Beam induced deposition of tungsten nanopillars using focused helium and neon ions

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Beam induced deposition using focused electron or ion beams is routinely used in processing applications requiring precise placement of metallic or insulating layers, for example, to deposit electrical contacts or insulator in circuit edit debug steps, to deposit a protective layer as part of focused ion beam (FIB) cross-sectioning protocol, and to grow nanostructures for device prototyping. Due to the predominance of the gallium FIB microscope in the field, which is based on liquid-metal ion source technology, the majority of focused ion-beam-induced deposition (FIBID) thus far has used the gallium ion beam. However, with the emergence of the Helium Ion Microscope (HIM), based on a novel atomically sharp gas field-ionization source (GFIS), FIBID using a focused helium ion beam has become increasingly of interest.[1] Further development of the HIM to enable operation of the GFIS with neon has also enabled neon-based FIBID.[2]

Helium and neon FIBID enable direct-write at a higher spatial resolution than gallium FIBID. This is primarily due to the nature of the beam-sample interaction, specifically, the narrower interaction volume near the sample surface from which secondary electrons are emitted (since the low energy secondary electrons are the species primarily responsible for the decomposition of the gaseous precursor). In the work presented here, high-resolution transmission electron microscopy (TEM), scanning TEM (STEM)-based nanobeam diffraction and x-ray energy-dispersive spectrometry (XEDS) are used to investigate the crystal structure and elemental composition of helium and neon FIBID nanostructures.

The nanopillar is chosen as a model system and the gaseous precursor investigated is tungsten hexacarbonyl (yielding deposits composed of tungsten, carbon and oxygen). In addition to FIBID using helium and neon, gallium FIBID nanopillars are grown for direct comparison. It is found that the ion species chosen strongly affects lateral and vertical growth rates, as well as the elemental compositions of the nanopillars, with the relative atomic percentage of tungsten increasing with increasing mass of the incident ion. Crystal grain size is also found to be affected by the growth conditions. In this presentation, underlying mechanisms governing these experimental observations will be discussed, in addition to strategies for tailoring FIBID experimental parameters to specific applications.

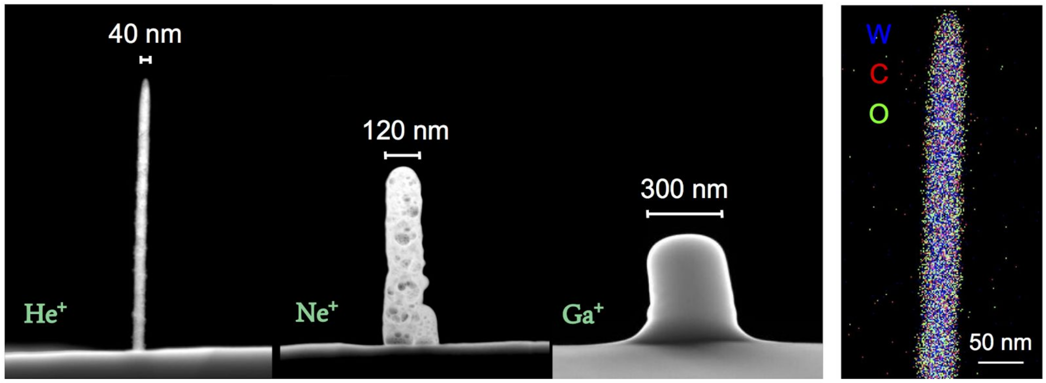

Figure 1: From left to right, dark-field STEM images of tungsten-based nanopillars grown by FIBID using 25 kV helium, 25 kV neon and 30 kV gallium ions at 10 pA. In the case of the Ne-FIBID pillar, broadening due to neon bubble formation is observed. On the far right, a composite elemental map obtained by STEM-XEDS of the He-FIBID nanopillar is shown. Quantification of the XEDS data reveals that this nanopillar comprises ~60 at.% tungsten.

[1]Alkemade, P. F. A., Miro, H. *Focused helium-ion-beam-induced deposition.* Applied Physics A 117(4): 1727-1747, 2014.
[2]Wu, H. M., Stern, L. A., Chen, J. H., Huth, M., Schwalb, C. H., Winhold, M., Porrati, F., Gonzalez, C. M., Timilsina, R., Rack, P. D., *Synthesis of nanowires via helium and neon focused ion beam induced deposition with the gas field ion microscope*. Nanotechnology 24(17): 175302, 2013.