Negative Tone Quantum Lithography at 200-nm Pitch Nanoimprinted Blanks

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Quantum lithography (QL) proposed by Pease et al [1] is a revolutionary approach to solve the throughput and cost issues in electron beam lithography (EBL). To make QL practical, we recently proposed and demonstrated the use of nanoimprinted tile array as the mask blank, termed quantum-patterning (lithography) using nanoimprinted-blanks (QUN) [2]. However, until now all the demonstrated QL patternings are in positive tone, namely the tagged tiles are etched away while the untagged tiles stay. Yet in many applications, a negative tone QL (where tagged tiles stay) is required, because it can greatly reduces EBL writing time. Here, we propose and demonstrate a novel method to realize negative tone QL. The new method, based on electrochemical etching, has achieved negative tone QL patterning on 200 nm pitch square Cr tile arrays with a narrow gap of sub-20 nm.

The key steps in the novel negative tone QL consists of (a) fabrication of the negative-tone QUN blank, which is a 200-nm-pitch square tile array with a narrow gap between tiles which are made of Al/Cr bi-layer and an EBL resist overcoat (PMMA in our case) (Fig. 1); (b) quantum lithography to tag the desired tiles of QUN blank and a selective etching to remove, through the exposed holes, the Al of each tagged Al/Cr tile but not Cr (Fig. 2); and (c) striping of the resist and another electrochemical selective etching with diluted HCl solution (1:3) to etch away untagged tiles while keep the tagged tiles (Fig. 2). The HCl solution etches the Cr tiles that are in contact with Al, but not Al or a pure Cr tile that does not contact Al. When the Cr tiles are etched away, the Al tiles on top will be lifted off, completely removing the entire untagged tiles.

In fabrication of the bi-layer tile array on the QUN mask blank (Fig. 1), we first deposited 20 nm Cr followed by 10 nm Al on a silicon substrate with a 130 nm SiO_2 top layer. Then we used nanoimprint lithography to pattern a resist using a square pillar mold with very narrow gaps. A lift-off formed 200 nm pitch Al/Cr square tile array on top of the SiO_2 layer, completing fabrication of the negative tone QUN substrate. Figure 3 shows the results of our experiments: the SEM images of (a) 200 nm period Al/Cr bi-layer tile array with a 30 nm gap fabricated on a QUN blank; and (b) the final "L" pattern achieved on the negative tone QUN blank using QL and the selective etching process described above. The SEM images show good quality of the final pattern using this negative tone QUN substrate and QL. The throughput enhancement of negative tone QL over conventional EBL is similar to that of positive tone QL, which is analyzed in [2] to be 1~3 orders of magnitude. depending upon the pitch of a QUN blank.

We believe the first demonstration of negative tone QUN blanks reported here will open up much wider applications to quantum 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, EIPBN 2008; Nanotechnology, in press, 2009.

