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Probe Optimization studies For High current Focused Ion Beam Instruments

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Xenon plasma focused ion beam (PFIB) instruments can operate in beam currents ranging from ~20pA at the low end to ~2µA at the high end of the current spectrum allowing for versatile use of the probe in imaging and milling applications. This is made possible by use of current limiting apertures of varying diameters resulting in a wide range of probe diameters and profiles. At the high current range (>300nA), probe profiles exhibit large probe diameters and extended beam tails. The tail regions representing a small fraction of the primary probe current can still have significant effects in causing over-milling and degradation of the samples during milling and trenching operations. Focused probe conditions at high currents can exhibit significant tails with gross degradation of the sample during milling, while defocused probe conditions show improved milling characteristics with reduced over mill beyond the target raster region [1]. Quantitative approaches to characterizing the probe profiles at high current settings can provide valuable insight in optimizing beam conditions. Previously researchers have used theoretical and experimental studies characterizing gallium (Ga) ion beams, employing a variety of methodologies in probe current distributions and modeling the primary and secondary profiles of the ion beam [2,3]. In this study we have used a combination of techniques in characterizing the Xenon (Xe) ion probe for high current applications.

The 1µA beam current setting on a Tescan FERA Xe PFIB was used to explore means of optimizing the probe for milling applications in the high current regime. In addition to empirical work done on characterizing probe conditions and performing milling comparisons using the different parameters we have also used AFM profilometry to measure the profile of a high current Xe ion beam to analyze the current distribution and profiles of the ion beam under varying conditions.

A new aperture with standard alignments and centering was used for the experiments. Beam burns were performed over a range of over-focus, focus and under-focus conditions. A mild over-focus condition of 17.10KV was used for comparisons with the standard focus condition at 17.26KV. Top down SEM measurements of the probe profiles and beam tail extension were complemented with AFM profiles of the probes to quantify the Z depth corresponding to the amount of material removed in the tail. Probe profile measurements were performed documenting the changes in probe profiles and extent of beam tail spread under various focus conditions. Figures 1(top and bottom) shows SEM and AFM profilometry measurements correlated to the probe burns at the over-focus and focus conditions respectively. Figure 1B shows the extent of material removal and tapering in the tail region of the probe which can be clearly seen with the extended tail of the focus condition resulting in a 45µm radius compared to only 26µm for the over-focus condition shown in Figure 1A. Comparisons of FIB milled regions using over-focus and focus settings confirm these results with the focus condition (Figure 2B) showing significant over mill with much of the forward region of the sample being already milled away. In comparison, in the over focus condition (Figure 2A), the over mill appears to be in good control and should be negated once lower current final polishing of the sample has been performed.

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Figure 1A

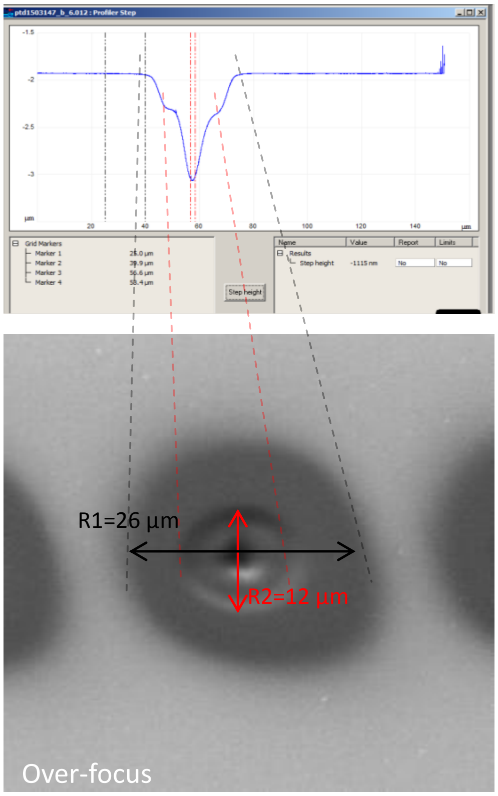

Figure 1B

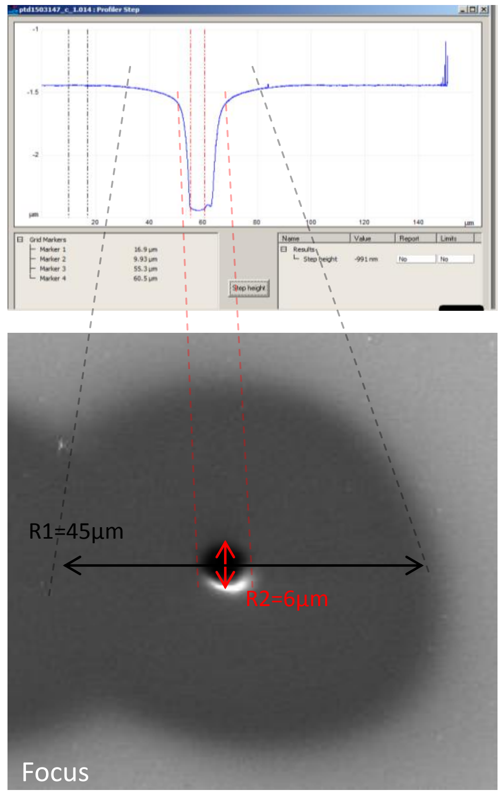

Figure 1A Top: AFM profile on top shows primary probe profile and extent of beam tail for under-focus condition. **Bottom**: SEM measurement of 1µA probe with 17.10KV objective voltage over focus setting. Primary probe radius measures 12µm with beam tail extending out to 26µm.
Figure 1B Top: AFM profile on top shows primary probe profile and extent of beam tail for focus condition. **Bottom:** SEM measurement of 1µA probe with 17.25KV objective voltage setting. Primary probe radius is smaller and measures 6µm but the beam tail is significantly worse extending out to 45µm.

Figure 2A

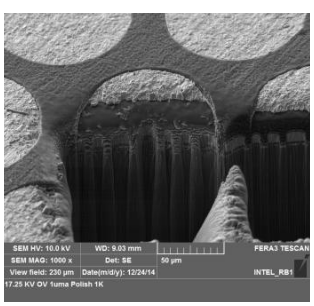

Figure 2B

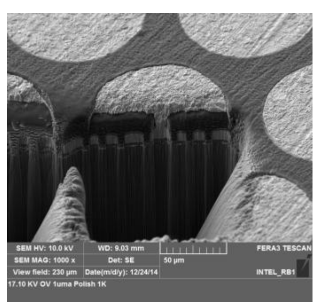

Figure 2: Shows comparison of locations milled using 1umA beam current at the focus setting of 17.25KV (2A left image) versus over-focus setting of 17.10KV (2B right image). Figure 2A shows the effect of extended beam tail with excessive material removal in the advance regions showing as compared with the more benign over focus setting.

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