Empirical Modeling of Lithographic Error in Direct Write Laser Lithography

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Direct write laser (DWL) lithography is a popular maskless lithography technique that transfers CAD patterns into photoresist (PR) films for mask making or micro-nanofabrication. Patterns printed by DWL lithography may yield errors including a positive or negative critical dimension (CD) bias versus the design, positional inaccuracy, and shape infidelity. To understand how to minimize these errors and determine the minimum possible CDs achievable by DWL lithography, we investigated these errors and built models to explain their source. The experiments were done by printing test patterns on MicroChem S1800 series PR on Si using a Heidelberg DWL66+ featuring a 355nm laser using the 2 and 10 mm write heads.

The errors of the patterns can be sorted into two types: universal systematic errors that occur in every pattern and large-region relative errors that occur among patterns at different positions. Figure 1(a) shows the universal errors: the CD response is strongly correlated to the power of laser beam (exposure latitude). Moreover, the CD bias has no observable dependency on pattern size and local density. When examining patterns in a large region, a periodic position error was found, and the period was equal to the stripe width employed, as shown in Figure 1(b). We also found poor shape fidelity at the stripe boundaries, where the width shrunk and the height expanded.

These errors can be explained by the models we built. The model explaining the universal errors is shown in Figure 2(a). During exposure, the write laser gives a shot at each pixel spot with an exposure intensity distribution (EID), and the total EID of DWL in the pattern field is the superposition of the contribution from all laser shots, which is similar to the EID in E-beam lithography except the absence of the backscattering contribution[1]. A threshold exposure intensity is needed to completely remove the PR, so the CD of a pattern equals the length between two intercepts of the total EID and the threshold intensity line. The exposure latitude in Figure 1(a) is decided by the edge shape of the total EID, which can be obtained from the experiment data, as shown in Figure 1(b). According to our model, this edge shape is only decided by the write head and does not depend on resist type and thickness. Thus, the exposure latitude may be gathered for a resist of any type and any thickness by doing only one exposure test on that resist. This model also indicates that the exposure latitude of DWL is limited by the EID of the write laser. The model explaining the large-region errors is shown in Figure 3. When writing, the write laser scans across a stripe through being deflected by an acousto-optic modulator, and the deflection has an error, causing a slight stripe expansion. This stripe expansion model can explain the periodic position errors of the patterns across stripes and the shape infidelity of the patterns at stripe boundaries. According to this model, the large-region fidelity of DWL lithography is limited by the accuracy of the beam deflection, and can be improved using multiple passes writing.

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[1] T. H. P. Chang, J. Vac. Sci. Technol., 12, 1271 (1975)

We built these two models based on the experimental results using 10mm write head and will expand our library of results to include sub-micron patterning using the 2mm write head.

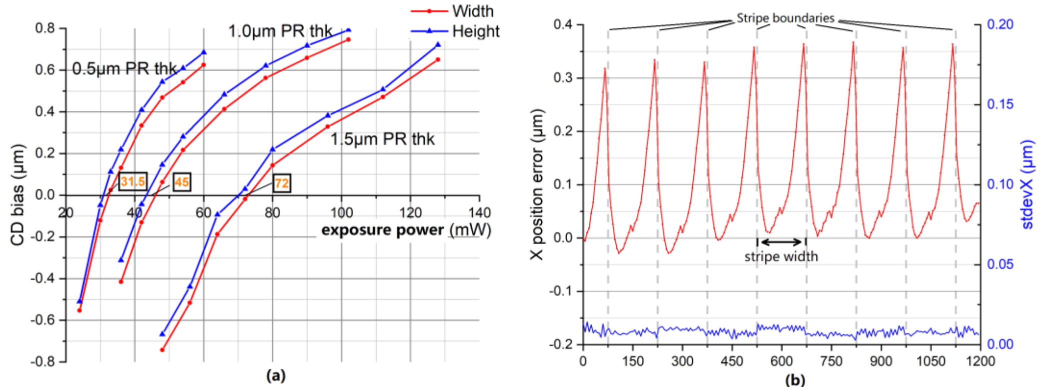

Figure 1: Errors of patterns printed by Heidelberg DWL66+ 10 mm write head: (a) Exposure latitude on different thicknesses PR. CD bias is measured CD of patterns - designed CD, exposure power is the power of laser beam shot on the PR. (b) Positioning errors of patterns across stripes. The position error is the measured coordinate of the centroid of a pattern - the designed coordinate. Y axis indicates the designed coordinate.

