Analytic Estimation of LER for Large-Scale Uniform Patterns in Electron-beam Lithography

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Electron-beam (e-beam) lithography plays an important role in nanofabrication, being able to transfer high-resolution patterns onto the resist. However, for a circuit pattern of nanoscale features, the proximity effect and the line edge roughness (LER) put a fundamental limit on the minimum feature size and maximum circuit density that can be realized. A simulation-based or experimental approach may be employed in an effort to estimate and minimize the LER. Such a method normally requires a great effort to analyze the relationship between the LER and e-beam parameters and thus is time-consuming. In our previous study, an analytic method of estimating and minimizing the LER for a single long line has been developed, which is proven to be able to achieve a high accuracy compared with simulation results. In this study, the analytic method for estimating the LER is extended for the large-scale uniform patterns.

In the previous study, the middle of a long line is considered such that the average of stochastic exposure (energy deposited in the resist) distribution may be assumed not to vary along its length dimension (Y-dimension in Fig. 1). The LER is analytically derived from the spatial distribution of stochastic developing rate (equivalently exposure), i.e., mean and variance, when the line is exposed with a uniform dose. The expression of the $1-\sigma$ LER is derived as $LER(s) = \frac{\sigma(T|s)\cdot m_R(s)}{cos\theta(s)}$, where s is a variable of edge location, $\sigma(T|s)$ is the variation of developing time, $m_R(s)$ is the average developing rate, and θ denotes the angle between the direction of resist development and the horizontal plane (X-Y plane). It is not straightforward to apply this result to a large circuit pattern since the exposure level varies with location with the pattern. However, for a large uniform pattern such as L/S patterns (Fig. 2(a)) where the same feature is replicated uniformly, the exposure level varies gradually in space (Fig. 2(b)). Note that the spatial variation of exposure level mainly depends on the global exposure. Therefore, it is possible to derive the LER analytically by adjusting the LER expression for a single line according to the location in a large uniform pattern. The analytic expression of LER is derived at three critical locations, i.e., center, edge and corner, by modeling the difference in the exposure distribution between the locations and incorporating it into the single-line result. The LER at other location may be obtained through an interpolation using the LER's at the critical locations.

The LER analytically derived by the proposed method is compared with the LER obtained through simulation at the three critical locations in a L/S pattern in Fig. 3. The L/S pattern consists of 5 lines where each line is 60nm×600nm and the gap between lines is 60nm (i.e., L=S=60nm). A typical substrate system composed of 300nm PMMA on Si, the beam energy of 50keV and the beam diameter of 3nm are assumed. All lines are exposed with a uniform dose of $640\mu C/cm^2$. The stochastic point spread function is generated by the software CASINO. In the figure, it can be seen that the analytic results are well matched with the simulation results. In this paper, the detailed procedures to derive the LER analytically in a large uniform pattern will be provided with more results on accuracy verification.

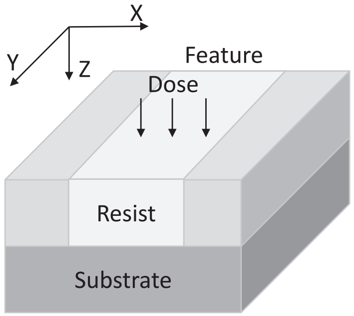


Figure 1: Model

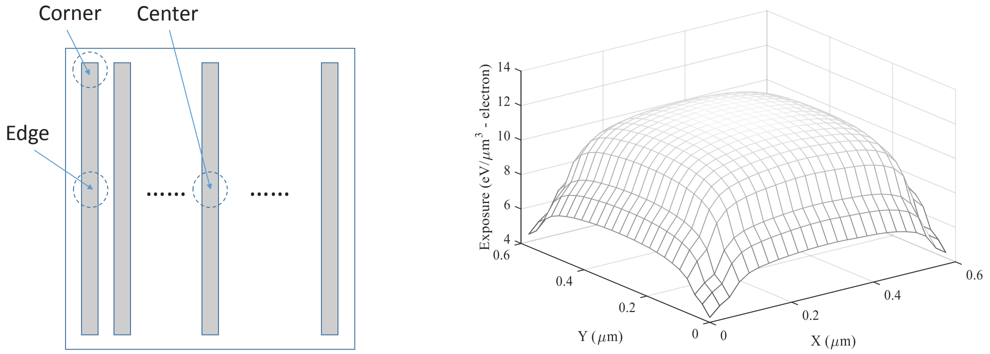
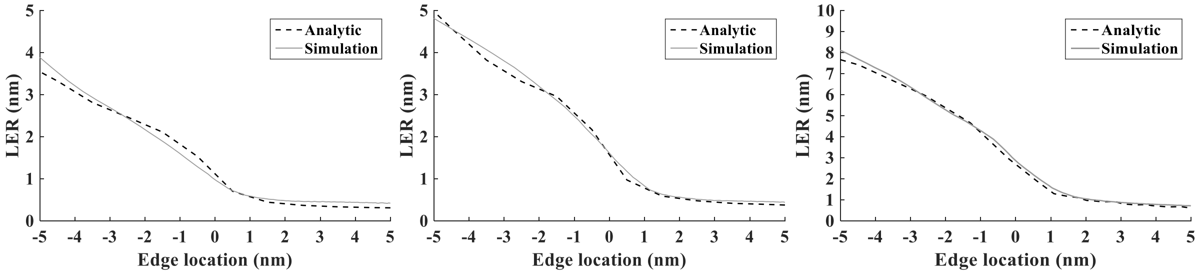


Figure 2: (a) A L/S pattern and (b) a typical global-exposure distribution for a large-scale uniform pattern.



(a) (b) (c)

Figure 3: The LER derived by the analytic method and direct simulation at the critical locations: (a) center, (b) edge, and (c) corner.