Generating Manhattan Patterns via Cutting and Stitching of Gratings

Lin Zhao and Minghao Qi*
Birck Nanotechnology Center, Purdue University, West Lafayette, IN 47906

For high-throughput manufacturing of Integrated Circuits (ICs), duplicating the circuit patterns on masks or templates via photons (*e.g.* optical lithography) or mechanical interaction (*e.g.* nanoimprint lithography) is currently adopted due to its massive parallelism. However, making the masks or templates still requires the electron-beam lithography, and is a low-throughput and high-cost process with long turn-around time.

IC patterns are the so-called "Manhattan Structures" where the patterns are along two orthogonal directions (Fig. 1). 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]. However, to be able to form arbitrary Manhattan structures, stitching the gratings at specific locations is highly desirable.

Here we demonstrate a process to generate Manhattan structures with highly smooth sidewalls at 64 nm pitch and 10-15 nm line width. With IL, the process can, in principle, significantly reduce the time and cost required to generate the templates for nanoimprint or optical projection lithography.

The fabrication process starts with e-beam (Vistec VB6) writing of 64nm pitch gratings in 45nm HSQ along the [111] crystal line on a [110] oriented silicon wafer (Fig. 2, left). It is well known that under basic solutions such as KOH or TMAH, the etch rate of silicon along the [110] and [100] crystal orientations are two orders-of-magnitude faster than that along the [111] direction. With KOH wet etching at 30 °C, highly smooth side walls were achieved for 25 nm lines at 64nm pitch (Fig. 2, right). In principle, grating lines in [110] silicon have higher quality (linewidth uniformity, line edge smoothness) than those generated directly with e-beam lithography and dry etch.

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. 3 shows the aligned cutting achieved for gratings of 64 nm pitch and 10 – 15 nm line width. To achieve stitching, a thin layer of HSQ was spun over the cut gratings, and the stitch areas were exposed. Upon development, the exposed areas become the "stitches" that form the Manhattan structure, while unexposed HSQ was removed, leaving the original gratings. We achieved grating lines stitched together at 64 nm pitch and 10-20 nm line width (Fig. 3). An advantage of the cutting and stitching process is that the proximity effects normally encountered in e-beam lithography is no longer a prominent issue as no 90°-turn patterns are to be exposed.

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).

* corresponding author: Minghao Qi, 1205 W. State St, Rm 1297, West Lafayette, IN 47906
Email: *mqi@purdue.edu*

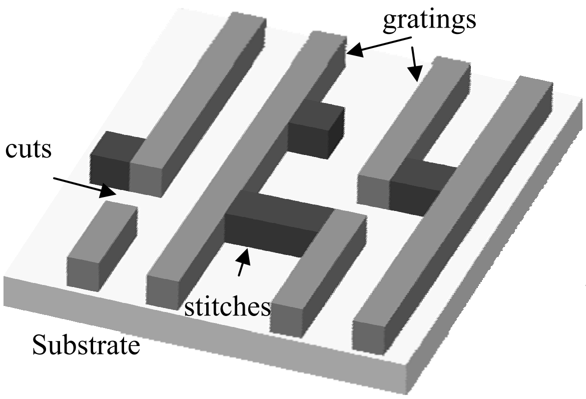

Fig. 1. Synthesis of arbitrary Manhattan structures from regular structures such as gratings. Gratings can be cut and then connected together. The areas to be cut or stitched are significantly reduced when compared to the total area of grating teeth, cuts and stitches. A 20-40 fold area reduction is projected, thus reducing the time to generate the pattern via serial process such as e-beam lithography.

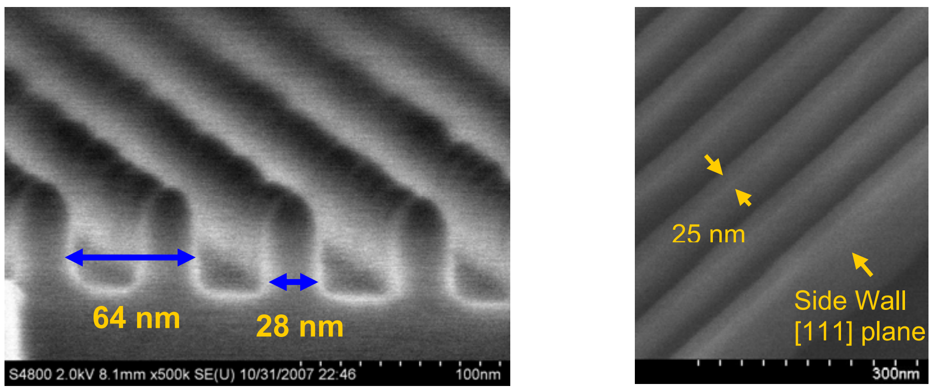

Fig. 2: (left) Gratings in 45 nm HSQ. Roughness is noticeable. (right) Gratings etched into [110] silicon in KOH, with highly smooth side walls.

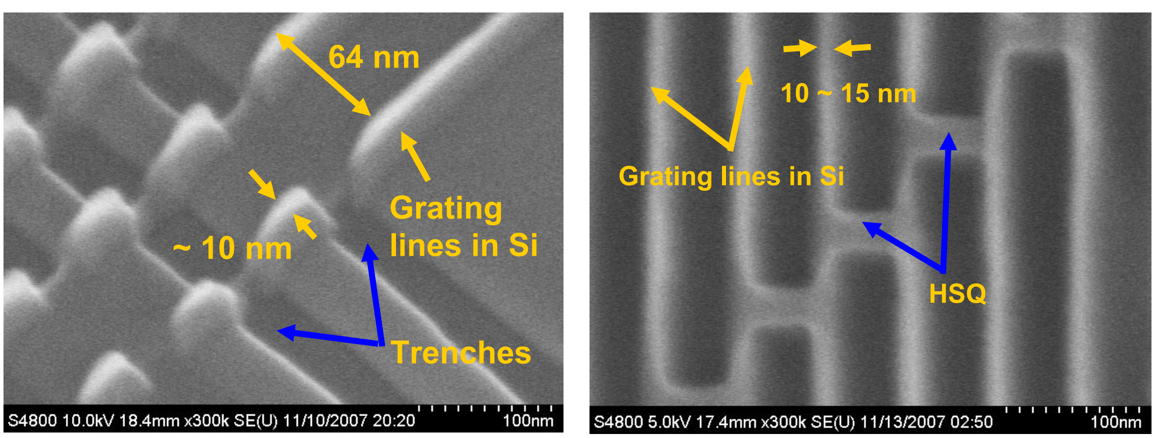

Fig. 3: (left) Aligned cutting achieved for gratings of 64 nm pitch and 10 – 15 nm line width. The recessed grating pattern can be eliminated if the gratings reside on a substrate that has selectivity over silicon during dry-etch. Moreover, if the pattern is to be duplicated via nanoimprint lithography, the recessed grating will not print. (right) Grating lines were accurately stitched together at 64 nm pitch and 10-20 nm line width. Even though the stitches are in HSQ and gratings are made from silicon, they perform the same function of deforming the resist during the nanoimprint process.