Fabrication of Large-Area 100 nm Checker Board Mold Using 3D Patterning with Multiple Nanoimprint Lithography and Self-Aligned Selective Etching

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Nano-checker board structures have many applications (e.g. surface enhanced Raman scattering) with high performances [1]. However, large-area nano-checker boards have not been fabricated before. Using EBL, it is impractical to write a needed large area and it also suffers proximity effects that prevent a writing of sharp corners, small structures and dense periods (all of them are important to SERS). Conventional double cycle nanoimprinting creates a two-dimensional net structure, but not a checker board structure.

Here, we propose and demonstrate a novel method to fabricate wafer-scale checker board structures with sub-100-nm squares and half-pitch, as well as sharp corners, without using EBL. The fabrication process utilizes 3D patterning with double nanoimprint lithography and self-aligned selective etching process to fabricate a checker-board mold, and then use it to do high-throughput duplication. We demonstrated a checker board nanoimprint mold with 100 nm wide squares.

The key fabrication steps in fabricating a checker board mold (Fig. 1): (i) fabricate a 1 D grating of 1:1 duty cycle in a SiO_2 layer on top of a silicon substrate, with the grating depth equal to a half of the total SiO2 thickness, using nanoimprint with a 1D master and RIE (Fig. 1.a); (ii) a second nanoimprint lithography was used to create a 1D resist grating that is normal to and on top of the 1D SiO2 grating (Fig. 1.b,c), (iii) by transferring the resist grating into the SiO2, it results in two 2D pillars sets interwoven with each other and each set has a different height (Fig. 1.d); (iv) a sacrifice polymer layer was spun on and a RIE exposes the set of pillars with a large height, while the ones with a lower height were still covered (Fig. 1.e); and (v) another RIE with different chemistry removes the set of taller pillars, but does not etch the set of lower height pillars which were protected by the sacrificial layer, forming a large-area checker board mold in the SiO_2 (Fig. 1f). A key novelty in the fabrication process is that the height difference in the higher and lower level pillars self-aligns the sacrifice polymer as a mask to protect the lower level checker board pillars and expose the higher level pillars to be etched.

Figure 2 shows SEM images of the fabrication results: (a) a cross-section of the 2 sets of 200 nm period SiO_2 pillars with different height (100 nm and 200 nm); (b) after coating the sacrifice polymer layer on top of 2-level pillars and exposing the top-level pillars by precisely controlled etching; (c) selectively etching of SiO2 over polymer leaves a checker board structure on the substrate with (d) as the zoom-in picture showing the details of the checker board structure. As expected, nanoimprint, which does not have proximity effects, gives very sharp corners. The current line edge roughness can be removed by self-perfection by liquefaction (SPEL) [2].

In summary, we present a novel approach to fabricate wafer scale sub-100-nm checker board structures without using EBL, which opens a path to a number of applications in surface enhanced Raman spectroscopy and plasmonic devices.

[1] S. Chen et al, Opt. Express, 16 (2008) 13016-13023
[2] S. Y. Chou and Q. Xia, Nat. Nanotechnol. **2008**, 3 (5), 295-300.

