Visualizing the Interaction Volume of Helium Ions in Hydrogen Silsesquioxane

Jingxuan Cai[1], Zhou-Yang Zhu[1], Paul F.A. Alkemade[2], Emile van Veldhoven[3] and Wen-Di Li[1]
[1]*Department of Mechanical Engineering, Univ. of Hong Kong, Hong Kong*
[2]*Kavli Institute of Nanoscience, Delft University of Technology, Delft, the Netherlands*
[3]*TNO, Delft, the Netherlands*
liwd@hku.hk

With the introduction of scanning helium ion microscope, a number of patterning applications using helium ion exposure have been developed. For example, sub-4 nm half-pitch lines were patterned in cross-linked hydrogen silsesquioxane (HSQ) through helium ion beam lithography [1]. Moreover, exposure of highly focused helium ions has created many novel applications, such as milling, etching and deposition of various materials [2]. Many of these applications involve scattering of helium ions in the exposed materials, which has been studied mainly through numerical simulation methods such as the Transport of Ions in Matter (TRIM) program. Experimental evidence about the actual interaction volume of helium ions in exposed matters will be helpful to understand the ion transport process and can be used to verify the numerical simulation results.

In this work, we demonstrate visualization of the scattering volume of helium ions in thick HSQ layer. 600 nm thick HSQ was first spincoated on top of a 20 nm thick silicon nitride membrane and dried in vacuum at room temperature for 12 hours. Focused helium ion beam was used to expose the thick HSQ layer from the back side of the silicon nitride membrane. After exposure, the HSQ was developed and only the sufficiently crosslinked HSQ was attached to the silicon nitride membrane. The experimental principle is schematically illustrated in Fig. 1a and 1b. Characterization of the profile of the remaining cross-linked HSQ structure provides important information about the actual spread of helium ions in the HSQ layer.

Fig. 1c shows the developed HSQ structures attached to the membrane after exposure using 15 keV helium ions from the bottom side. As expected from the TRIM simulation, the HSQ structures exhibit bubble-like shapes which correspond to the lateral and vertical spread of incident helium ions in the HSQ. In our experiment, a series of HSQ bubbles were exposed at different helium ion doses and different initial exposure area. HSQ bubbles created by helium ions of different energies were also fabricated and characterized. Fig. 1d plots the diameters of HSQ bubbles, with an initial exposure area of 50 nm by 50 nm square at area doses varying from 50 to 2000 $\mu C/cm^2$.

Detailed modeling of the helium ion scattering and HSQ crosslinking process based on the characterization of the actual exposed HSQ bubbles will provide us insightful guidance on many applications using focused helium ion beam exposure.

[1] W.D. Li, W. Wu, R. Stanley Williams, Combined helium ion beam and nanoimprint lithography attains 4 nm half-pitch dense patterns, Journal of Vacuum Science & Technology B: Microelectronics and Nanometer Structures, 30 (2012) 06F304-306F304-304.
[2] P. Alkemade, E. Veldhoven, Deposition, milling, and etching with a focused helium ion beam, in: Nanofabrication: Techniques and Principles, M. Stepanova and S. Dew (editors) (2011) 275-300.

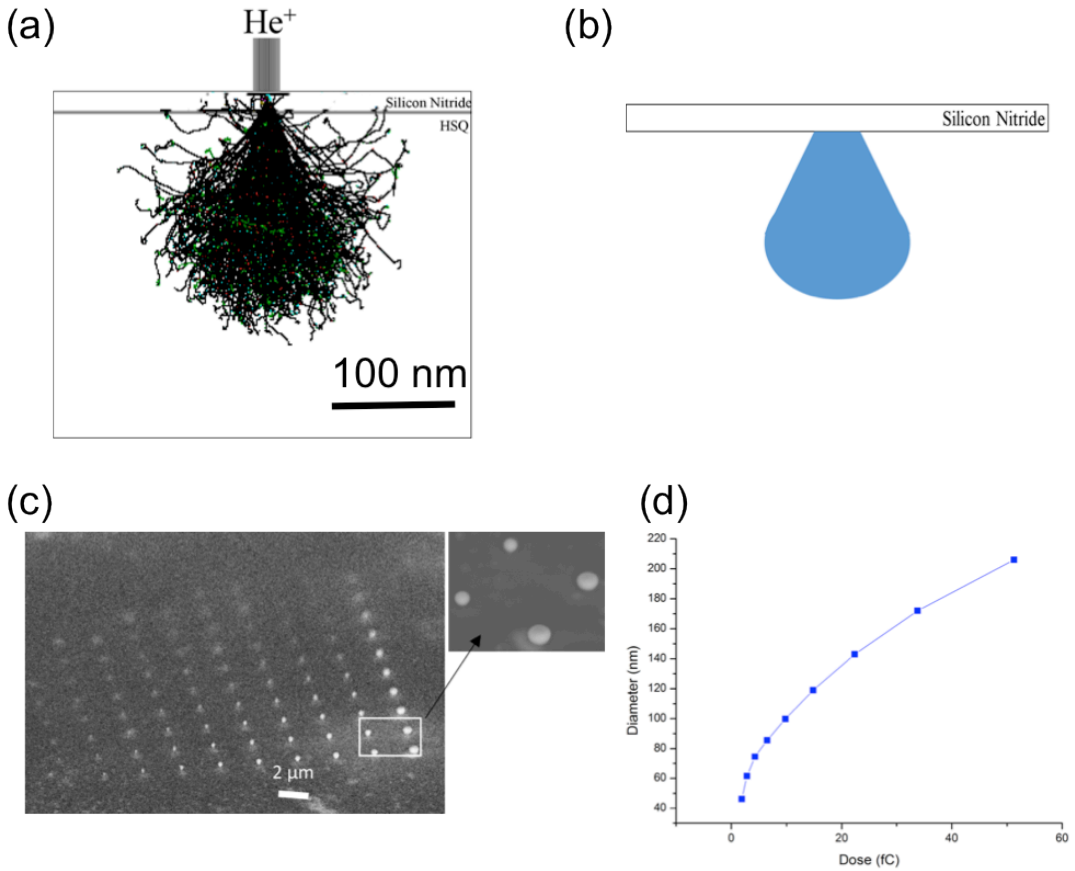

Fig. 1 (a) Schematic of helium ion injected into a thick HSQ layer through a thin silicon nitride membrane; (b) Schematic of cross-linked HSQ bubble attached to the silicon nitride membrane after exposure and development; (c) SEM images of HSQ bubbles created by helium ion beam with vary doses; (d) Plot of diameters of HSQ bubbles versus the exposure dose.