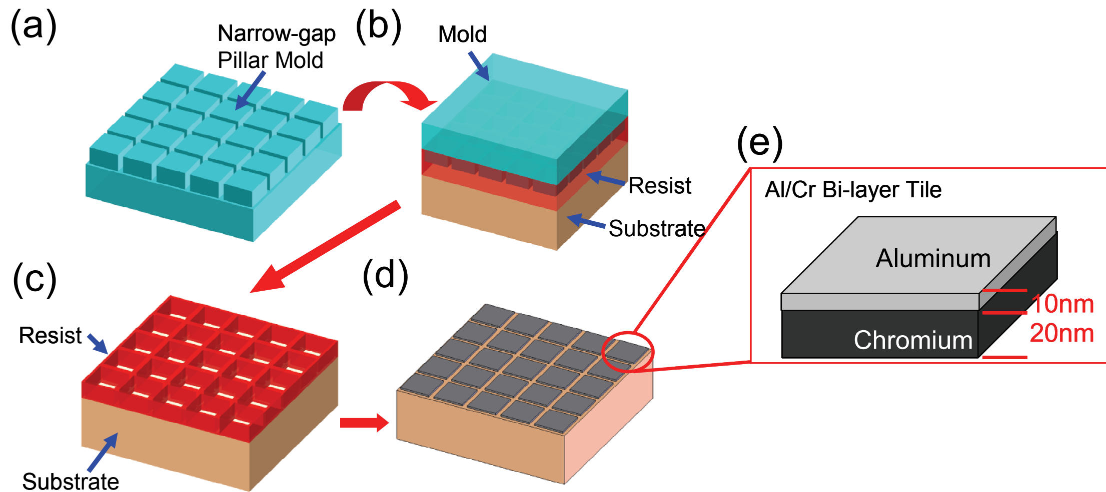

Fig. 1. The key steps in fabricating a negative tone QUN blank, (a) a square pillar mold with very narrow gaps; (b) imprinting the mold into resist spun on a substrate; (c) imprint resist carrying the square patterns; (d) Al/Cr bi-layer tiles array formed through normal e-beam evaporation of chromium and aluminum subsequently and lift-off; (e) structure of an individual Al/Cr bi-layer tile.

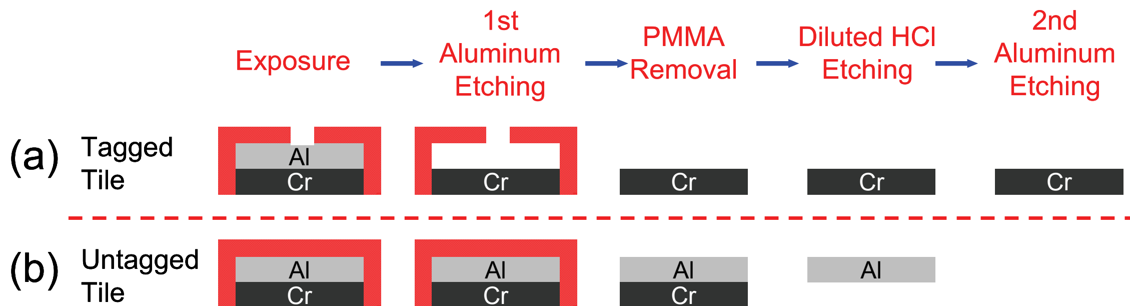

Fig. 2. QL and selective etches on tagged tiles (a) and untagged tiles (b). For tagged tiles (a), Al was etched away first and Cr will remain in the diluted HCl etching which etches the Cr of untagged tiles because it is electrically connected with aluminum. Finally, a second aluminum etching cleans up all the

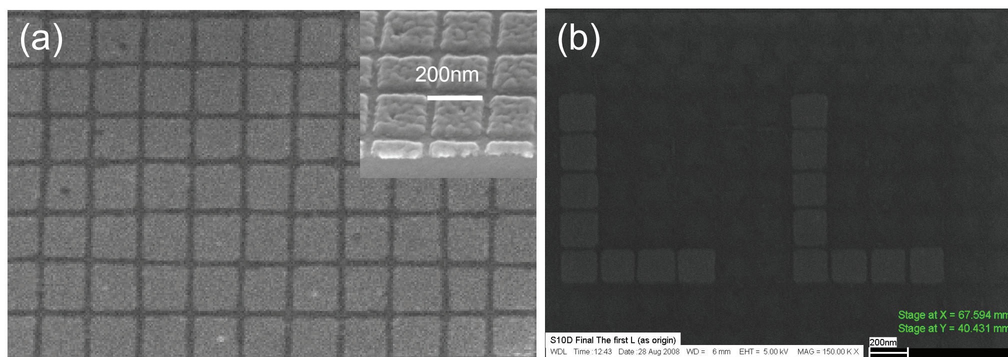

Fig. 3. SEM images of (a) a negative-tone QUN blanks with 200 nm pitch; (b) the final "L" pattern by negative tone quantum lithography that tagged the "L" shape.