Large-Area Manhattan Patterns via Cutting of Gratings

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IC patterns are the so-called "Manhattan Structures" where the patterns are mostly along two orthogonal directions. Fritze, *et al*, demonstrated using the highly parallel and high-resolution process of interference lithography (IL) to generate dense gratings, and then cut the gratings to form IC patterns [1]. This allows IC patterns to be generated much faster than what is achievable with electron-beam lithography. Meanwhile, forming arbitrary Manhattan structures requires stitching the gratings at specific locations. Recently we demonstrated cutting and stitching of highly-smooth gratings at 64nm pitch and with individual feature sizes down to 10~15nm using electron-beam lithography [2].

Here we report our effort to generate large-area Manhattan structures with highly smooth side walls, via cutting gratings exposed by IL. A [110] oriented silicon wafer was oxidize in a Blue-M furnace at atmosphere to yield a 70nm thick oxide. An 80nm thick PFI-88 photoresist was spun on directly on the oxide and exposed in a Lloyd's mirror setup with a 325nm He-Cd laser (Fig. 1a). Grating was aligned along the [111] direction. Dry etching with CHF_3 transfers the pattern to the oxide layer (Fig. 1b). Gratings with highly smooth side walls were achieved with KOH wet etching at 55 °C (Fig. 3a).

Typical IL exposures require an anti-reflective coating layer to suppress the reflection which can significantly reduces the process window. Fortunately, due to the self-smoothing effect of orientation dependent etch, we can tolerate high level of line-edge roughness and therefore do not require anti-reflective coating.

Figure 2 illustrate the process we adopted to cut the gratings. A layer of ZEP 520A was spun over the gratings and e-beam exposure was done at the areas where the gratings are to be removed, followed by reactive-ion-etching in a high-density plasma tool (STS ASE) with a mixture of SF_6 and O_2. Fig. 3a shows the aligned cutting achieved. Note the much smoother grating line edges than those shown in Fig. 1. The e-beam exposure dose is controlled such that there is always a residue layer of resist in the grating grooves to protect the substrate. This is possible as the resist in the grooves of the grating is thicker than that over the grating teeth. As a result, small misalignment will not deform the pattern. Fig. 3b shows such protection. The cut area was over etched. However, the area next to the cut is protected with a residue layer of e-beam resist and was not etched.

We will conduct stitching of gratings and then transfer the Manhattan pattern to the substrate via nanoimprint lithography.

References:

[1] M .Fritze, *et al*, "Hybrid optical maskless lithography: Scaling beyond the 45nm node", *J. of Vac. Sci. & Technol. B,* **23**, 2743-2748, (2005).

[2] L. Zhao and M. Qi, "Generating Manhattan patterns via cutting and stitching of gratings", *52nd International Conf. of Electron, Ion, and Photon Beam Tech. and Nanofabrication*, Portland, OR (2008).

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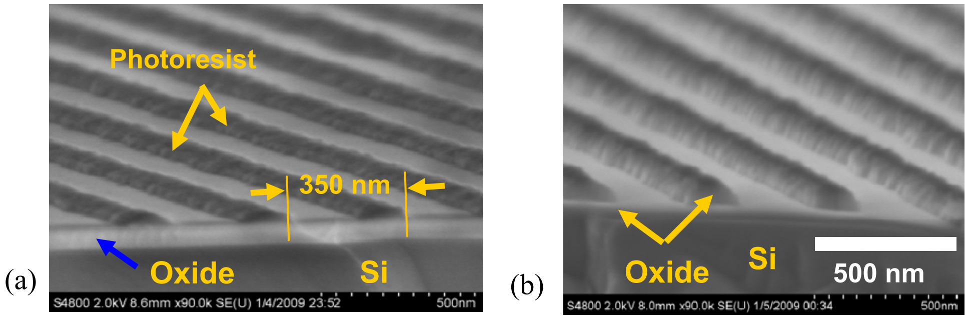

Fig. 1: (a) Gratings in 80-nm thick photoresist after IL exposure. (b) Gratings partially etched into oxide layer. Line-edge roughness is noticeable due to the lack of anti-reflective coating. However, the line edges will be smoothed out in the subsequent orientation dependent etch of Si.

