Mitigation of Microloading Effect in Nanoimprint Mask Fabrication

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Lithography and etch processes are critical to mask making. Both photomask and nanoimprint mask fabrication need optimized models and processes to adjust for proximity effect in the lithography step and loading effects in the etch step. The impact of microloading on photomask etch has been widely studied in the last decade; microloading results in differing etch depths for different pattern densities. Various techniques have been proposed to minimize microloading; these include using an optimized etch process [1], using an etch-stop layer, spacers [2], and a multi-step etch [3]. Techniques used to reduce microloading in photomask etch cannot always be directly extended to nanoimprint masks. In case of nanoimprint mask fabrication, the effects of litho and etch are more critical because of the 1:1 reproduction of features on the mask. Also, to keep the imprint mask cost low, simpler processes are preferred.

The proposed technique uses grayscale lithography [4] to reduce the microloading effect, Fig. 1. Wide trenches are exposed with a slightly lesser dose than needed for full resist dissolution, thus leaving behind a thin layer of resist in these regions. Narrow trenches are exposed normally. This cancels the effect of microloading, resulting in a uniform trench depth across the substrate. A combination of electron-beam lithography and ICP etch is used to demonstrate the technique. The first step in the process is to extract dose-depth curves for the lithography process; then a reference pattern consisting of various trench dimensions and areal densities is taken through a litho and etch process to characterize the microloading effect. The trench opening varies from a few microns to a few nanometers. The dose-depth data and the etch data are fed to a model that calculates the necessary dose distribution for the pattern file while including proximity effects. This step is repeated a few times until the desired results are obtained.

ZEP 520A is chosen as the resist because of its high etch resistance compared to other positive resists. Silicon is used as the substrate for making the imprint mask. For electron-beam lithography, a 100 kV tool - JEOL JBX-9300FS - is used. The optimized silicon etch process uses a combination of Ar and Cl_2 in an ICP chamber. Trench-depth characterization was carried out using a Veeco AFM with a 20 nm tip radius that limited the resolution to trench widths on the order of 50 nm. A Zeiss Ultra 60 SEM was used to study CD uniformity.

The dose-depth curve for 330nm ZEP 520A on Si is extracted and the dose for 90% dissolution is 148 uC/cm^2. Fig. 2 shows the trench depth vs. trench area before and after implementing the proposed process. After two iterations of modeling and litho/etch, we achieve a reduced microloading effect. The proposed process is modeling intensive but repeatable and requires no extra process steps. The method can be extended to fabricate templates using a variety of other materials.

References:

[1] T. Faure, E. Fisch, C. Huynh, and S. Crawford, *Proc. SPIE*, **5567**, 155 (2004).
[2] M. Tsai, and C. Yang, United States Patent 6,251,791, 2001.
[3] S. Kato, M. Sato, and Y. Arita, *JVST A*, **12**, 1204 (1994).
[4] R. Murali, D.K. Brown, K.P. Martin, and J.D. Meindl, *JVST B,* **24**, 2934 (2006).

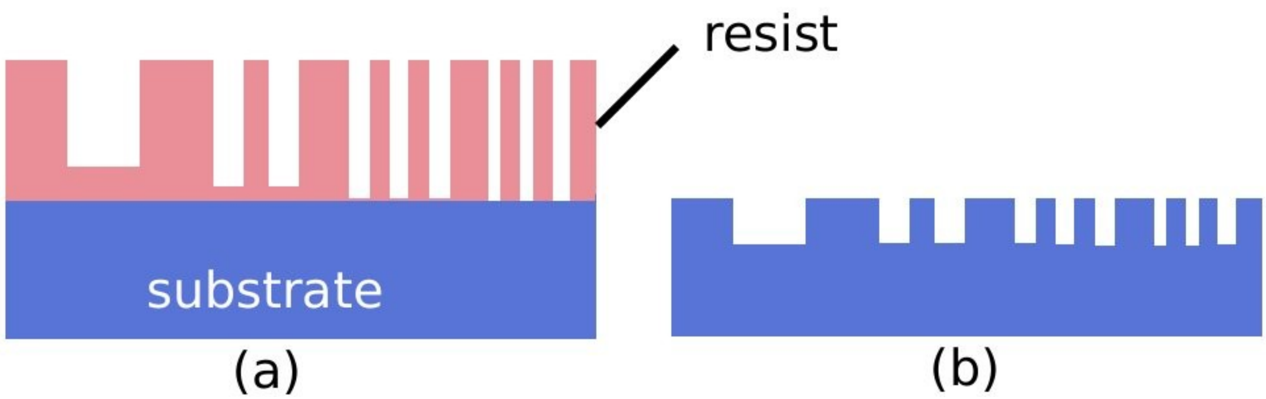

Figure 1: Wide trenches are exposed with a slighly lesser dose than needed for full resist dissolution, (a). Narrow trenches are exposed normally. This cancels the effect of microloading resulting in a uniform trench depth across the substrate, (b).

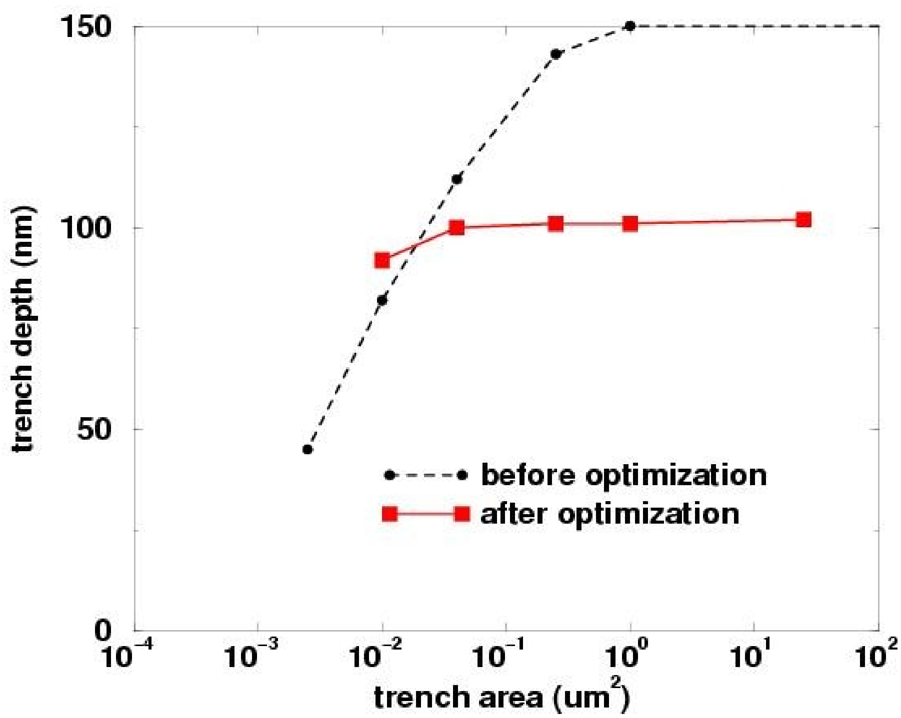

Figure 2: Etch depth vs. trench area before and after optimization. Using the proposed optimization process, the microloading effect has been significantly reduced compared to the original process.