Enhancing the Etch Resistance of PMMA-Based Photoresist to Meet ITRS Target from Year 2022

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Photoresists currently in use for industrial 193 nm photolithography have poor resistance to plasma etching and are inadequate as a high-fidelity etch mask. Attempts to mitigate this weakness with a thick photoresist film lead to high aspect-ratio resist features, which can collapse during wet development. A usual solution involves using an intermediate hard mask. However, even in this scenario the photoresist needs to have a minimum amount of etch resistance to allow pattern transfer into the hard mask. Finding a suitable material for the hard mask can be difficult since it must satisfy many different requirements. This has motivated recent work to improve the etch resistance of the polymeric resist layer by Sequential Infiltration Synthesis (SIS).[1, 2]

We show that the plasma etch resistance of JSR-ARF-AR1682J (JSR Micro, Inc.), a photoresist for 193 nm photolithography based on poly(methyl methacrylate) (PMMA), can be improved significantly using SIS. In this approach, the developed photoresist film is reacted with trimethyl aluminum and water in an atomic layer deposition (ALD) chamber.[1, 2] The SIS treatment improves the photoresist's etch resistance to several plasma chemistries targeted for common materials in semiconductor manufacturing (Table 1). In an HBr-based Si etch recipe, this SIS-treated photoresist etches ~40 times slower than silicon, allowing deep trenches to be etched without using intermediate hard masks (Figure 1).

We demonstrate for PMMA, the major component of JSR-ARF-AR1682J, that the improved etch resistance due to SIS treatment relaxes the lower limit of usable resist thickness. A resist film thin enough to prevent pattern collapse can be used, while still allowing deep structures to be etched. A 30 nm PMMA layer, treated by SIS, has sufficient etch resistance for the creation of high-aspect ratio structures (> 5:1) in silicon (Figure 2), with no need for intermediate hard masks. Importantly, the SIS treatment does not degrade the as-developed line-edge roughness (LER). This LER is maintained even after plasma etching, with no observable degradation, for line widths as small as 30 nm.

These results imply that a very thin layer of PMMA-based photoresist, treated by SIS, may be used directly as an etch mask. The thickness of this layer may be reduced to prevent pattern collapse, while still having sufficient etch resistance for pattern transfer via plasma etching. These improvements meet the ITRS requirement on resist thickness until the year 2022.

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[1] Y.C. Tseng *et al.*, J. Vac. Sci. Technol. B **29,** 06FG01 (2011).
[2] Y.C. Tseng *et al.*, J. Mater. Chem. **21,** 11722 (2011).

Target material	Etch rate of photoresist with no SIS treatment (nm / min)	Etch rate of SIS-treated photoresist (nm / min)	Enhancement factor
SiO_2	582	317	1.8
Cr	286	62	4.6
SiN	136	48	2.8
W	155	25	6
Si (Cryo)	189	11	17
Si	230	4	60

Table 1: Etch rate of photoresist before and after 5 cycles of SIS treatment. The target material (first column) is the material intended to be etched by the specific plasma chemistry.

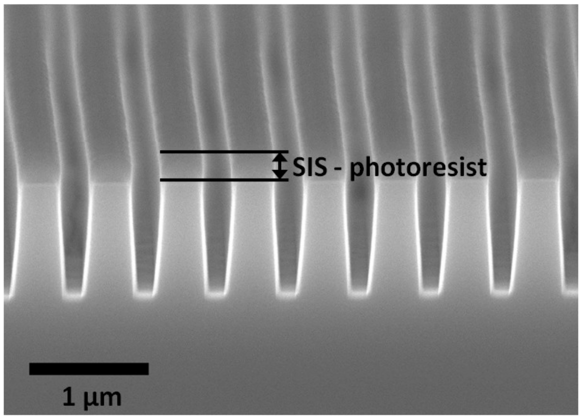

Figure 1: Cross-sectional SEM image of trenches etched in Si using SIS-treated JSR-ARF-AR1682J photoresist as etch mask. Trench dimensions: depth ~ 1 µm, width ~130 nm. No intermediate hard mask was used. Patterning was done using 193 nm photolithography at the North Carolina State University nanofabrication facility.

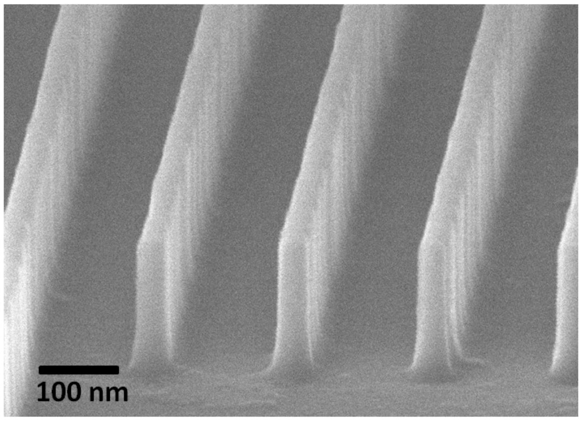

Figure 2: Cross-sectional SEM image of sub-30 nm, high aspect-ratio lines in silicon patterned using SIS-modified PMMA mask. The starting PMMA thickness was 30 nm. No intermediate hard mask was used.