Nanoimprint Mold Fabrication by Quantum Lithography on Nanoimprinted Blanks

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Quantum lithography (QL), proposed by Pease et al, is a path-changing new method in mask making, potentially offering over 10x higher throughput, better patterning precision, and much lower cost than conventional e-beam lithography [1]. QL has been demonstrated in making photomask [1]. Recently we further advanced QL by using nanoimprinted mask blanks, termed quantum-patterning using nanoimprinted-blanks (QUN), and demonstrated photomasks with 100 nm half-pitch tile arrays (hence 25 nm half-pitch after 4X reduction) [2]. However, QL cannot be directly applied to the fabrication of nanoimprint molds (masks), which, being 1x mask, have far greater needs for higher resolution than 4X photomasks. This is because the gaps between the tiles in QL, which is much less than the exposure wavelength and hence "invisible" in photolithography, will be faithfully produced in nanoimprint and destroy the intended patterns. Here, we demonstrate a method that can seal off the gap and hence produce good nanoimprint mold by QUN.

In our method, an atomic layer deposition (ALD) was used to seal the gaps on the blanks after the nanoimprint mold was patterned by QUN [3]. Specifically, the fabrication of the nanoimprint mold started with a standard positive tone QL (Fig. 1) on nanoimprinted-blanks, where an electron beam tags (selects) a set of Cr tiles on the blank by exposing a hole in the covering PMMA resist to compose the intended patterns, while other Cr tiles were unexposed. After the e-beam exposure, a chromium etchant was flowed through the exposed holes, removing tagged Cr tiles but keeping untagged Cr tiles. After striping the resist, the remaining Cr tiles were used as etching masks to pattern underlying SiO_2 by fluorine-based reactive ion etching.

Then, ALD was used to deposit a conformal layer of aluminum oxide on the surface with enough thickness to completely fill the gaps, as shown in Fig. 2. In the ALD process, alternating pulses of trimethylaluminum (TMA) and water vapor are flowed into a chamber which is heated at 180˚C and each cycle grows a single atomic layer (~1.1Å) of aluminum oxide. Totally 44 nm aluminum oxide was grown on the sample to ensure a complete filling of the gaps. Fig. 3 shows the SEM pictures taken on the sample before ALD filling (Fig. 3(a)) and after ALD filling (Fig. 3(b)). The nanoimprint mold with gaps filled by ALD was treated with an anti-sticking layer and used in a thermal nanoimprint process, and Fig. 3(c) shows the SEM picture of imprinted resist.

In summary, we demonstrated the use of quantum lithography on prepatterned nanoimprinted tile array blanks together with ALD to fabricate nanoimprint molds with feature size smaller than 200 nm without any gaps between the tiles. This approach has achieved a throughput enhancement of two orders of magnitude over conventional e-beam lithography.

[1] Maluf, N.I. and R.F.W. Pease, *Quantum Lithography.* Journal of Vacuum Science & Technology B, 1991. **9**(6): p. 2986-2991
[2] S. Y. Chou, W.D. Li and X. Liang, "Quantized Patterning using Nanoimprinted Blanks", Nanotechnology, 20, 155303, 2009.
[3] M. Qi, S.Y. Chou and R.F.W. Pease, private communication, 2006.

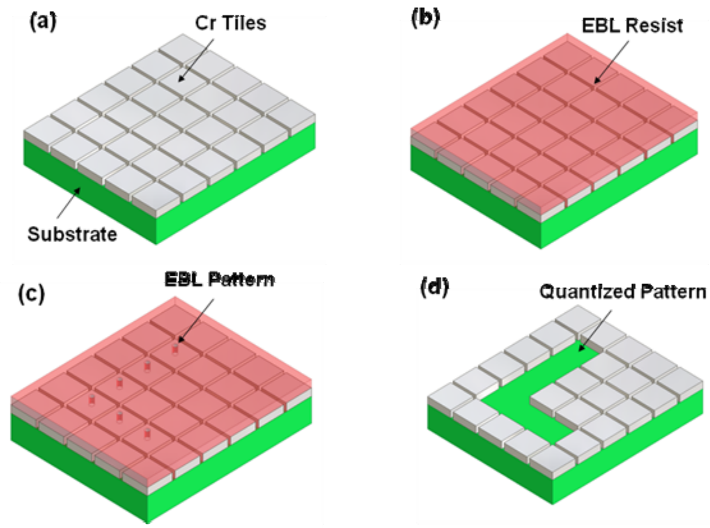

Fig. 1. Schematic of a positive-tone quantum lithography process: (a) a Cr tile array blank fabricated by nanoimprint lithography, featuring 200 nm pitch and a narrow trench of sub-30 nm; (b) spin EBL resist (PMMA 996K) on the blank and bake overnight at 160C to ensure good sealing the trenches between tiles; (c) electron beam tags a set of tiles composing designed patter by exposing a hole on the resist covering the targeted tiles; (d) chromium etchant flows through the exposed holes in PMMA resist and etches away selected tiles.

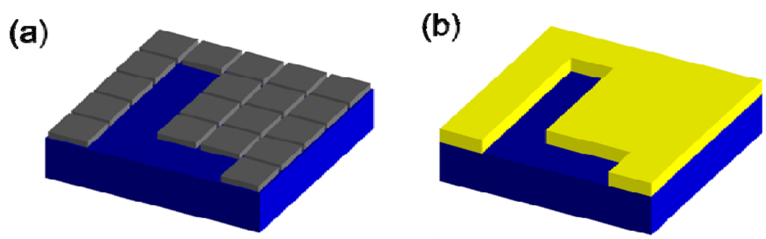

Fig. 2. Nanoimprint mold fabrication using quantum lithography. (a) the positive designed patter after quantum lithography on the tile array blank; (b) atomic layer deposition is used to conformally deposit a layer of Al2O3 with precisely controlled thickness and seals the gap to complete the fabrication of a nanoimprint mold

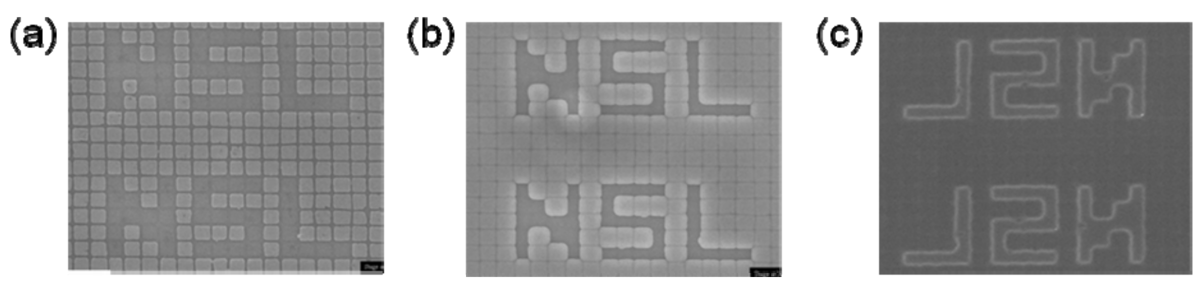

Fig. 3. SEM images of (a) a Cr tile array blank patterned with arbitrary patterns by quantum patterning using nanoimprinted-blanks (QUN); (b) a nanoimprint mold made by etching into underlying SiO2 using the Cr tiles as masks followed by filling gaps using ALD; (c) imprinted pattern in resist using the nanoimprint mold in (b); there are no gaps between tiles.