Sub-Surface Damage from Helium Ions as a Function of Dose and Beam Energy

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In recent years, helium ion microscopy has produced images with novel contrast mechanisms and high resolution. However, when using any charged particle beam, one must consider the potential for sample damage. In this paper, we will consider the helium-induced damage as compared to the traditional gallium beam for semiconductor applications.

Three types of ion induced damage are considered: surface sputtering, lattice damage (e.g. dislocations), and the implantation of the ions. The damage from the traditional 30 keV gallium ions (mass = 69 amu) striking silicon has been well studied in terms of surface sputtering, implantation, and extensive lattice damage in depths ranging from 30nm to 50nm below the surface[1]. This damage is quite extensive – for each incident ion there are about 3 sputtered silicon atoms, and about 740 dislocations. By comparison, a beam of 30 keV helium ions (mass = 4 amu), produces only 0.08 sputtered atoms per incident ion. And the helium-induced dislocations occur at a rate of 146 per incident ion, with a depth range from 200 to 300 nm. Taking these in combination, the dislocation density is about 47 times less for helium compared to gallium at 30 keV. This gives helium a distinct advantage for imaging and metrology applications.

For most focused ion beam applications, the ions ultimately come to rest some distance below the surface of the sample - a problem that has been well documented for gallium ions[2]. For low mass ions (principally helium and hydrogen) at high dosages, the trapped gas atoms can coalesce into sub-surface micro-bubbles before the gas atoms can diffuse out of the bulk[3]. This phenomena occurs in silicon at dosages of about 2 or 3 orders of magnitude above the dosage required for most imaging applications. Figure 2 shows this effect. For helium beam nanomachining of silicon, larger dosages may be required and the formation of micro-bubbles may play an important role. Further experimental results and simulation results will be presented.

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[1] J. F. Ziegler, J. P, Biersack, U. Littmark (1984). The Stopping and Range of Ions in Solids, vol. **1** of series "Stopping and Ranges of Ions in Matter," Pergamon Press, New York (1984). For the updated version, see SRIM Version 2006.02 (www.SRIM.com)

[2] J. Orloff, M. Utlaut, L.W. Swanson, "Interaction of Ions with Solids" in *High resolution Focused Ion Beams*, Boston: Kluwer Academic / Plenum Publishers, 2003, pp. 123-145.

[3] B Scherzer, "Development of Surface Topography due to Gas Ion Implantation" in *Sputtering by Particle Bombardment*, New York: Springer-Verlag, 1983, pp 271-355.

