# Analytic Minimization of Line Edge Roughness for Large-Scale Uniform Patterns in Electron-beam Lithography

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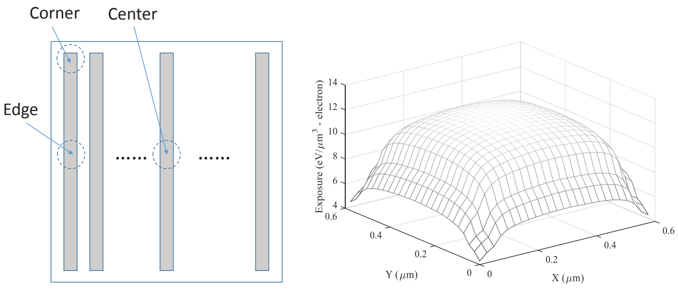
Electron-beam (e-beam) lithography is well known for its ability to transfer high-resolution patterns onto the resist. However, as the feature size decreases into nanoscale, the proximity effect and the line edge roughness (LER) in the resist put a fundamental limit on the minimum feature size and maximum circuit density that can be realized. A simulation or experimental approach may be taken in estimating or minimizing the LER, but such a method is normally time-consuming and costly. In our previous study, an analytic approach to the estimation and minimization of the LER for a single line was developed. Later, the LER estimation was extended for large-scale uniform patterns. In this study, the LER minimization is considered for large uniform patterns is considered.

In the previous study, for a single line exposed with a uniform dose, an analytic expression of LER was derived from the spatial distribution of stochastic developing rate, i.e., $LER(s) = \frac{\sigma(T|s)\cdot m_R(s)}{cos\theta(s)}$, where $\sigma(T|s)$ is the variation of developing time to reach the edge location, $s$, $m_R(s)$ is the average developing rate, and $\theta$ denotes the angle between the direction of resist development and the horizontal plane. For a large uniform L/S pattern (Fig. 1(a)), the LER is derived at three critical locations, i.e., center, edge and corner, by modeling the difference in the exposure distribution among the locations and incorporating it into the single-line result. The LER at other location is obtained through an interpolation using the LERs at the critical locations. In a large uniform pattern, both CD (e.g. linewidth) and LER can significantly vary with the location in the pattern. First, the deconvolution surface (Fig. 2), which is obtained from the global exposure distribution (Fig. 2), is used to derive the spatial dose distribution which achieves the same or similar CD at the critical locations. Then, a cost function consisting of the CD error and LER is employed to further optimize the dose distribution by finding the dose adjustment needed at the critical locations. The final dose distribution is obtained through an interpolation with the dose adjustments.

In the optimization, the cost function consisting of the CD error and LER is employed, i.e., $CDerror + 3 \cdot LER$. Three test locations are selected for the accuracy analysis as shown in Fig. 3(a). The results obtained by the proposed method are compared with those from simulation as shown in Fig. 3(b). The uniform pattern consists of 500 lines, where each line is $50\mu m$ long and $50nm$ wide, and the gap between lines is $50nm$. A typical substrate system is simulated using the CASINO software with 300nm PMMA on Si, the beam diameter of 3nm, and the beam energy of 50 keV. It is seen that the minimum value of cost function obtained by the analytic procedure is close to that by the simulation under the same dose distribution.



(a) (b)

Figure 1: (a) A L/S pattern and (b) a typical global-exposure distribution for a large-scale uniform pattern

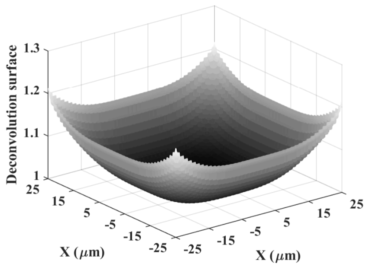
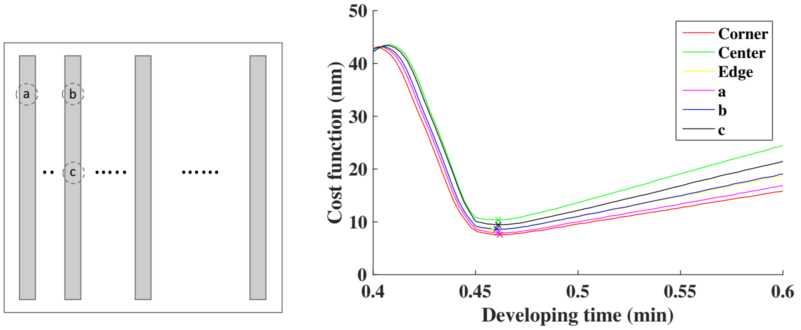


Figure 2: Deconvolution surface



(a) (b)

Figure 3: (a) Three test locations and (b) the cost function evaluated by the simulation and the lowest value (marked by "x") obtained by the analytic procedure.