive ion and laser-assisted focused ion beam techniques can be used to enhance the sputtering and thus minimize sub-surface damage. To emulate focused ion beam nanomachining, we have developed the EnvizION simulation code, which at its core uses SRIM/TRIM statistical descriptions of ion-solid interactions to model 3D substrates through a voxelized substrate.

The nanoscale resolution and ability to image insulating samples provides ion microscopes formidable nanofabrication abilities. In this presentation we will overview our groups recent experimental work in gas field ion nanomachining and complement the experiments with various EnvizION simulations. Applications include defect generation in two-dimensional materials such as transition metal dichalcogenides, gas assisted deposition to print 3D PtC structures from a $(CH_3)_3Pt(C_pCH_3)$ gas precursor, and laser + XeF_2 gas pulsing methods to enhance the material removal rate of WSe_2 and SiO_2. The laser assisted XeF_2 has been shown to enhance the etch yield by 9x relative to a pure helium sputtering process. Finally, we have incorporated reactive gas etching in the EnvizION simulation and have performed an exhaustive comparison with both Ga^+ and Ne^+ milling and XeF_2 reactive etching. Since the subsurface damage is a function of the dose these types of enhancements are stepping stones to overcome damage related roadblocks.

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HI-Contributed On Demand-10 Imaging of SARS-CoV-2 infected Vero E6 Cells by Helium Ion Microscopy*, **Natalie Frese**,* Bielefeld University, Germany*; P. Schmerer,* Justus-Liebig-University Giessen, Germany*; M. Wortmann,* Bielefeld University of Applied Sciences, Germany*; M. Schürmann ,* Bielefeld University, Germany*; M. König,* Justus-Liebig-University Giessen, Germany*; M. Westphal,* Bielefeld University, Germany*; F. Weber,* Justus-Liebig-University Giessen, Germany*; H. Sudhoff, A. Gölzhäuser,* Bielefeld University, Germany

Helium ion microscopy (HIM) enables the visualization of biological samples such as cellular structures, virus particles, and microbial interactions with sub-nanometer resolution, large depth of field, and high surface sensitivity. The charge compensation capability of the HIM allows imaging of insulating biological samples without conductive coatings. In this contribution, the first HIM images of uncoated SARS-CoV-2 infected Vero E6 cells are presented [1]. Several areas of interactions between cells and virus particles, as well as among virus particles, were imaged. The images show the three-dimensional appearance of SARS-CoV-2 on the surface of Vero E6 cells and demonstrate the potential of the HIM in bioimaging, especially for the imaging of interactions between viruses and their host organisms.

[1]N. Frese et al., *Beilstein J. Nanotechnol.* 12(1), 172-179 (2021).

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