Focused He Ion Beam Induced Implantation and Damage in Si
——A Preliminary Study

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Focused He ion beam (HIM) technology has been used successfully in high resolution imaging and nano-fabrication of thin films, 2D materials and nanostructures. However, for bulk silicon-based materials, HIM has low sputtering rate and would mainly induce damages on crystal structure and He implantations in the interaction area. Tan's group [1-3] has systematically studied HIM-Si interactions for both Si bulk and film and given the smart solutions. Here, we focused on the physical mechanism of damages and implantations by high-resolution transmission electron microscopy (TEM) and Monte Carlo simulations. For 30keV HIM, He ions distribute around the area of 300 nm depth and do not have enough energies to diffuse to the incident surface. According to SRIM (Stopping and range of ions in matter) simulations, the most of HIM energies loss by ionization rather than recoils events. Our TEM characterizations showed that nano-bubbles (shown in Fig.1) generated under the dose larger than 2.8×10^{10} ions/nm^2 in the continuous focused spot milling mode and thus induced micrometer-sized bump on the surface(Fig.2). When the dose decreased to 1.9×10^{8} ions/nm^2 per spot, defects appeared randomly in the Si crystal, shown in Fig.3. The transitions from amorphous area to defective enriched region and to perfect crystal were found under larger dose of 2.9×10^{8} ions/nm^2 per spot with disordered boundaries (Fig.4). The nano-sized bubbles generated not only in the amorphous area but also in the regions of crystal-defects transition, as is shown in Fig.5. According to our preliminary studies, a schematic physical process, see Fig.6, was proposed to illustrate focused HIM induced He implantations and damages in Silicon. The following deeper work has been proceeding about the impacts of crystal orientation and HIM parameters on the He implantations and damages and the defect-induced strain distribution by focused HIM implantations.

References:

[1] Richard Livengood, Shida Tan, et. al., J. Vac. Sci. Technol. B, 27, 3244 (2009).
[2] Shida Tan, Kate Klein, et. al., J. Vac. Sci. Technol. B, 32, 06FA01 (2014).
[3] Michael G. Stanford, et. al., Small, 12, No. 13, 1779–1787 (2016).

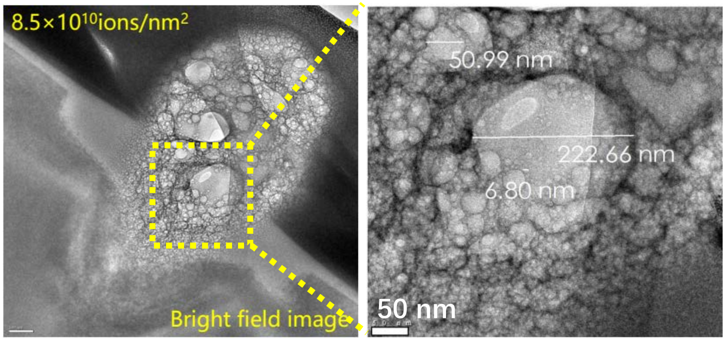

Fig.1 TEM images of nano-bubbles generated under large dose.

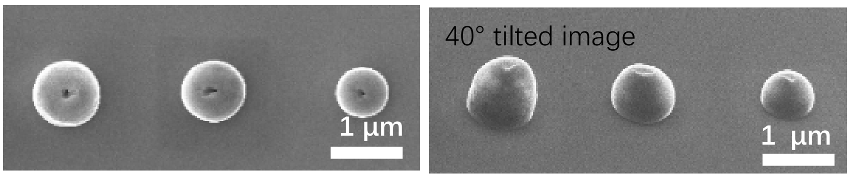

Fig.2 Morphologies of continuous focused spot milling on single crystal (100) Si under doses of 8.5, 5.7 and 2.8×10^{10} ions/nm^2 (from left to right).

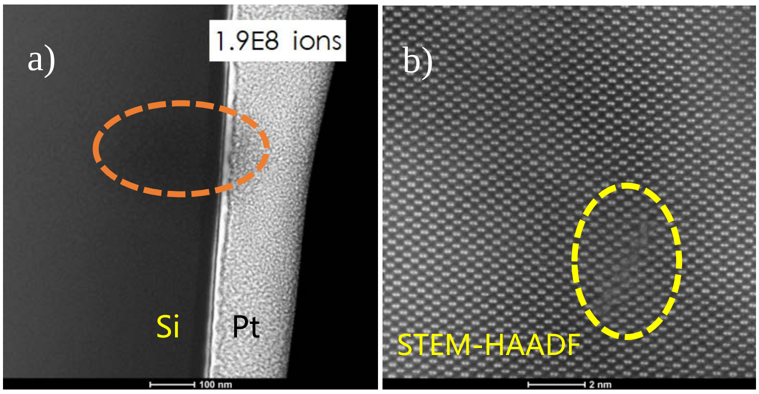

Fig.3 Local defect observed under low dose 1.9×10^{8} ions/nm^{2} per spot by aberration-corrected TEM. The orange ellipse circle in a) shows the implanted area. The yellow circle in b) gives a defect structure.

