Self-Limited Self-Perfection by Liquefaction for Sub-20 nm Trench/Line Fabrication

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Pressed self-perfection by liquefaction (P-SPEL) has demonstrated the ability to perfect the profile of nanostructures after their initial fabrication, such as narrowing a trench width from several hundred nanometers to sub-10 nm and smoothing out the line edge roughness [1]. However, one of key challenges in P-SPEL is the need to precisely control the gap between the top pressing plate and the substrate., which in turn determines the final trench width, and the need of such control over entire wafer. Here, we propose and demonstrate a self-limiting process to P-SPEL, which eliminates the need of such control. Using the self-limited P-SPEL, we achieved 20 nm trenches and lines from initial 90 nm trenches and 140% improvement in line edge roughness.

A schematic of a self-limited P-SPEL process is shown in Fig. 1. The initial sample before SPEL is a thermoplastic polymer gratings on a silicon substrate, that was fabricated by thermal nanoimprint (Nanonex NX-2000 imprinter) followed by O_2 reactive ion etching (RIE) to remove the residual resist layer. To create a self-limited process, a 20 nm thick SiO_2 stopper layer was shadow evaporated onto the top and one side-wall of the grating at 55^o angle. Finally, the sample was processed by P-SPEL, where a top flat plate was pressed on the sample while being heated to 150^oC which is higher than the glass transition temperature of the thermoplastic. Since the final trench width is self-limited by the SiO_2 stopper layer thickness, there is no need to precisely control the gap between the top plate and the substrate, nor the pressing pressure, temperature and time.

After the self-limited P-SPEL, CHF_3/O_2 based RIE was used to etch away both the SiO_2 and polymer top at an equal rate (Fig. 1d); then HF wet etching was used to remove the remaining vertical SiO_2 stopper, followed by another O_2 RIE to remove the residual layer, forming a trench as narrow as the SiO_2 stopper thickness. To convert the resist trench into a metal line, a lift-off process can be used.

Figure 2 shows the results of the self-limited P-SPEL process. The initial grating was 200 nm (3σ=5.5 nm) period and 90 nm wide, with a 3σ-LER of 8.2 nm. After self-limited P-SPEL, the grating is 200 nm (3σ=6.3 nm) period and 20 nm wide, with a 3σ-LER of 3.4 nm. We noticed that after the self-limited P-SPEL, the period remains unchanged and the 3σ-LER is reduced to 3.4 nm – improved over 140%.

The self-limited P-SPEL, which can significantly reduce a trench width beyond what permitted by conventional methods and can greatly reduce LER, should have a broad range of applications in semiconductor ICs, nanophotonics, nanobiotech and other disciplines.

[1]. Y. Wang; X. Liang; Y. Liang and S. Y. Chou. Nano Lett., 2008, 8 (7), 1986-1990

