Helium Ion Microscopy: a Technology for Characterization and Nanofabrication of Challenging Materials

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The Helium Ion Microscope (HIM) has been described as an innovative technology offering new insights into the structure and function of nanomaterials. Combining a high brightness Gas Field Ion Source (GFIS) with unique sample interaction dynamics, the helium ion microscope provides images offering unique contrast and complementary information to existing charged particle imaging instruments such as the SEM and TEM. Formed by a single atom at the emitter tip, the helium probe can be focused to below 0.25nm offering. The small spot size together with the small interaction volume between the helium beam and the sample, and the relatively small scattering length, offers the highest recorded resolution for secondary electron images with stunning surface detail [1,2].

Besides imaging, the helium ion beamcan be used for fabricating nanostructures at the sub-10nm length scale. HIM offers thus the abilityto carry out both high precision ion machining and sub-nanometer resolution imaging with high surface sensitivity in order to inspect patterns created on graphene. Helium Ion Beam Lithography (HIBL) has been investigated to generate random defects in graphene lattice [3] and recently patterning and characterization, using HIM and HIBL, of graphene 5nm wide nanoribbons for chemical sensing applications and nano device [4,5] have been reported.

Researchers have used the helium ion beam for exposing resist and features as small as 4nm. The main advantage of helium ion lithography over electron beam lithography is the minimal proximity effect. The helium ion beam has also been used for deposition and etching in conjunction with appropriate chemistries. Helium induced deposition results in higher quality deposits than with Ga-FIB or EBID (Electron Beam Induced Deposition). Finally, the helium ion beam can be used for direct sputtering of different materials and 3.5nm holes in silicon nitride membranes have been realized.

However, due to its lower mass, the helium sputter rate is significantly lower than with gallium. Further, helium tends to implant rather than sputter silicon which is an issue for FIB applications in semiconductors. To overcome these issues, Zeiss have developed the GFIS to operate with Ne.

The Gas Field Ion Source has been modified and the gun redesigned to allow the use of both He and Ne source gases. Although Best Imaging Voltage (BIV), defined as the optimal voltage to get the highest source brightness, is lower for Ne, the system is optimized to operate under the same column conditions for both gases. The neon probe size is greater than helium and is measured between 1-2nm although additional improvements are expected. However this is not a limitation from a nanofabrication standpoint. The sputter yield of Ne is about 30X higher than He, and the Ne beam has a shallower penetration depth resulting in lower sub-surface damage. The sputtering of materials with Ne is significantly better than He and generally within a factor 2X of Ga.

Neon ion beam has been used for Lithography and is shown to be 1000X more efficient than 30keV electron beam with the ability to print 7nm lines. This work has culminated in the development of an ion microscope with a gas field ion source that can operate with both He and Ne.

References

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