3D Nanofabrication by Geometrically-Confined Helium Ions in Diamond Nanostructures

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Helium ion microscopes (HIM) can be used for nanometrology and nano fabrication.[1] Damage induced by ion beam irradiation such as the formation of nanoscale voids, helium deposits, and structural deformation may limit the viability of the tool for some nanofabrication applications, but has also been exploited for applications where defect formation is desirable.
Here, we have studied the distribution of helium ions deposited in nanostructured matter using a combination of focused ion beam and transmission electron microscopy (TEM). The HIM was used to expose thin membranes of single-crystal diamond. Diamond has recently been of significant interest for applications in quantum optics and computing [2], and can be used in order to make beam splitter for quantum electron microscope [3]. Dose-dependent ion ranges were observed in diamond membranes by TEM with longer ion ranges observed for higher ion doses. We attribute the dose dependence to the onset of defect formation in the diamond lattice and ultimately the formation of voids within the crystal during ion irradiation (Figure 1). Previous studies of focused helium ion beam (FHIB) on materials considered different material morphologies *e.g.* bulk and in-plane membranes, and did not report similar findings to those observed here [4]. We interpret our novel results as being due to the specific geometry of our test structures.
We expanded this study (defect formation) to include building novel 3D nanostructures defined by the geometrically-confined helium ion distribution (Figure 2(a-c)). Various nanostructures, shown in Figure 2(a-c), were designed and fabricated as templates. Point and line exposures of the FHIB were then used to create 3D nanostructures on the basis of the template geometry (Figure 2(b_{1-2})). This new 3D nanofabrication method potentially can be used to add functionality to nanostructures by adding greater geometric complexity.

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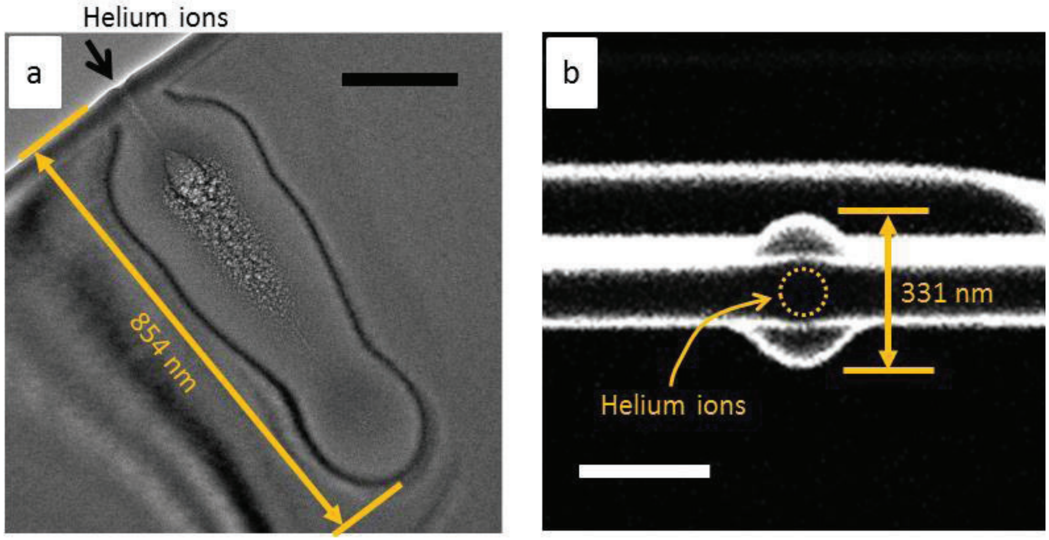

Figure 1: (a) Transmission electron micrograph of a diamond membrane irradiated in-plane by the focused He ion beam. We observed an 854nm-long helium ion propagation. (b) Helium ion micrograph of the volume expansion formed by FHIB exposure onto single-crystal diamond. The dose was 2.4E+08 ions/point at 35 keV. The scale bars are 200 nm.

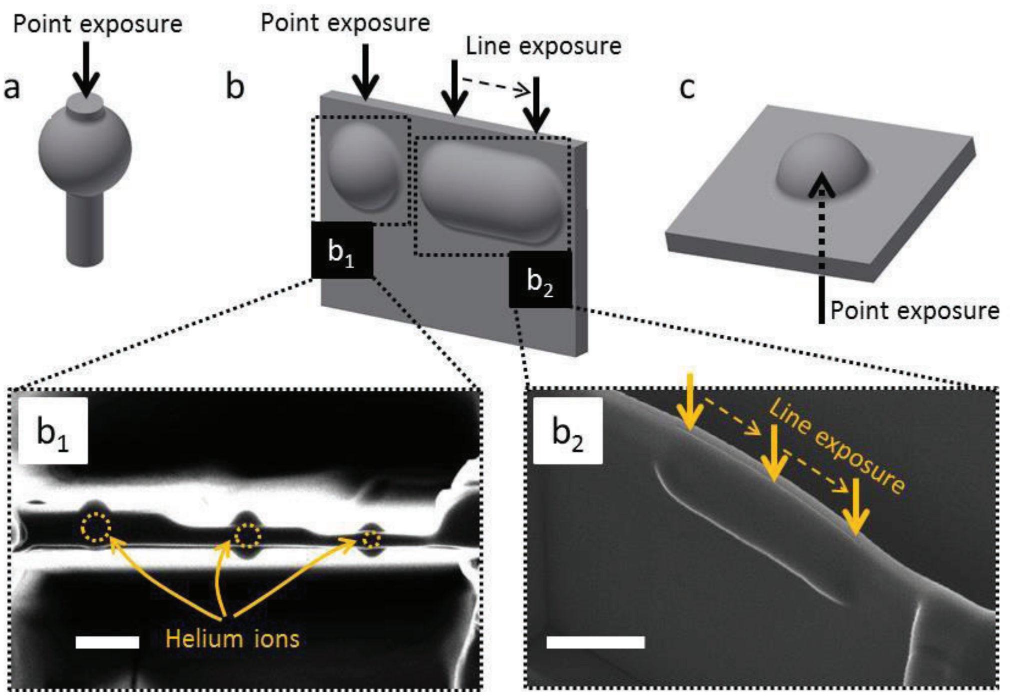

Figure 2. Schematics of embedding 3D nanostructures by geometrically-confined helium ion distribution on existing nanostructures, such as: (a) pillar with point exposure, (b) vertical membrane with point and line exposures, and (c) membrane with perpendicular exposure. Examples of embedded 3D nanostructures in diamond: (b_1) sphere-size dependency of geometry (thickness of walls) and (b_2) cylindrical shape along the wall, on the basis of Figure 2(b). The scale bars are 400 nm.