A comparative study of resists and lithographic tools using Lumped Parameter Model

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In any lithographic process, the most technologically important parameter is the critical dimension (CD) of the patterned resist as a function of energy (Dose), which results from the interplay of the characteristics of the resist and of the aerial image. The Lumped Parameter Model (LPM) by Mack[1,2] is based on the segmented development model of resist after exposure, providing an accurate estimate of the CD vs. Dose. However, its exact analytical modeling is difficult in practice due to its heavy computational burden, and therefore approximate models are usually employed.

In this work we present a numerical implementation in MATLAB of the exact LPM formula and the resulting CD vs. Dose for the following lithographic processes and corresponding aerial images: 1. Conventional photolithography with a gaussian beam profile; 2. Interference lithography (IL) with a sinusoidal aerial image; 3. Electron and ion beam lithography with a combination of gaussian beams. For instance, it was found that the CD vs. Dose, calculated for the same negative-tone resist parameters and patterned in dense line/spaces of pitch 200 nm (Figure 1), shows remarkable differences between different lithographic methods. In projection photolithography, the CD plot is steep and saturates at about 5x the base dose, i.e. when the feature size equals the pitch. In interference lithography instead, the CD plot flattens and never saturates even at higher doses. As a result, in the latter process the feature size of dense line/spaces patterns is less sensitive to dose fluctuations than it is in the former.

In addition, we used a non-linear least squares method to fit our LPM implementation to experimental CD vs. Dose data. Experimental data were obtained by analytical metrology (SuMMIT software) of top-down SEM of dense line/spaces exposed by: 1. extreme ultraviolet (EUV) projection optical lithography; 2. EUV IL; 3. 100 keV electron beam lithography; 4. 30 keV He^+ ion beam lithography. We chose HSQ, PMMA and other EUV photoresists from undisclosed manufacturers, which are patternable by all these tools. The fitting of LPM to the data from an IL exposure of a 60 nm-pitch positive-tone chemically amplified resist (Figure 2) showed a high goodness ($R^2 = 0.95$) and yielded realistic values of the fitting parameters (resist contrast $\gamma = 6$, dose to clear = 7.4 mJ/cm^2). We thus validated the reliability of our implementation, which is versatile and applicable to any lithographic process and resists in order to extract either the resist parameters or beam profile of the tool.

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[1] Chris A. Mack, A. Stephanakis, R. Hershel, Interface ’86, Proc., (1986) pp. 228-238.
[2] Chris A. Mack, Optical/Laser Microlithography VII, Proc., SPIE Vol. 2197 (1994) pp. 501-510.

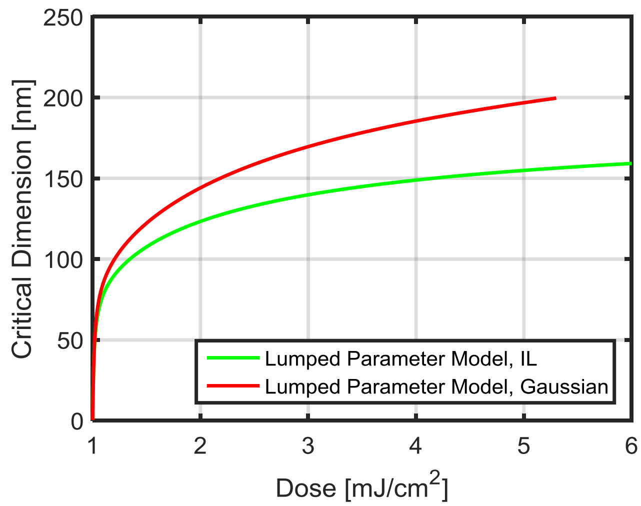

Figure 1: Critical dimension vs. Dose data, calculated by our implementation of LPM for a resist (contrast γ=5, dose to clear = 1 mJ/cm^2), patterned in dense line/spaces with pitch 200 nm. The two plots show the feature size of the resist exposed by 2-beam interference photon lithography (green line) and by conventional gaussian-shaped photon lithography (red line), with same intensity.

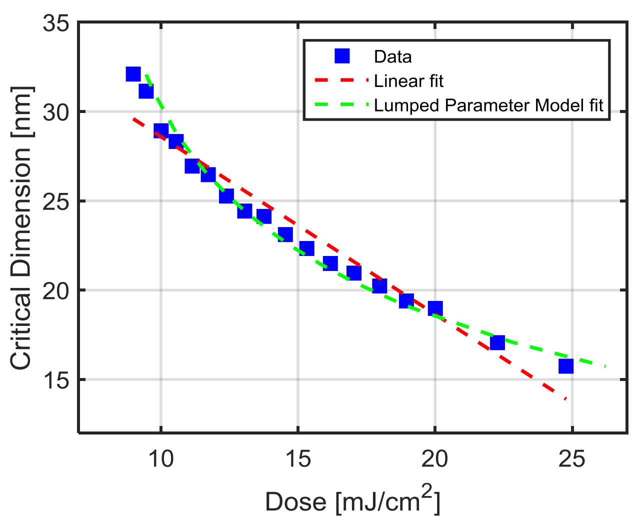

Figure 2: Experimental Critical Dimension vs. Dose data from an interference lithographic exposure of a positive-tone chemically amplified resist in dense line/spaces with pitch 60 nm (blue squares), its least squares fit by a simple linear model (dashed red line), and its non-linear least squares fit by our implementation of the LPM (dashed green line). The latter model clearly provides a better fit to the data, with $R^2 = 0.95$ and fitting parameters: resist contrast $\gamma = 6$, dose to clear = 7.4 mJ/cm^2.