Mechanism and Applications of Helium Transmission Milling in Thin Membranes

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The helium ion microscope's unique high-resolution imaging and nano-patterning capabilities have been explored in many different applications since its debut in 2007. Compared to gallium-based focused ion beam (FIB) systems, the smaller probe size and lower atomic weight of the helium beam provides greater resolution, precision and control in certain patterning and machining applications. Great success was reported on fabricating sub-10 nm structures in thin films, such as C-apertures, nanopores, grapheme-based devices, etc.[1-4] However, contradictory results have been obtained in bulk semiconductor substrates due to the high implant range, low sputter yield and low permeability of helium ions.[5] In this work, the different ion-material interactions and machining mechanisms were analyzed as a function of dose for a 34.5 keV well-focused helium beam in bulk Si and a Si membrane by cross-sectional transmission electron microscope (TEM) imaging as well as theoretically via SRIM modeling.

An example of helium implant/milling progression in a 140-nm-thick Si membrane and bulk Si substrate are shown in Fig. 1. Both the membrane sample and bulk Si are single crystalline materials and are ideal substrates for analyzing the ion beam interaction.[6] Using TEM to analyze the propagation of dislocations and amorphization within the substrate, a clear delineation of the interaction volume and sputtered regions can be seen for both thin film and bulk substrates.

The results show that in the case of the Si membrane, the helium ion collision events result in both backward and forward sputtering, which results in a narrow cut (< 10 nm) in the membrane with funnel shaped opening at both the beam entry and exit surfaces. By comparison, in the bulk Si substrate, the majority of the collision events result in amorphization of the substrate with only a small amount of backward-sputtered material. Additionally, at high doses, the cumulative sub-surface implantation of helium causes the Si substrate to swell up.

In this paper, in-depth empirical results, theoretical simulation, and membrane sample and TEM lamella preparation will be discussed.

References:

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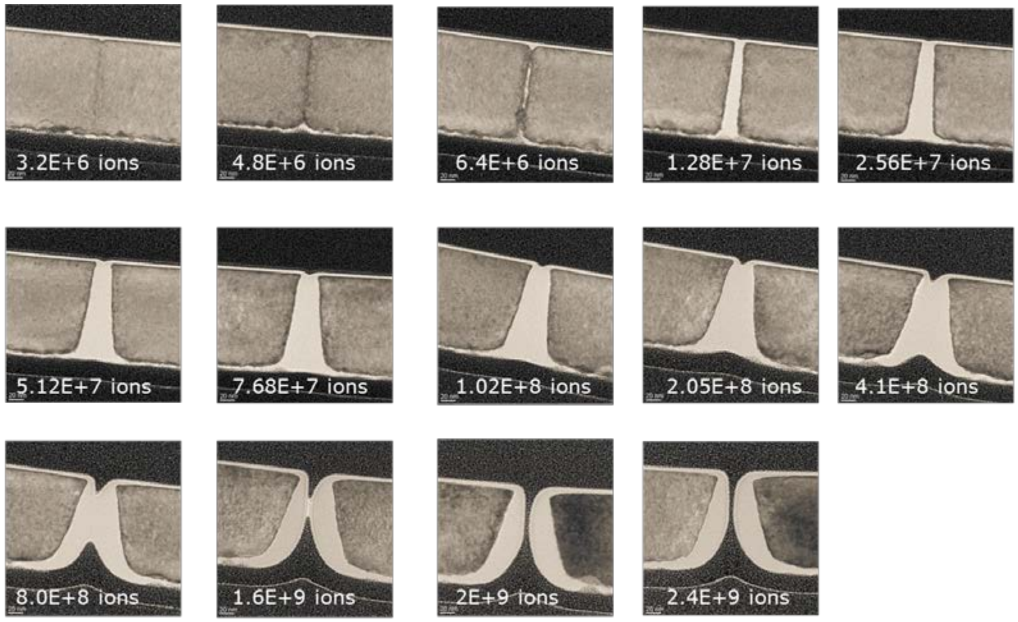
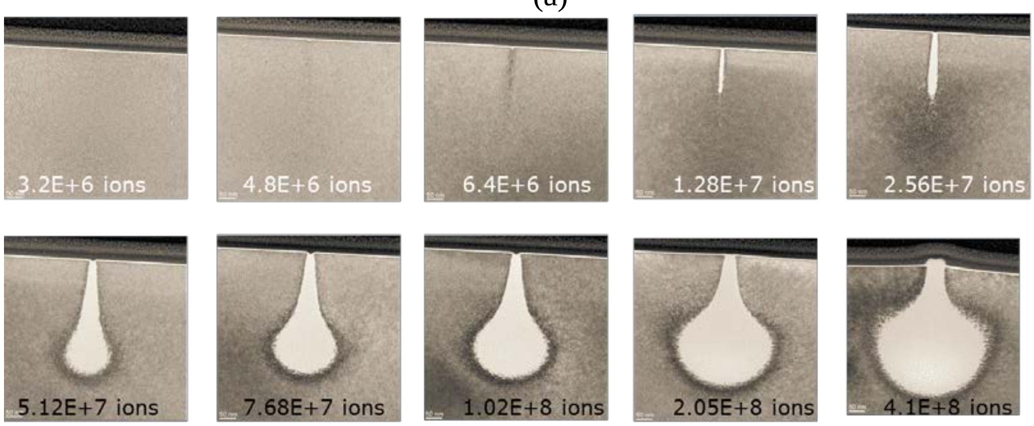
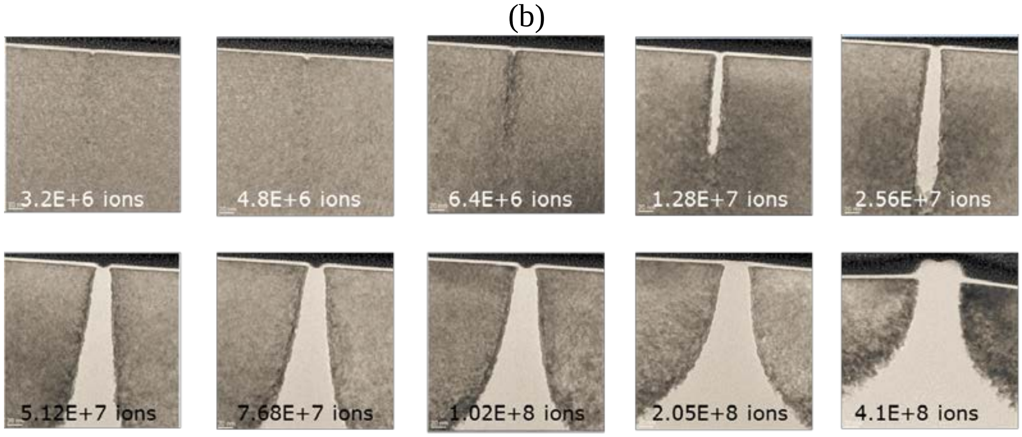


(a)



(b)



(c)

Figure 1: TEM micrographs of an increasing dose series of 34.5 keV focused helium beam implantation in (a) a 140 nm thick single crystalline Si membrane with 240 nm FOV and (b) bulk single crystalline Si substrate with 520 nm FOV. (c) Zoomed in views from the bulk substrates in (b) with 240 nm FOV.