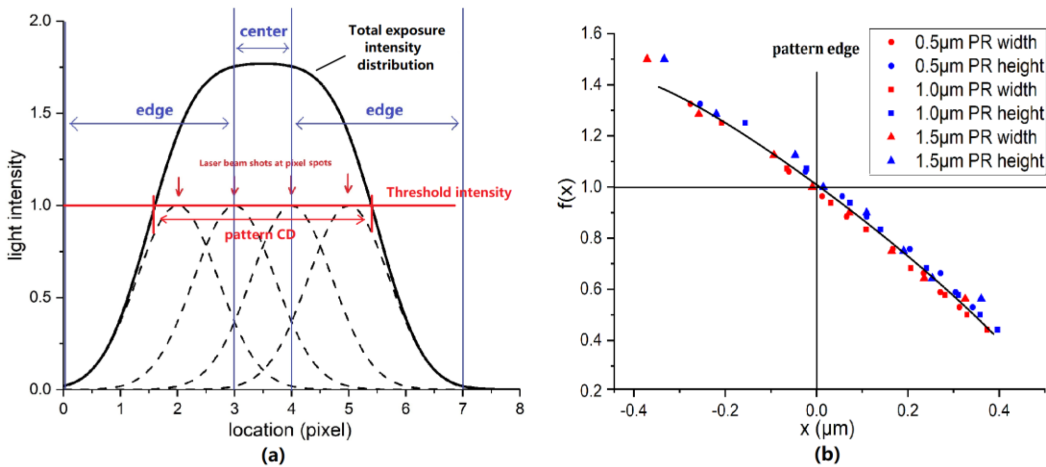

Figure 2: A model explaining the universal errors. (a) Exposure intensity distribution of DWL. (b) The proposed physical model shows good agreement to the empirical measurements.

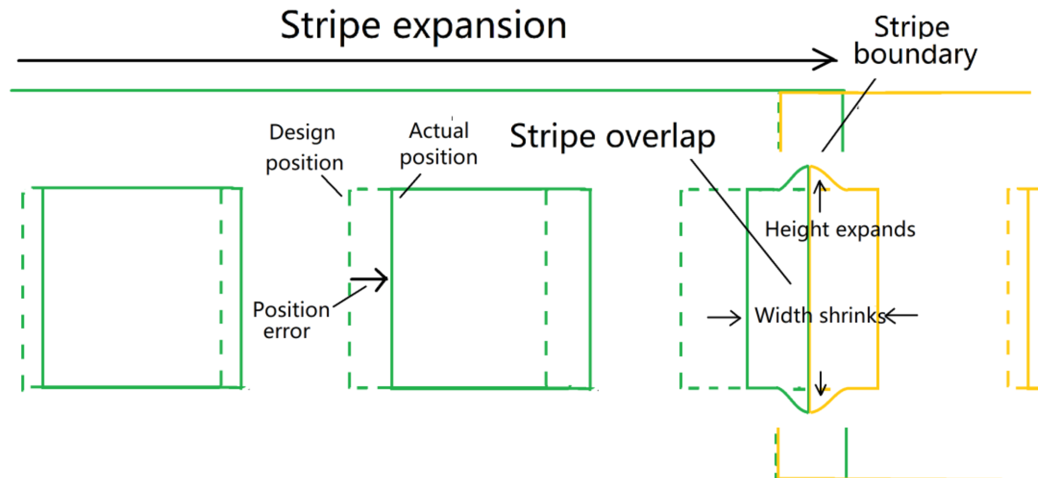

Figure 3: A model explaining the large-region errors.