Displacement Talbot lithography for uniform high aspect ratio gratings fabrication

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Silicon based gratings with high aspect ratio are the essential component of X-ray grating interferometry systems[1]. To fabricate a phase-shift grating, a lithography step to prepare the pattern and then an etching step to transfer the pattern into the substrate (see Figure 1) are required. Displacement Talbot lithography (DTL) was introduced to enable rapid patterning of periodic structures with submicron feature sizes and large depth of focus to improve the pattern uniformity on wafer scale[2,3]. During the exposure process in DTL the distance between the mask and the substrate is scanned by one or several Talbot distances. However, the scanning stage movement affects the pattern causing an alternating linewidths, that is called "beating effect". Consequently, the trenches in the gratings are then etched to an alternating depth due to micro-loading effect during the deep reactive ion etching (DRIE) process. Figure 2 schematically illustrates these two effects.

In this work[4], we simulated the beating effect and experimentally validated that the increase of the scanning range lead to uniform structure fabrication.

The DTL process was done with an Eulitha Phable R200 tool using a 2 μm pitch linear grating π-phase shift photomask, which produces a 1 μm-pitch linear grating pattern in the photoresist. The duty cycle uniformity was improved by increasing the scanning distance during the DTL process (see Figure 3(a)-3(d)), which further moderated the micro-loading effect during the DRIE of the high aspect ratio grating structures (see Figure 3(e)-3(h)). A grating with a pitch of 1 μm and duty cycle 0.5 was etched into a depth of 27 μm, resulting in an aspect ratio of 54:1.

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2. Jefimovs, K. *et al.* Fabrication of X-ray Gratings for Interferometric Imaging by Conformal Seedless Gold Electroplating. *Micromachines* 12, 517, doi:10.3390/mi12050517 (2021).
3. Jefimovs, K. *et al.* High-aspect ratio silicon structures by displacement Talbot lithography and Bosch etching. *Advances in Patterning Materials and Processes XXXIV (March 27, 2017)* 10146, 101460L-101460L-101467, doi:doi: 10.1117/12.2258007 (2017).
4. Shi, Z., Jefimovs, K., Romano, L. & Stampanoni, M. Optimization of displacement Talbot lithography for fabrication of uniform high aspect ratio gratings. Japanese Journal of Applied Physics 60, SCCA01, doi:10.35848/1347-4065/abe202 (2021).

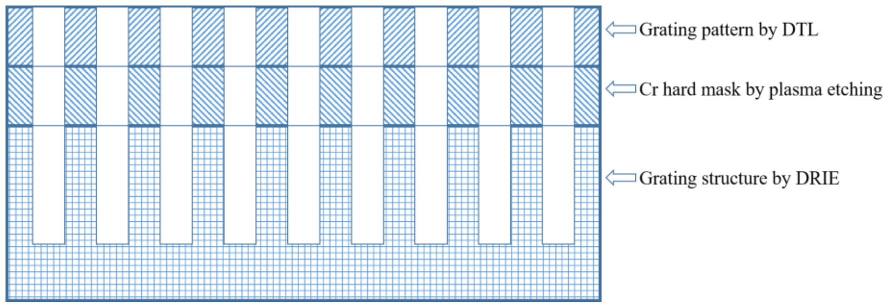

Figure 1: Schematic process flow of grating fabrication.

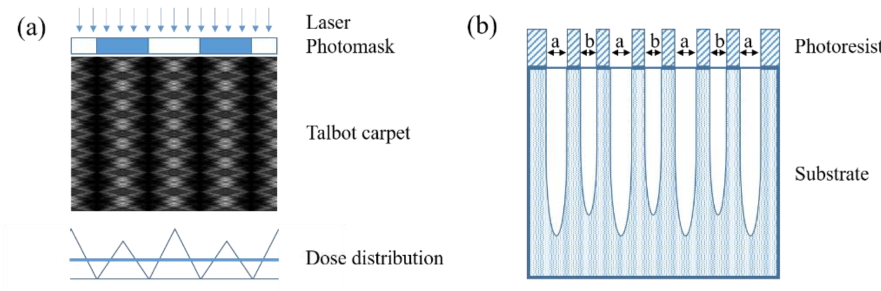

Figure 2: Challenges in grating fabrication. (a) light dose beating during DTL process causing alternating widths of grating lines a and b; (b) micro-loading effect during DRIE resulting wider trenches to be etched deeper.

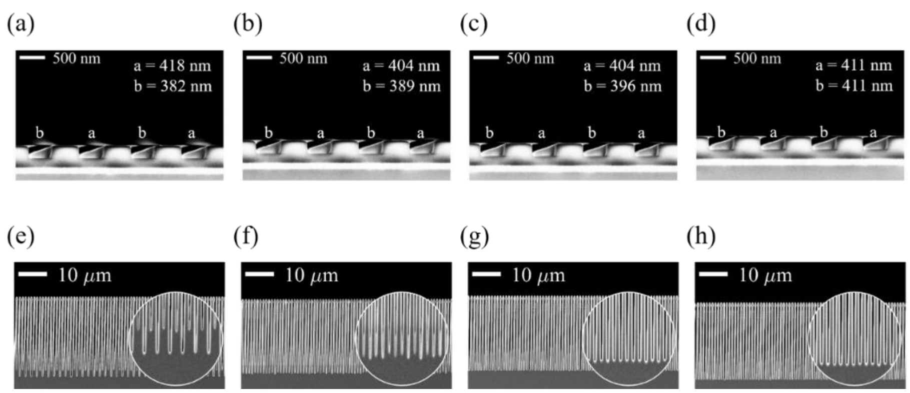

Figure 3: SEM images in cross-section of photoresist after development and grating structure, with DTL scanning distances of: (a)/(e) 26.5 µm, (b)/(f) 53 µm, (c)/(g) 106 µm, (d)/(h) 159 µm.