Neon Ion Beam Etching on Photoresist Patterns

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Helium ion microscopy (HIM) has attracted many applications in imaging, nanofabrication and analysis. One important field of study in nanofabrication is milling or etching materials with a helium or neon ion beam, with and without chemical assistance. In particular, neon ion beam has relatively high sputtering rate with lower probability of swelling and re-deposition issues compared to helium ion beam. [1, 2] Neon ion beam has been investigated for etching Si and Cu film, [1] Ti_3N_4 metal connection [2] and for exposing hydrogen silsequioxane (HSQ). [3] There is less work on neon ion beam etching on photoresist (PR) patterns. Here, neon ion beam etching method is investigated for milling and repairing electron-beam lithography (EBL) defined HSQ and polymethyl methacrylate (PMMA) patterns on two samples.

Various 500nm thick HSQ patterns on 30nm metal layer on Si substrate are easy to view with HIM images, including the residual particles (white arrow indicated) from developer solution as shown in Fig. 1.A. Different doses of neon ion beam etching lead to different etching profiles (cuts in PR vertical walls) as shown in Fig. 1.B. Using the same dose ($0.8nC/\mu m^2$), uniform gap arrays (~40nm) can be achieved on thick HSQ walls (Fig. 1.C). With XeF_2 assistance, neon ion beam etching can be enhanced by a factor of 2 (Fig. 1.D). Helium ion beams can also etch thick HSQ patterns, but with much lower etch rates (~1/7). Furthermore, residual particles in trenches can be selectively removed using ion beam etching without affecting the PR patterns.

Pattern-placement errors in 100 nm thick PMMA patterns on Si substrate exposed using EBL are easy to check with HIM images (Fig. 2.A). Neon ion beams can effectively etch PMMA patterns (Fig.2.B). The unwanted connections (white arrows in inset image in Fig. 2.A) could be etched away using neon ion beam. Helium ion beam etching is not suitable for this sample due to swelling in Si substrate.

Neon ion beams could be exploited for etching many different PR patterns defined by various lithographic methods. The etching rates vary with different PR patterns, material systems etc. Neon ion beam etching could effectively modify or repair PR patterns, and remove residuals.

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[1] S. Tan, R. Livengood, D. Hack, R. Hallstein, J. Notte and S. McVey, J. Vac. Sci. Technol. B, **29**, 06F604 (2011).

[2] D. Xia, S. McVey, C. Huynh and W. Kuehn, ACS Appl. Mater. Interfaces, in press (2019).

[3] D. Winston *et al*, Nano Lett. **11**, 4343 (2011).

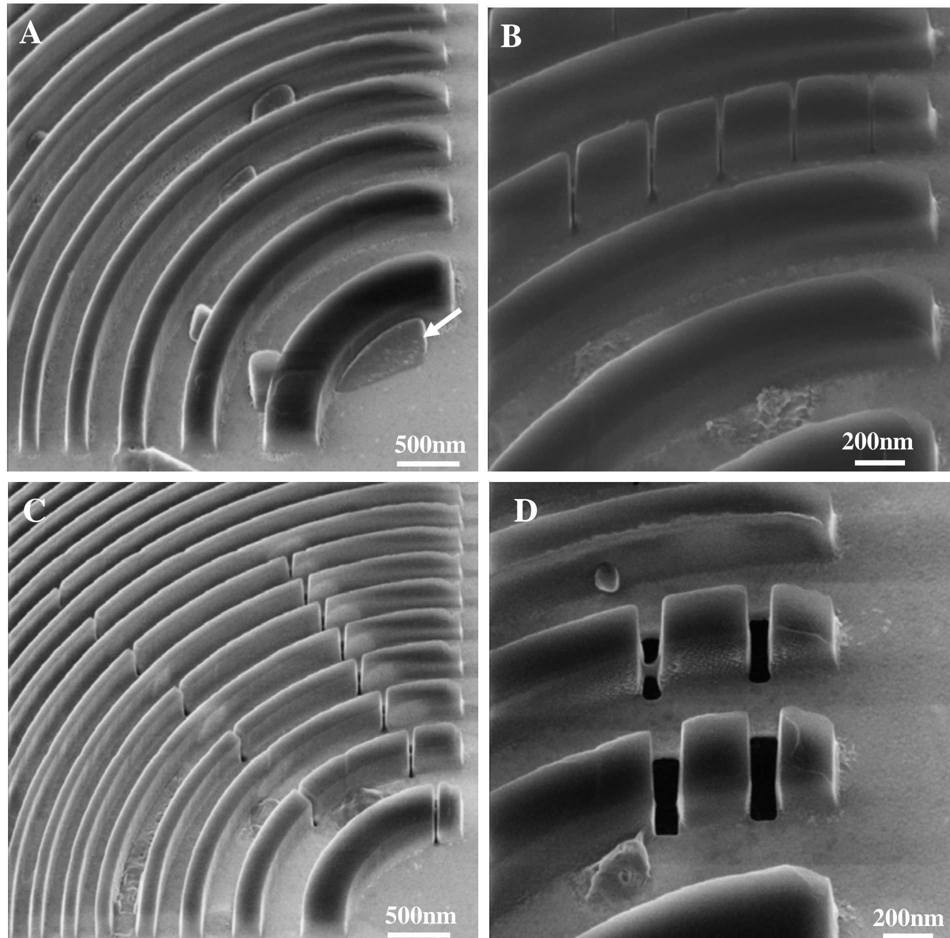

Figure 1: Tilted HIM images of HSQ patterns: (A) PR patterns; (B)-(D) after neon ion beam etching; (B) dosage of 2, 1.5, 1, 0.8, 0.5nC/μm^2; (C) 0.8nC/μm^2; (D) 0.6, 0.8nC/μm^2, upper row without XeF_2, bottom row with XeF_2.

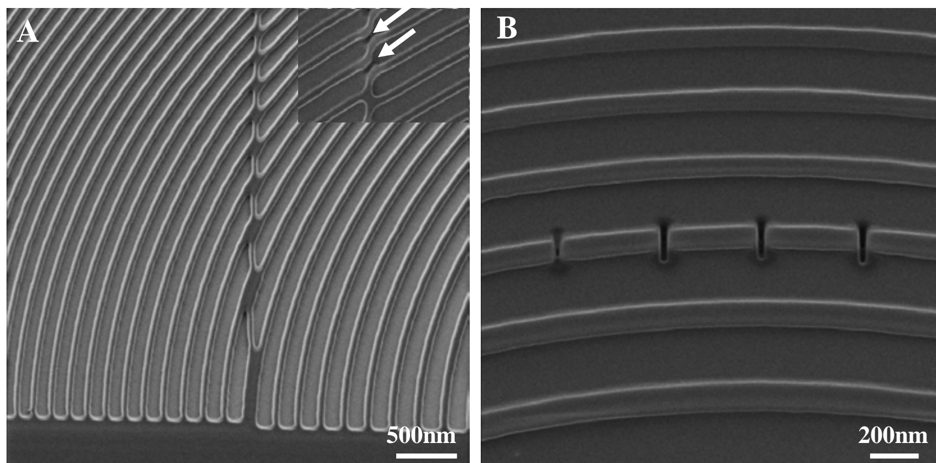

Figure 2: Tilted HIM images of PMMA patterns: (A) PR patterns (inset image showing etch-away of connection); (B) after neon ion beam etching with dose of 0.5, 1, 1.5, 2nC/μm^2.