Multiple Double-Nanoimprint Fabrication of Wafer-scale Nanopillar Array Mold with Varying Pillar Shape, Pillar density, and Pillar Spacing Without EBL

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In many applications, including nanoimprint mold making, there is a great need for new technologies that can fabricate complicated nanostructures over entire wafer without using electron beam lithography (EBL) to achieve high throughput and low cost. Here we report the proposal and the first demonstration of a new method that can fabricate wafer-scale (4" dia) nanopillar array with varying pillar shape, pillar spacing, and pillar density (number of pillars per unit cell) without using EBL. Our approach can be extended to fabricate other complex nanopatterns and has been proved to be very useful in SERS study.

Our method is based on two rounds of double-nanoimprint fabrications. In the first round double-nanoimprint fabrication, a linear grating master mold (200 nm pitch and 4" diameter) was used to fabricate an intermediate pillar mold, by two cycles of nanoimprint and etching on the intermediate mold substrate (Fig. 1.a, b). In the second cycle, the grating mold was aligned a small angle off from the normal to the grating patterned in the first cycle, which results in a pillar array mold (200 nm pitch and 4" diameter) with pillars slightly rotated from a regular square array.

In the second round of double nanoimprint fabrication, the intermediate pillar mold was used in two cycles of nanoimprint and etching to fabricate the final pillar mold (Fig. 1c, d). In the second cycle, the intermediate pillar mold was aligned another small angle off to a parallel axis of the pillar array created by the first cycle. It makes the final pillar mold to have a varying of pillar shape, pillar spacing, and pillar density (number of pillars per unit cell), depending upon local overlap of the double imprints (Fig. 1e).

Figure 2 shows the Cr pattern made after the second round of double nanoimprint and lift-off. The Cr later was transferred to SiO2 pillars by RIE. The nanopattern on the wafer varies from a round single pillar per cell (due to local perfectly overlap in the second round of double nanoimprint by the intermediate pillar mold) (Fig. 2a), to a single elongated pillar per unit cell (locally slight off-set in the second round of double nanoimprint) (Fig. 2b), to two separate pillars with a small gap per unit cell (Fig. 2c), and to two separate pillars with equal spacing per unit cell (Fig. 2d). The separation between each center of the two pillars in a unit cell can be varied from zero (perfectly overlap) to 100nm (totally separate with a small gap). The separation varying rate can be controlled by off-set angle used in double nanoimprint. For an off-set angle of 3.7º in the first round and 0.3º in the second round, the separation varying rate in Fig. 2 is 4.5nm/1um.

Our approach can be further extended, with certain variations, to the fabrication of other complex nanopatterns on wafer scale (4" dia or larger) without using electron beam lithography, and should have rather broad applications to different fields.

[1] S. Y. Chou, P. R. Krauss, W. Zhang et al., "Sub-10 nm imprint lithography and applications", Journal of Vacuum Science & Technology B, Vol. 15, Issue 6, Page 2897-2904, 1997

