doi:10.1017/S1431927613003784
Microsc. Microanal. 19 (Suppl 2), 2013

Theoretical 3D Imaging with He^+ Ions

L.A. Giannuzzi
L.A. Giannuzzi & Associates LLC, 12580 Walden Run Dr, Fort Myers, FL 33913 USA.

Multi-beam ion and electron beam platforms are used for 3D tomography typically with an ion beam for slicing, and either an ion beam or an electron beam for imaging. Electronic stopping dominates light ions of moderate energy [1]. This creates a situation where the ion range is very large and the sputter yields are very small (i.e., typically << 1). Under these conditions, steady state sputtering conditions are never reached and the ion implantation concentration increases monotonically with dose. Likewise, if light ions are used to image slices in a 3D stack, implantation damage can accumulate in the volume with each slice. For a given imaging dose per slice, if the slice thickness is larger than the ion implantation depth, then there will be no accumulation of ion implantation damage to the remaining volume of material other than that given by the initial imaging dose. However, if the slice thickness is smaller than the total ion range, then the ion dose will indeed accumulate with each image after each slice and possibly damage the region of interest within the volume.

A theoretical approach is presented whereby it is assumed that slicing imparts no target damage, while the cumulative ion implantation dose due to a scanning He^+ ion beam for imaging each slice within the target volume is monitored. SRIM [2] is used to determine the initial ion range distribution. In this theoretical experimental set up, the He^+ ion energy is 25 keV, the dose is 250 ions per pixel, the slice thickness is 20 nm, the incident angle is 0^o, and the target is Si. The imaging pixel size is assumed to be 1 nm and therefore, the total imaging dose per pixel is 3.2E16 ions/cm^2. Previous work showed no observable defects in Si at 32 keV He^+ doses of 1E15 ions/cm^2, amorphization of Si at 5E16 ions/cm^2, and nanobubble formation in Si at 5E17 ions/cm^2 [3]. The energy and dose per slice is this theoretical work is a bit less than that needed to amorphize Si.

FIG. 1 shows the He^+ ion dose distribution into the target volume after imaging the 1st, 5th, 10th, 15th, and 20th slice. Note that the initial peak concentration level and the projected range occur below the surface at ~ 250 nm and that a significant portion of the ions reach a depth of ~ 400 nm. Since the slice thickness for this experiment is much less than the projected (or total) range, the accumulation and retention of ions within the volume as measured from each new surface created by the slicing occurs with the 2nd slice onward as shown in FIG. 1. Note that with each subsequent slice, part of the previous distribution 20 nm from the surface is removed, and the same imaging dose is added to the remaining distribution to create a new distribution which pushes the peak concentration implantation level towards the surface. Steady state conditions are met when the peak concentration level reaches the surface. In this example, steady state is reached after ~ 20 slices and the distribution of ions will remain the same for each subsequent slice. This is analogous to the situation for steady state sputtering whereby an increase in dose merely recedes the surface, but does not change the implantation concentration distribution [4]. For these experimental conditions, the dose accumulation in the volume is much larger than that required to amorphize or form nanobubbles in Si even before steady state conditions of 20 slices is ever reached.

If the imaging dose per slice is too large, than it may be possible for the accumulated dose to damage the volume of interest and affect the analyses. For a given target and beam energy, large dwell times per pixel with high resolution voxels (e.g., small x,y,z) yield the worse possible combination for the possibility of accumulated ion implantation damage. However, with careful experimental set up of the ion energy, dose per slice, incident angle, target, and slice thickness, the accumulation of He^+ ion implantation damage may be kept below the amorphization threshold of the target and may be used as an imaging beam for 3D tomography.

References

[1] L.A. Giannuzzi and F.A. Stevie (eds.) Introduction to Focused Ion Beams, (2005) Springer.
[2] J.F. Ziegler, SRIM, www.srim.org
[3] Richard Livengood et al., JVSTB 27(6) (2009) 3244-3249.
[4] T. Ishitani, H. Koike, T. Yaguchi and T. Kamino, JVSTB 16(4) (1998) 1907-1913.

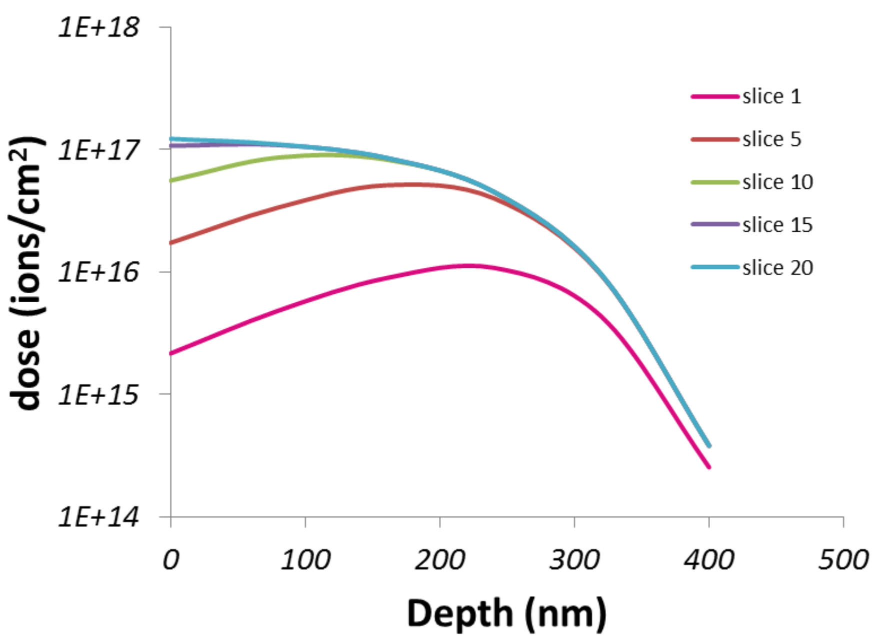

FIG. 1. The distribution of 25 keV He^+ ions into Si after 1,5,10,15, and 20 slices, with a dose per slice = 3.2E16 ions/cm^2. Each slice is 20 nm.

https://doi.org/10.1017/S1431927613003784 Published online by Cambridge University Press