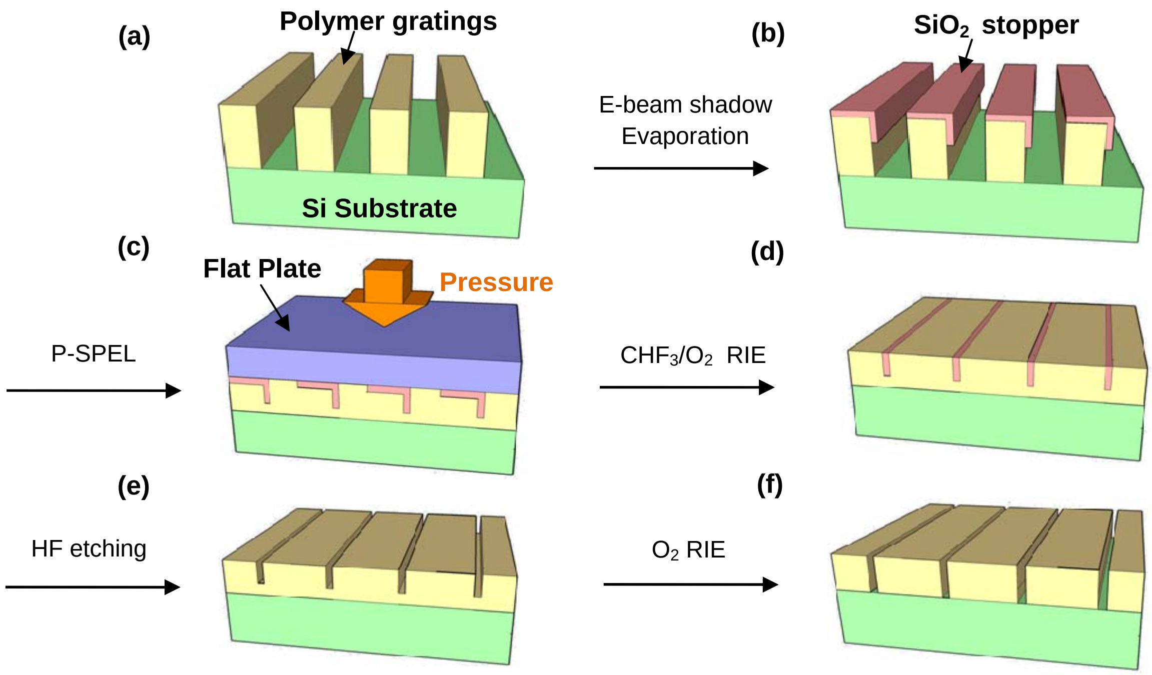

Fig. 1: Schematic of a self-limited pressed self-perfection by liquefaction (P-SPEL) process.

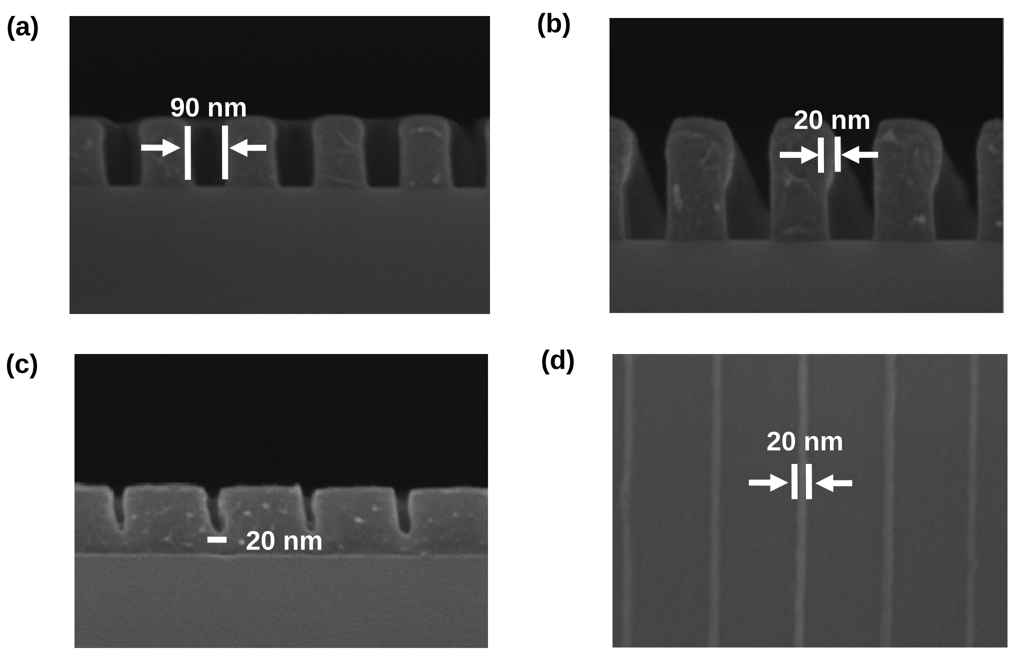

Fig. 2: (a) The initial sample before self-limited P-SPEL: a resist grating with a 90 nm gap and 200 nm pitch, fabricated by nanoimprint using a grating mold; (b) one-side, 55^{o} E-beam shadow evaporation of 20 nm SiO_2 which acts as a stopper; (c) after self-limited P-SPEL and removing the vertical of SiO_2 stopper; (d) 20 nm Cr lines after O2-RIE removing the residue resist in the trench and a Cr lift-off.