Characterization of photoresist using double-exposures with interference lithography

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The effect of image contrast and dose (average energy per unit area) on linewidth in interference lithography (IL) is important in applications requiring precise control of linewidth or requiring good linewidth uniformity. Previous papers [1, 2] have discussed the effect of image contrast and dose on linewidth using an experimental approach that requires one exposure for each combination of spatial period, dose and image contrast. This leads to a need for a large number of exposures. We describe a novel experimental method to characterize photoresist behavior, measuring the same data using a single exposure (albeit a double-exposure) for each combination of period and dose.

The method consists of double-exposing the photoresist, using the same image contrast and dose for both exposures. The substrate is rotated slightly (1-2 degrees) between the two exposures. The result is effectively an intensity distribution with constant period and dose, but image contrast varying continuously from zero to the contrast of the two individual exposures. Depending on the dose and type of resist used, the developed pattern will consist of discontinuous slots or lines. By measuring the length of the slots or lines, and the period of the pattern in the same direction, it is possible to determine the minimum contrast required for lines to develop for the given resist, period and dose. When the contrast is lower than this, either all the resist develops away, or it does not fully develop. By measuring the linewidth at a variety of points on the sample it is also possible to determine the linewidth as a function of contrast using a single sample. In addition, the double-exposure method makes it easy to identify the dose where the linewidth varies least with contrast, which is of particular interest for many applications.

A Lloyd's mirror IL system was used to demonstrate the double-exposure method with both positive and negative resists. Conventional, single-exposures were performed for comparison. It was found that the fractional linewidth (width/period) is largely independent of the period, and that the linewidths in high-contrast regions of the double-exposed samples match the linewidths obtained from single-exposures (where the contrast is the same). The results were also compared to a simple, binary-resist model, revealing important differences between the behavior of real and ideal photoresists.

References:

1. Juan C. Montoya, Chih-Hao Chang, Ralf K. Heilmann, and Mark L. Schattenburg, J. Vac. Sci. Technol. B **23**, 2640 (2005).

2. A. Bourov, S. A. Robertson, B. W. Smith, M. A. Slocum, E. C. Piscani, Proc. SPIE 6154, (2006)

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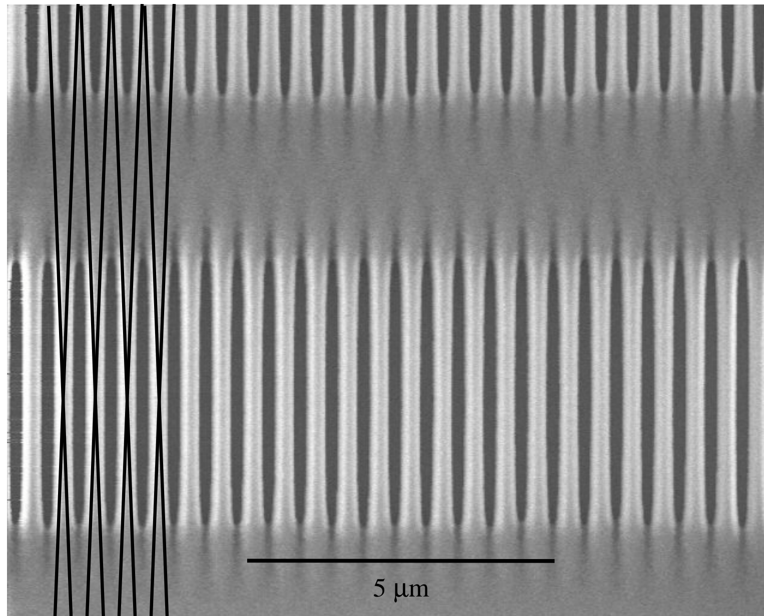

Figure 1. Typical result of narrow-angle double exposure test using Ohka THMR-iN PS4 negative photoresist. Lines are drawn in the left portion if the micrograph to indicate the relative orientation of the two exposures that formed this pattern (the lines indicate where the intensity maxima would have been.) Contrast is high where the two patterns are in phase, and drops to zero where the patterns are out of phase. Slots form in areas of high contrast. In low contrast areas the resist has not cleared fully. Spatial period is 500 nm.

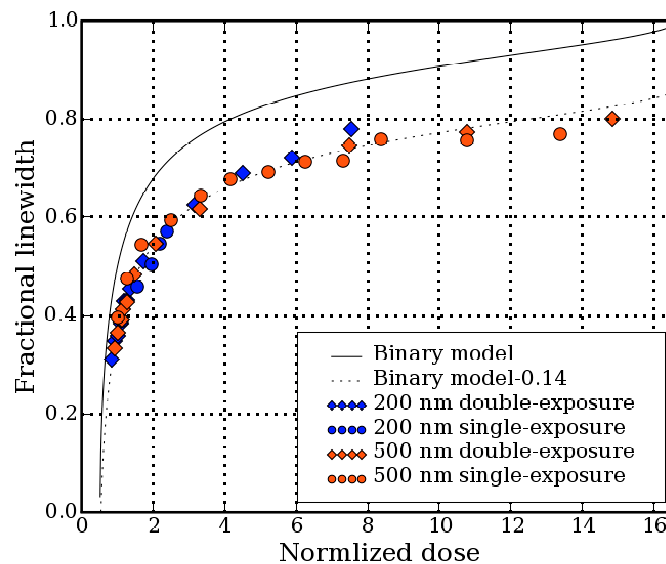

Figure 2. Fractional linewidth obtained with negative photoresist for various combinations of dose and period. Using the double-exposure method, the linewidths obtained in the high contrast region (where the contrast is equal to the contrast in a single exposure) match the linewidths obtained from a single exposure at the same dose. The experimental results follow a curve with the same shape as predicted by a binary model but shifted by a constant amount.