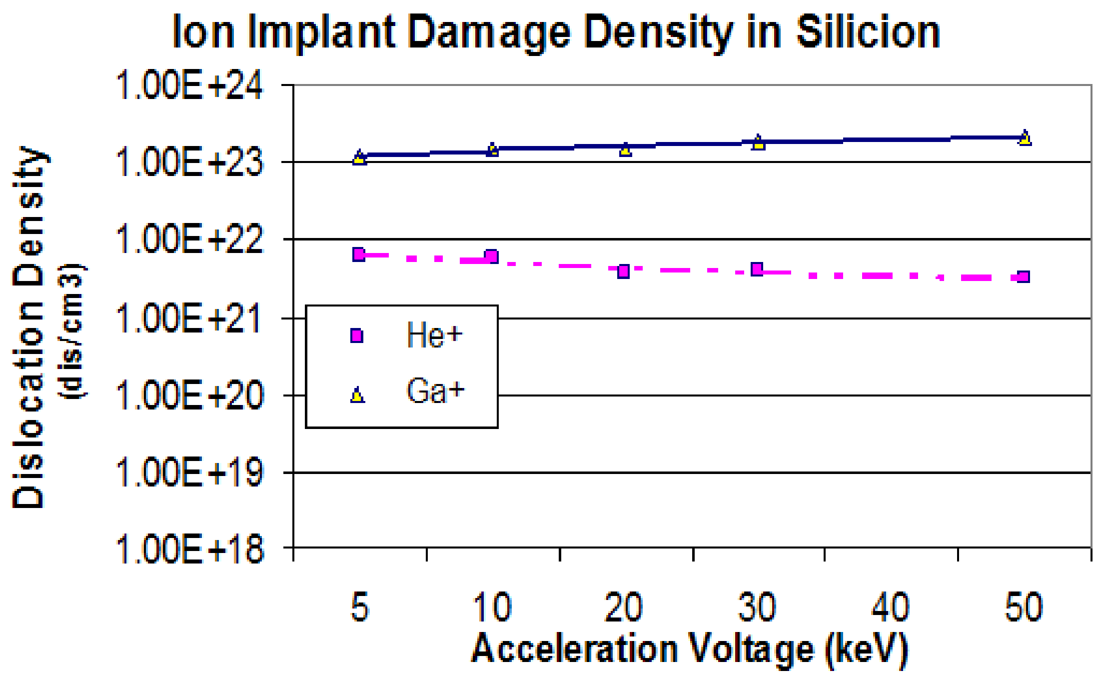

Figure 1: The defect density of helium and gallium are graphed as a function of energy. For 30 keV beams, gallium produces 47times more sub-surface damage than helium.

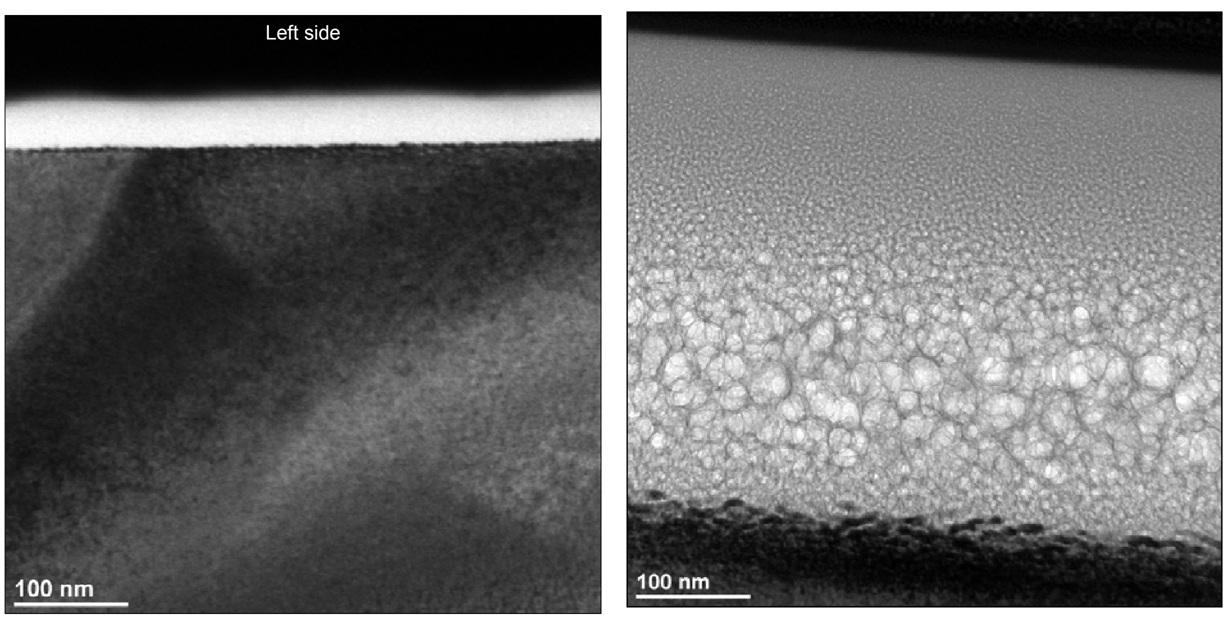

Figure 2: TEM micrograph of silicon after exposure to a typical imaging dosage of 1E15 ions / cm^2 (left), and an extreme exposure of 5E18 ions / cm^2 (right). Under normal imaging dosage, there is no evident damage. But for much higher dosages, the formation of micro-bubbles is evident.