1260 CD
DOI: 10.1017/S1431927606065469

Microsc Microanal 12(Supp 2), 2006

Reducing FIB Damage Using Low Energy Ions

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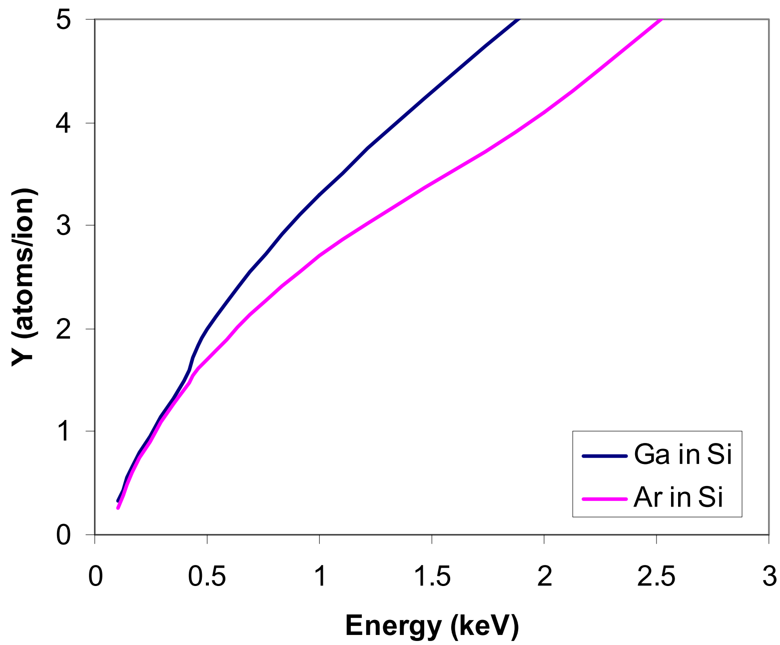
TEM specimen preparation requirements are more stringent now that aberration corrected microscopes are commercially and routinely available. In most cases, TEM specimens must have as little surface damage as possible and be as thin as possible. However, conventional FIB milling using 30 keV Ga^+ ions will result in the ubiquitous ~ 22 nm of sidewall amorphization damage in Si [1]. Reducing the FIB Ga^+ ion energy to 2 keV yields less than 2 nm of amorphization damage in Si on each specimen side and allows for TEM imaging with an information limit at the sub-angstrom level [1]. Physics dictates that any ion bombardment process will result in some degree of ion implantation damage. As shown in Fig. 1, for a given target (e.g., Si) and at a given incident angle (e.g., 88^o), heavier ions will result in higher sputter yields (and therefore, will yield less ion implantation damage) [2]. Fig. 1 also shows that as energy decreases, the differences in sputter yield, and therefore, the amount of ion damage between ions of different masses, is negligible. Thus, virtually any combination of ion mass and ion energy may be chosen to suitably limit and reduce ion implantation damage in TEM specimens. However, as also evident in Fig. 1, if the ion energy is too low, then the sputter yield will drop to < 1 and more ions will be implanted into the target surface then will be removed, thereby resulting in deleterious consequences for quality surfaces.

As shown in Fig. 2, FIB milling a specimen as thin as possible at 30 keV can result in the case where most if not all of the specimen consists of specimen preparation artifacts. Thus, for quality high resolution TEM imaging, the best specimen preparation techniques should incorporate replacing 30 keV FIB damage with subsequently smaller amounts of lower energy damage. As shown in Fig. 3, this is most easily performed by starting with a relatively "thick" specimen and thinning the specimen to its desired thickness and surface quality with lower energy ion beams. This technique results in a thin specimen with minimal specimen preparation artifacts. These techniques can be performed most effectively in-situ using a DualBeam instrument where the low energy ion beam can be focused and placed at a site specific location using secondary electron ion imaging, and the specimen thickness and quality can be directly monitored using either the SPI/SEM or SPI/STEM mode of operation.

References

[1] Giannuzzi et al., Microsc Microanal 9(Suppl 2), (2005) 828.
[2] JF Ziegler and JP Biersack, SRIM 2003, www.SRIM.com.



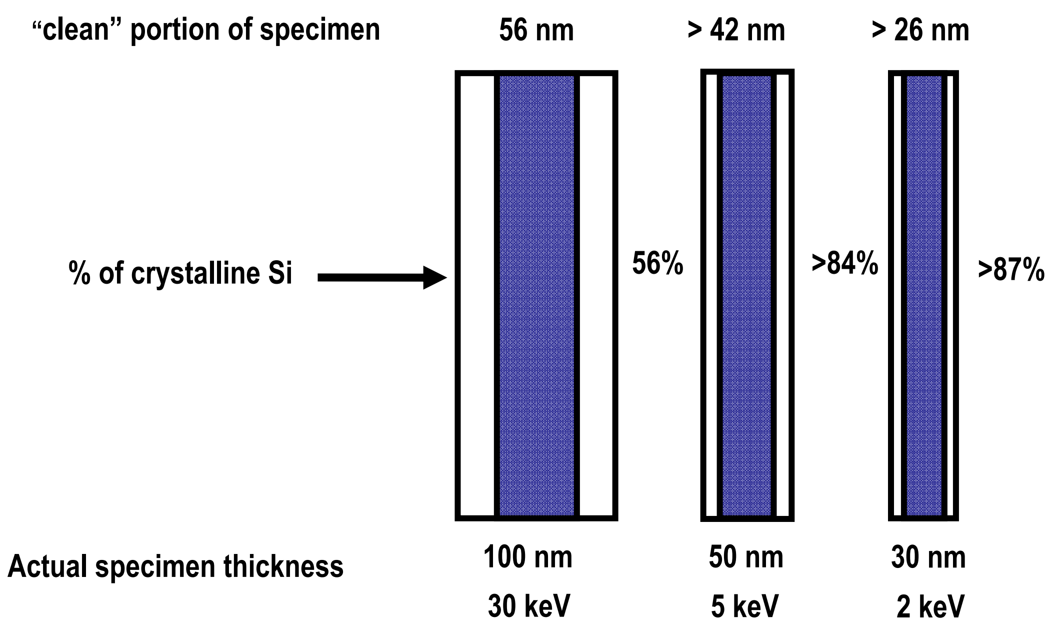


Fig. 1 TRIM results showing sputter yield as a function of ion energy for Ga in Si (top blue line) and Ar in Si (bottom magenta line) at 88^{o} incident angle.
Fig. 2 A schematic diagram showing suggested technique for reducing and replacing high energy FIB milling damage with low energy damage.

https://doi.org/10.1017/S1431927606065469 Published online by Cambridge University Press