GFIS & LMIS Charged Particle Material Interaction Study for Semiconductor Nanomachining Applications

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Noble gas field ion sources (GFIS) is an emerging source technology that has been deployed as the ion source technology for the Helium Ion Microscope (HIM) over the last few years. The HIM microscope source technology has some very impressive properties such as a sub 0.5 nm probe size, high brightness, and has demonstrated resolution on the order of 0.35 nm. In addition to helium, other noble gas based GFIS sources (e.g., neon or argon) may be well suited for applications beyond microscopy, such as Focused Ion Beam (FIB) induced cross sections, TEM prep or Circuit Edit (CE).

For over 20 years gallium liquid metal ion source (LMIS) technology has been the work horse charge particle beam for the FIB industry. Within the semiconductor industry, the gallium FIB is used for nearly all failure analysis (FA), TEM sample preparation, and circuit edit applications. Innovations have fueled gallium LMIS to scale the probe size down to sub 10 nm regime. However, it is unclear if LMIS can continue to scale at the rate needed for performing FA, material analysis (MA), and especially circuit edit tasks on future process generations. As processes technology node evolves to 22 nm, 15 nm, and 11 nm generation over the next several years, a paradigm shifting charged particle beam technology will likely be required to replace or supplement gallium FIB with improved probe size and sputter rate.

In addition to beam probes size and brightness, two additional important considerations for an FIB nanomachining ion source are the ion mass and beam energy operating range. These two parameters define the material interaction volume and the material sputter rates, which are critical to achieving high acuity nanomachining. In Fig. 1 are shown TRIM [1] Monte Carlo modeling results for different noble ion species in a silicon substrate as a function of beam energy. It is important to note that at an operating range of 10-30 keV, which is the typical operating range for FIB's, argon has a sputter rate comparable to gallium (~6 atoms / ion), while Neon's lower sputter rate (2 atoms / ion) might still be viable for nanomachining requirements. Helium however, with a sputter rate of ~0.1 atoms per ion may be insufficient for some nanomachining applications.

Finally, ion invasiveness and implant depth are also important attributes to consider for nanomachining. Ideally, the damage induced by the ion is limited to the surface of the substrate, with a sufficient momentum transfer at or near the surface, to produce sputtering of the desired material. Penetration depth and subsurface cascade induced defects are greatly influenced by ion mass and beam energy. In Fig. 2, TRIM and Casino [1, 2] modeling show the penetration depth and the corresponding cascade events from electron, gallium, and various noble gas ion beams.

In this paper, results from thorough simulations and experimental analysis conducted using various ion species incident on common semiconductor materials are presented for a range of beam energies and doses typically used in imaging and nanomachining regime. The sputter and implantation characteristics of each beam and their general suitability for nanomachining applications are compared and discussed.

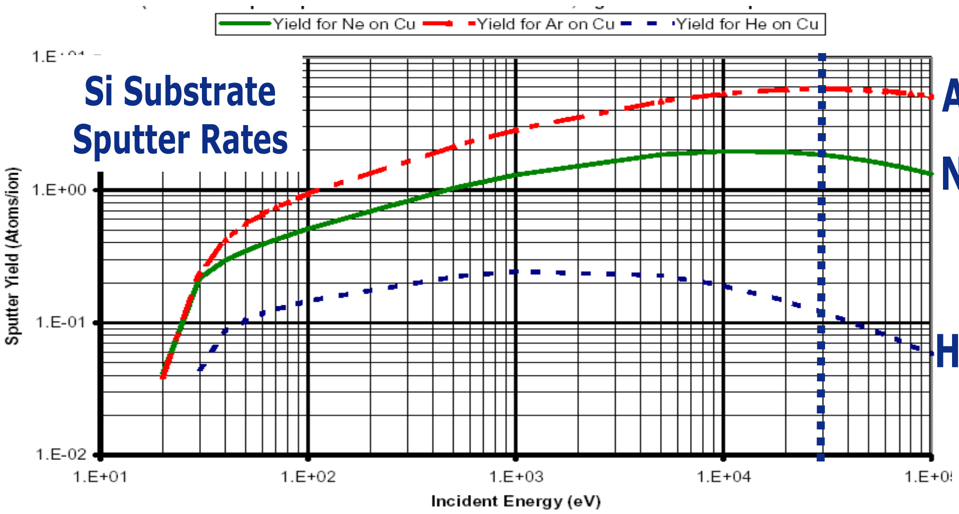

Figure 1: Sputter rates of various noble gas ions incident upon a silicon substrate as a function of beam energy.

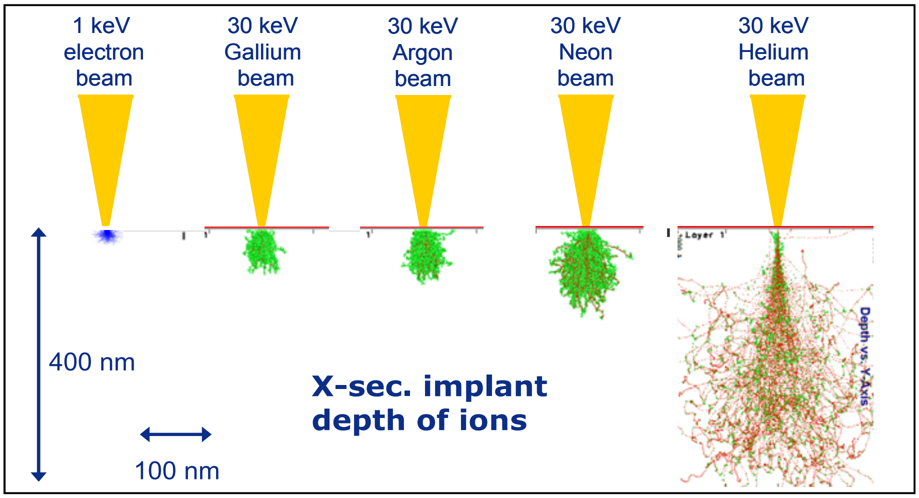

Figure 2: Casino[2] and TRIM modeling of an electron beam (left most) and various ion beams incident upon a silicon target.

Reference

[1] J. F. Ziegler, J. P, Biersack, U. Littmark., The Stopping and Range of Ions in Solids, 1 (Pergamon Press, New York, 1984). (www.SRIM.org).

[2] D. Drouin, A. R. Couture, D. Joly, X. Tastet, V. Aimez, CASINO V2.42 – A Fast and Easy-to-use Modeling Tool for Scanning Electron Microscopy and Microanalysis Users, Scanning, **29**, 92 (2007).