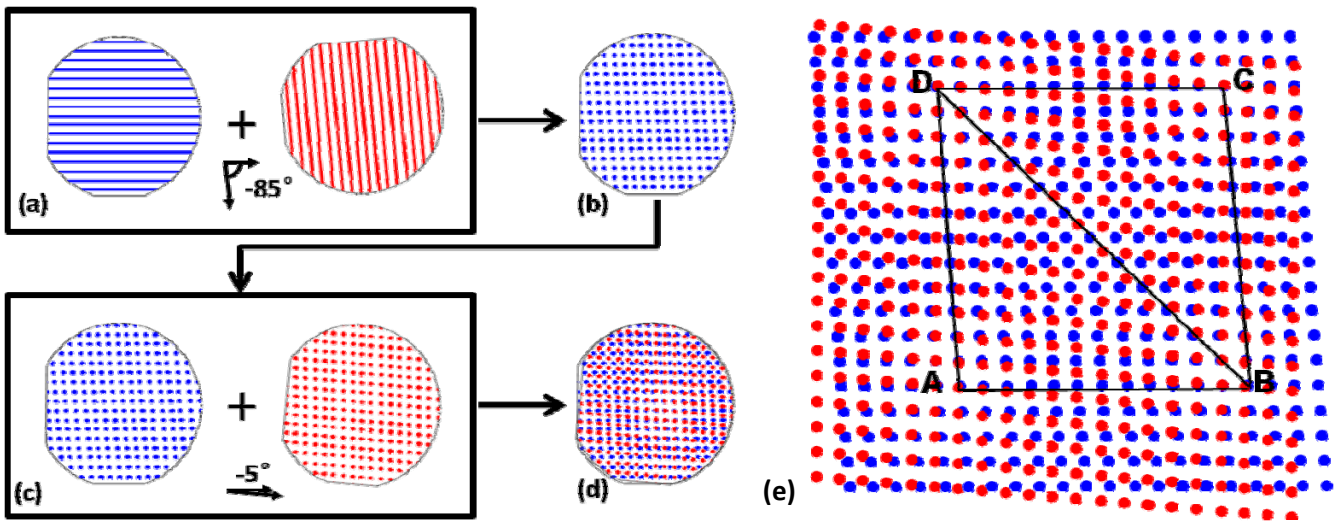

Fig.1. Schematics of wafer-scale nanopattern generation by two rounds of double nanoimprint. (a) In the first round, a liner grating master was used. (b) an intermediate pillar mold formed, (c) In the second round, the intermediate pillar mold was used. (d) Pillar array with varying pillar shape, spacing, and number of pillar per unit cell. And (e) Zoom-in of nanopatterns in Fig. 1d, where equilateral parallelogram ABCD shows one period of the pattern variation.

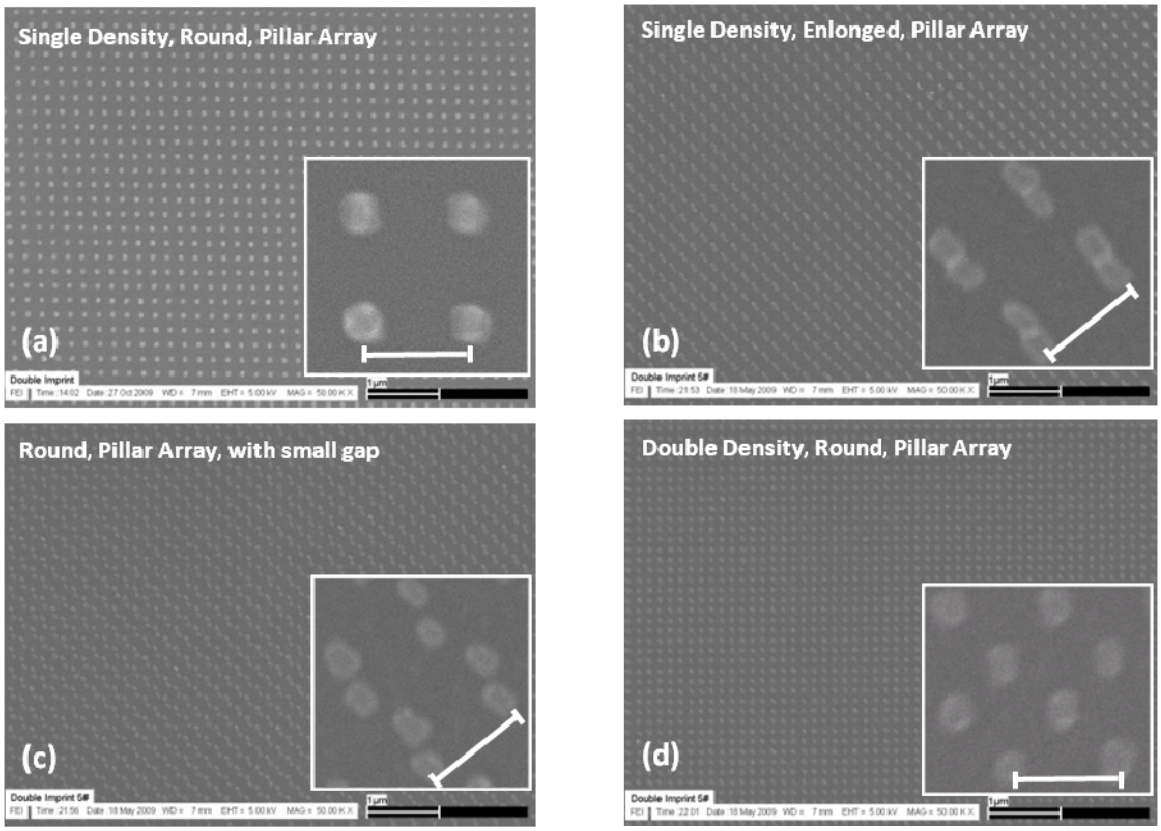

Fig.2. SEM of different locations of the Cr pattern on SiO_2 of a Si wafer made right after the second round of double nanoimprint and lift-off (followed by RIE into SiO_2 using Cr as mask). The pillar shape, spacing, and the number of pillars per cell of the pillar array are (a) single round pillar per unit cell, (due to perfectly overlap between two nanoimprint in the second round) (b) single enlonged pillar per unit cell (partially overlap, with longitude axis changing linearly) (c) two round pillars per unit cell with a small gaps (non-overlap). (d) two round pillars per unit cell with equal spacing. The scale bar: 200nm.