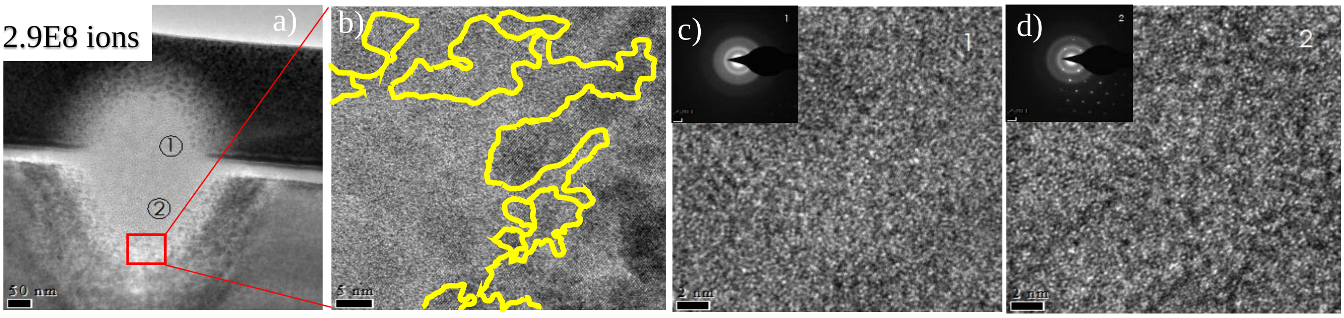

Fig.4 Transitions from amorphous area to crystal under middle dose 2.9×10^{8} ions/nm^{2} per spot. a) shows the whole morphology of the implanted area; b) gives the transition region and the boundaries indicated by the yellow lines; c) and d) show the high-resolution morphologies and electron diffraction pattern of the two area selected in a), respectively.

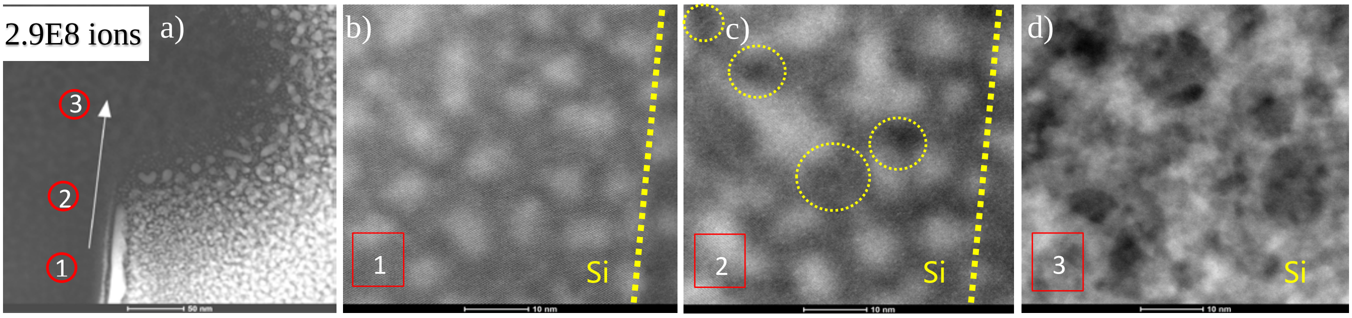

Fig.5 High-resolution STEM characterizations of the nano-sized bubbles distributions. The whole implanted area is shown in a). The sub-areas denoted in a) are enlarged in b), c) and d), respectively. The yellow dashed line is the boundary between Si crystal and natural oxidation layer. The yellow dashed circles in c) give the possible nano-sized bubbles. In b) and c), the disordered white regions with diameter of 5-10 nm may be induced by impurities sputtering in the sample preparation processes. The structures of nano-sized bubbles can be viewed clearly in d).

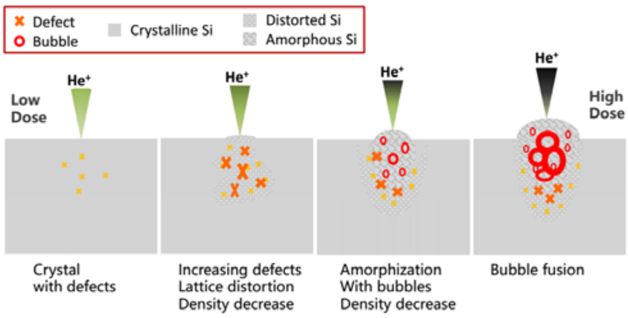

Fig.6 A schematic physical process of focused HIM induced He implantations and damages in Silicon.