Forward sputtering of thin films using focused helium ion beam

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The recently introduced helium ion microscopy does not only provide a new generation imaging tool with sub-nanometre resolution, but also introduces unprecedented capability for sub-10 nm patterning applications. Scanning helium ion beam lithography based on an Orion helium ion microscope has achieved 4 nm half-pitch dense lines [1]. Moreover, milling of materials using focused helium ions has been demonstrated on graphene, silicon nitride membrane, gold, etc.[2-4], with patterning resolutions higher than conventional Ga ion beam milling. Particularly, helium ion beam has demonstrated the capability of forward sputtering, i.e., knocking off atoms from the backside of a thin membrane [2], which may inspire new applications of patterning thin layer of materials with high resolution. Through forward sputtering of a layer of metal on the backside of a silicon nitride membrane, 5-nm half-pitch dense lines have been patterned in the metal while the carrying membrane on the front side is still continuous, as shown in Fig. 1.

However, there is still a lack of systematic study on the forward sputtering process using focused helium ions and comparison with frontside sputtering behaviors. Particularly, in some applications such as shown in Fig. 1, it is preferred to enhance the forward sputtering effect while suppressing the backward sputtering from the front surface.

In this work we use SRIM software to numerically study the forward sputtering behaviours of focused helium ions on thin layer of materials. We plot the simulated forward sputtering yield (FSY) and backward sputtering yield (BSY), as defined by the average number of target atoms leaving from the film from the back side and front side respectively with one incident helium ion, with respect to the film thickness for different ion energies and different film materials.

Several properties can be seen in our results demonstrated in Fig. 2 and Fig. 3. As the thickness of the membrane increases, BSY also increases and then reaches a stable value beyond certain thickness, while the FSY typically reaches a peak value, and then drops to zero. The plot of the ratio of the FSY to the BSY, as shown in Fig. 2b and 3b, provides a good guideline for determining the relevant strength between forward sputtering and backward sputtering at different thickness. More analysis of the forward and backward sputtering processes on thin films under helium ion irradiation is ongoing.

In summary, we numerically studied the forward sputtering behavior on thin films of typical materials under helium ion irradiation. These results will be useful for developing new techniques in high-resolution nanofabrication and material modification applications.

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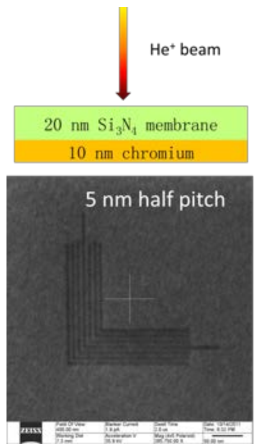

Fig. 1: 5-nm half-pitch lines milled in 10 nm chromium layer with helium ions through 20 nm thick silicon nitride membrane

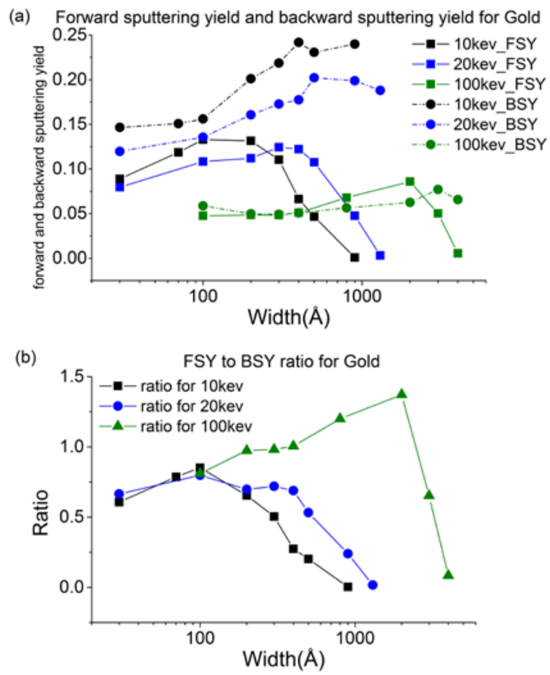

Fig. 2: (a) Simulated forward sputtering yield and backward sputtering yield of a gold membrane. (b) Plot of the ratio of FSY to BSY.

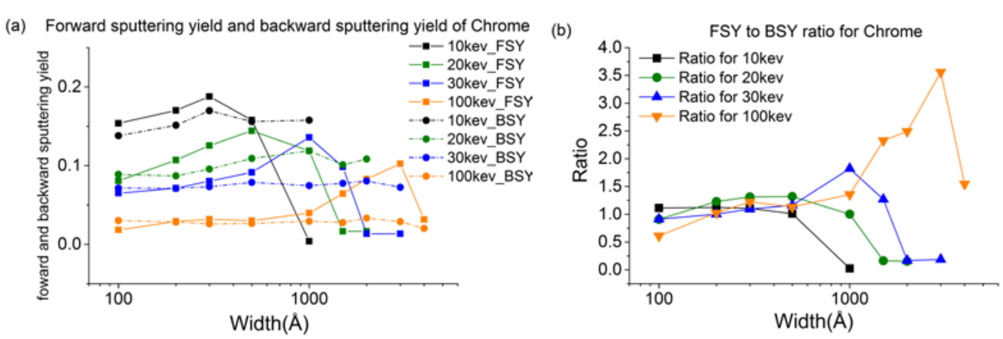

Fig. 3: (a) Simulated forward sputtering yield and backward sputtering yield of a chromium membrane. (b) Plot of the ratio of the FSY to the BSY.