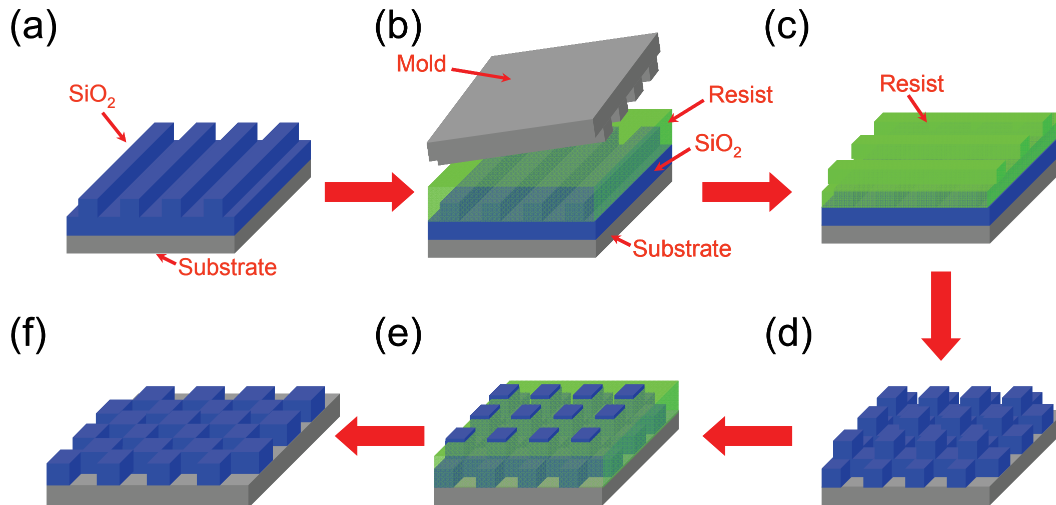

Fig.1. Fabrication flowcharts of the checkerboard mold by nanoimprint lithography: (a) 1-D SiO_2 grating cycle fabricated with depth of half total SiO_2 thickness and duty cycle of 1:1;(b) another 1:1 duty cycle grating was fabricated in a resist which covers the original SiO2 grating. (c) The grating's orientation is perpendicular to SiO2 grating. (d) Transferring the resist grating into the SiO2, forming 2 sets of pillars with different height. (e) Apply a sacrifice polymer layer, and expose and etch away *only* the top level oxide pillars. (f) Final checkerboard pattern after cleanup the sacrifice polymer.

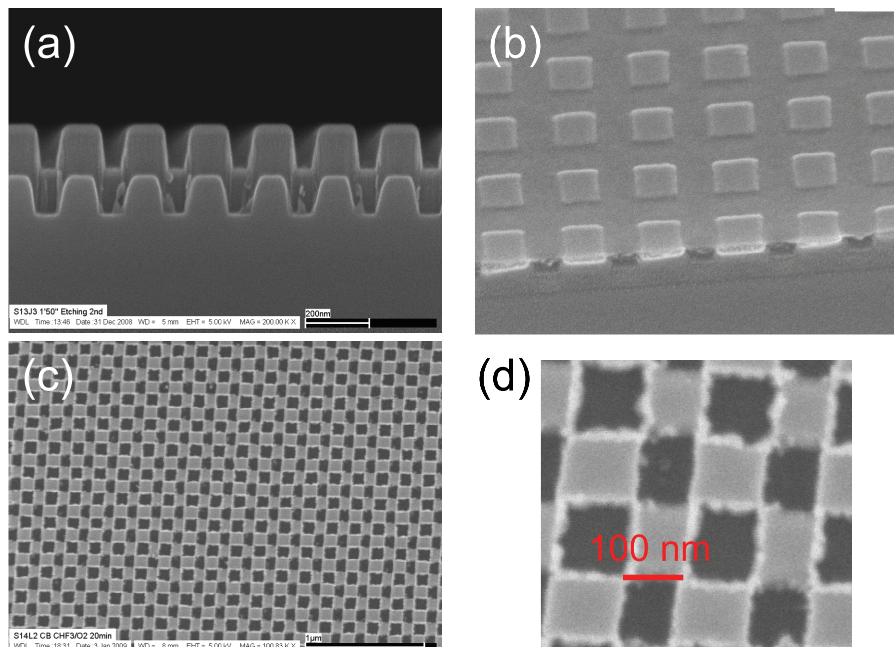

Fig.2. SEM images of the fabrication process. (a) Two sets of pillars with different heights after double cycles of nanoimprints and RIE. (b) Sacrifice polymer layer on the substrate with a partial of it etched away, exposing the tall pillars (but not the lower pillars). (c) Final checkerboard mold. (d) Zoom-in of the final checkerboard mold.