Broadening of FIB applications using Xe plasma FIB

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Development of FIB-SEM (also known as “DualBeam™”) equipment has undergone significant progress during recent years. Conventional Gallium FIB is still unsurpassed in precision of milling/deposition for features in the range of 10 nm - 30 µm. Meanwhile the release of Xe^{+} plasma FIB (PFIB) made it possible to combine comparable precision with much higher milling productivity [1]. Due to significantly larger beam currents and marginally higher sputter rate, it is possible to mill structures of up to several hundred microns within a reasonable time or to increase significantly the throughput for traditional structures. Moreover, the milling with Xe PFIB produces better quality of surface.

The following new applications have become available due to the higher milling rate of the Xenon based PFIB and are being adopted to extend the capabilities to larger structure sizes as compared to the Gallium based FIB-SEM:

- Tomography and 3D EBSD/EDS characterization of volumes up to $(100\ \mu m)^3$
- TEM lamella preparation of large areas or multiple places within shortest amount of time
- Large area cross-section; larger than 100x100 µm size
- Patterning of extended area of surface for optical and technological applications
- Sample preparation for techniques such as micro-CT and micro-size compression/tensile testing
- Through wafer milling, as well as inspections of TSVs (through silicon vias) and wire bonding

Minimizing of surface defects during milling is critical for a number of applications. Amorphization and penetration depth of ions is less for Xe^{+} versus Ga^{+} in the same conditions [2]. Some applications are not possible due to the creation of Ga FIB milling artifacts, such as droplets liberation during InGaAs milling, eutectic formation with In, Al, Zn, Pb metals [3], or segregation of Ga at the grain boundary of Al TEM lamellas. In these cases, Xe is an inert element and is showing promise to investigate these materials without the challenges of Ga.

FIB alone allows removing material faster, but it is the combination with high resolution SEM that makes the Helios PFIB DualBeam a powerful instrument for imaging and for analytical investigation. Significant precision and throughput are achievable in 3D imaging, EBSD and EDS applications. Fully automated routines such as 3D EDS and EBSD as well as SEM imaging 3D software are available to collect serial image stacks through areas of interest. TEM sample preparation and manufacturing of designed structures can be done at high level of automation as well, making the Xe FIB-SEM a useful tool to characterize the 2D and 3D material structure, properties and ultimately relate these to functionality.

An expanded, continuous range of length-scales is now accessible for 3D characterization by variety of microscopy and tomography correlative methods. It spans from sub-nanometer TEM resolution to mesoscale range of micro-CT. Plasma FIB covers the intermediate range in-between, i.e. µm-mm range. Combination of several such methods allows achieving comprehensive and complementary studies of the object of interest. As the next step, the 3D-data treatment, analysis and versatile visualization can be done by 3D reconstruction & visualization software suites such as FEI Avizo.

Combining SEM with Xe^{+} or Ga^{+} ion beam, the proper system can be specified for certain applications to gain significant advantage from Xe or Ga, whereas in other cases performance is comparable and interchangeable. In summary, Xe Plasma FIB/SEM technology enables dramatically improved material removal rates compared to traditional methods - while maintaining exceptional surface quality, high-contrast and ultra-high resolution imaging performance. Ga FIB allows the fabrication of smaller precise structures. Both techniques have applications in materials science where they enable better material characterization.

References

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