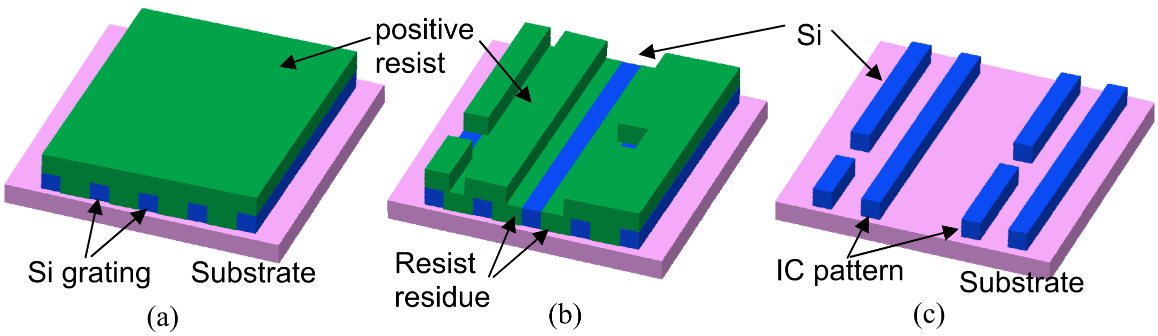

Fig. 2: Schematic of a process to cut gratings. (a) A thick positive e-beam resist (ZEP 520A) is spun over the gratings. (b) Exposure over the areas where the gratings are to be removed. The dose is controlled such that there is always a residue layer of resist to protect the substrate. As a result, small misalignment will not deform the pattern. (c) Reactive-ion etching (RIE) to cut the gratings at desired locations.

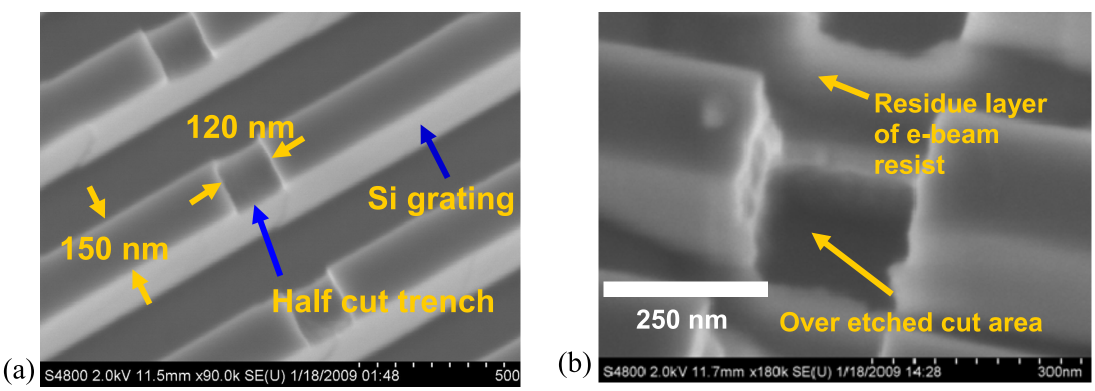

Fig. 3: (a) Aligned "half" cutting achieved for a grating of 350nm pitch. Notice the smooth sidewalls of the grating in Si. The sharp corners indicate reduced proximity effects. The cutting depth could be adjusted by changing the dry etching time to expected value. (b) Protection of the substrate with resist residue in the grooves of the grating. Exposure was chosen such that the resist in the grating grooves will not be fully exposed. Fig. 3b shows that despite the over-etching in the cut area, the adjacent areas in the grooves were covered by resist and not etched.