Direct transfer by plasma etching of 2.5D patterns obtained by grayscale lithography

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Grayscale lithography enables the 2.5D patterning of a low-contrast photosensitive resist and allows for the creation, in a single step, of structures with profiles that are particularly useful for various optical applications. However, it is important to ensure that the pattern formed in the resist is accurately transferred to the underlying substrate. This control concerns not only the dimensions of the patterns but also the surface roughness, which must be minimized—particularly in the field of optics—to limit phenomena such as scattering. It is therefore particularly important to develop plasma etching processes that offer controlled selectivity while also limiting surface roughness. We developed such a method as part of the European SCARBOn project (Horizon 2020) [1], which aims to develop miniaturized hyperspectral imagers for measuring greenhouse gases (CO_2 and CH_4) from space. We have thus fabricated grating arrays with step differences of 25 nm in silicon. The figure 1 presents the arrays developed into the resist maP1225G resist (thickness 480 nm) exposed with a 385 nm maskless process on the Smart Print UV equipment (Microlight3D), and one array after etching into the Si substrate. The integration of this interferometer array into an optical system has led to its use for quantifying the optical signature of greenhouse gases in the atmosphere.

The plasma process used in the ICP DPS chamber of the CENTURA etching cluster at LTM is based on a mixture of HBr (120 sccm), Cl_2 (40 sccm), and He-O_2 (5 sccm), commonly used in microelectronics. It results in a selectivity of 2.6 between the etching rates of Si and MaP-1225G resist,. We deliberately used this highly reproducible process, which has a selectivity greater than one, unlike most existing studies based on fluorinated gases [2,3]. It requires only adjusting the developed profile in the resin to obtain the expected steps in the silicon. The selectivity is demonstrated on figure 2 which compares the thickness etched into Si to the resist profil resulted from the developed thickness as a function of the exposure dose. Some periodic irregularities due to standing waves are observed on the contrast curve, and are transferred into Si. Moreover, we analyzed the surface roughness depending on the exposure dose on the resist and on the substrate after the etching step. The figure 3 demonstrates that the roughness ~3 nm in the resist increases up to 6 nm for doses corresponding to the maximum impact of the standing waves. The 3 nm roughness on the resist is slightly increased up to 4 – 5 nm on the Si surface, that is coherent with the SCARBOn specifications, but it is important to limit the excessive roughness resulting from the standing waves.

This result confirms that the use of a Bottom Anti Reflective Coating is necessary to limit the impact of the standing waves at two levels: control of the pattern profile and surface roughness. We finally use a Barli film between the resist and the substrate. We will show that the resist contrast curve is then regular and that the resist roughness is uniform close to 3 nm. The impact of the BARC film on the transfer by plasma etching will be detailed. Its etching rate is 1.33 higher than the resist one. We will demonstrate that despite the introduction of this layer the pattern can be transferred with a good control of the profile, with a reduced roughness.

References

1. https://www.scarbon-project.eu
2. *A. Bouchouri et al, 2024, doi.org/10.3390/mi15070866*
3. *Hai Binh Phi et al. 2023 doi.org/10.1007/s10404-023-02663-2*

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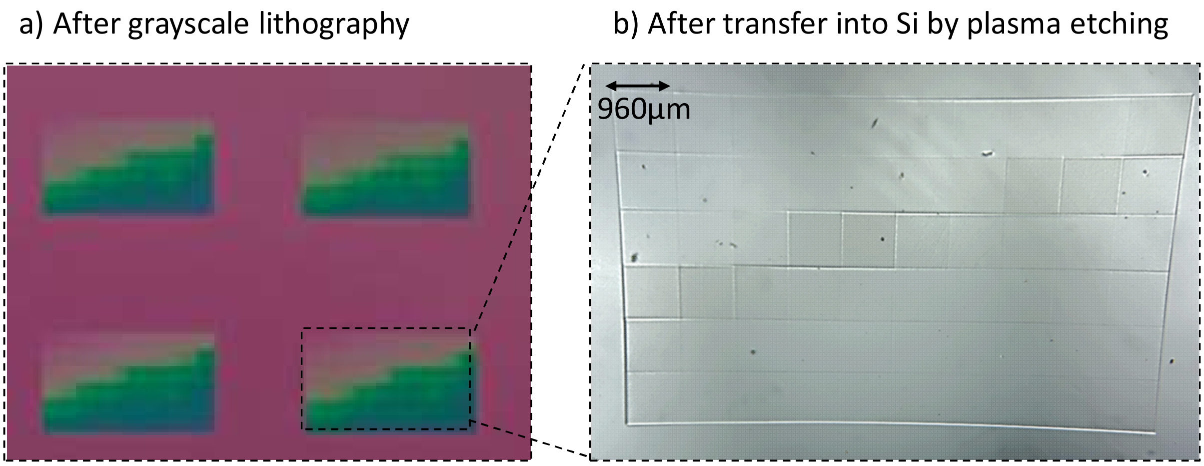

Figure 1: (a) arrays of 960x960 µm² developed in the photoresist using grayscale lithography; (b) one array after transfer into the Si substrate by plasma etching

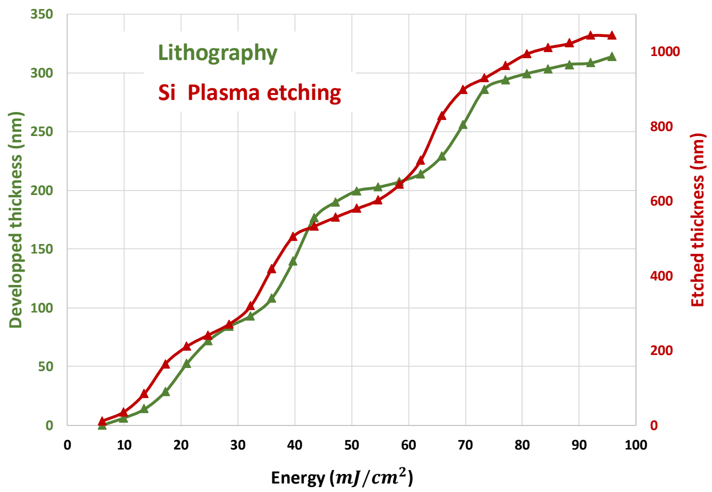

Figure 2: resist thickness after development (green) as a function of exposure dose, and corresponding Si depth after plasma etching (red)

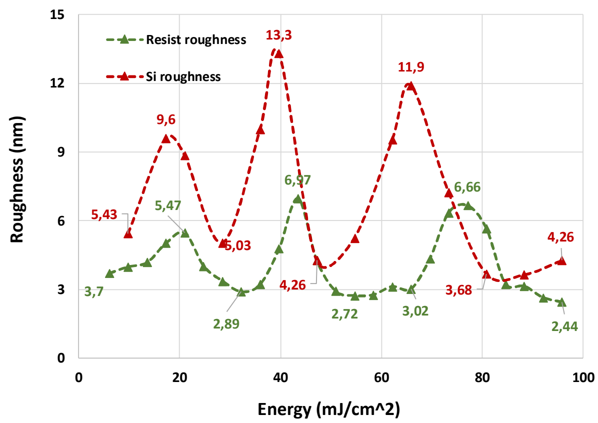

Figure 3: R_q roughness obtained in the resist after lithography (green) and in the Si substrate after plasma etching (red)