Analytic Derivation and Minimization of Line Edge Roughness in Electron-Beam Lithography

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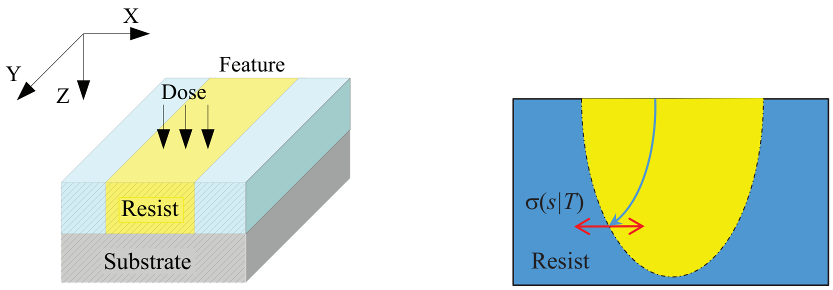
Line edge roughness (LER) has become a limiting factor of the achievable resolution in the electron-beam (e-beam) lithography. In efforts to minimize the LER, it is essential to have an efficient and accurate method to estimate it. In our previous study, an analytic procedure of deriving the LER was developed in order to avoid repeated simulations or experiments. However, multiple involved steps are required in the analytic derivation and the resulted expression of LER is not a function of the e-beam lithographic parameters so that its practical applicability is limited, e.g., in the minimization of LER. In this study, a new approach to the analytic derivation of LER is taken to make the derivation procedure simpler and the LER expression more applicable. Then, the analytic expression of LER is employed in minimizing the LER with respect to a lithographic parameter.

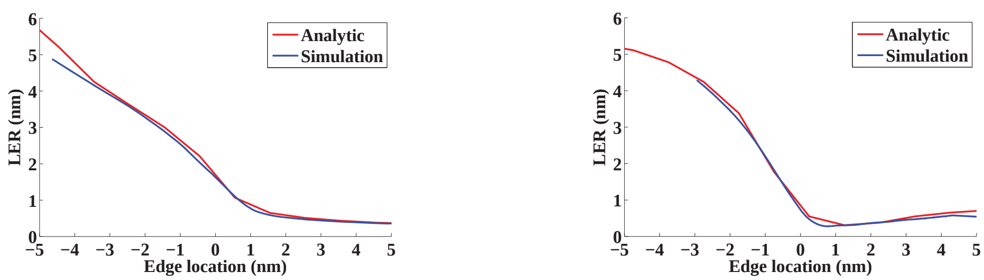
A typical substrate system is depicted in Fig. 1-(a), and the cross-section of the remaining resist profile is shown in Fig. 1-(b) where a developing path is illustrated. A developing path is defined as a path along which the resist development can be traced to determine the remaining resist profile. The developing path is parameterized by the variable s such that $s = 0$ at the starting point of the path. Then, the LER may be defined as $\sigma(s|T)$, i.e., the standard deviation of edge location given a developing time, T. In the new derivation procedure, $\sigma(T|s)$ is first derived by approximating it to be the sum of the standard deviation of $\frac{1}{R(s)}$ along the developing path where $R(s)$ is the developing rate. The time variation ($\sigma(T|s)$) is converted into the location variation ($\sigma(s|T)$) through the relationship $\sigma(s|T) \propto \sigma(T|s) \cdot m_R(s)$. The direction of a developing path is not always completely lateral while the LER is to be evaluated along the lateral dimension. Therefore, $\sigma(T|s) \cdot m_R(s)$ needs to be projected onto the lateral dimension to get the final expression of (lateral) LER. The LER tends to show a monotonic behavior as a function of the edge location and should not be minimized independent of the CD (critical dimension) error. Therefore, a cost function involving both the LER and CD error is minimized through differentiation of the cost function with respect to a lithographic variable (parameter) to be optimized, e.g., the dose.

In Fig. 2, the analytic method is compared to the simulation method for two different cases where it can be seen that the LER by the analytic method is closely matched with the LER obtained through the simulation. In Fig. 3, the cost function (defined as the sum of CD error and 3×LER) is evaluated by the analytic and simulation methods with the dose varied. It is clear that the same optimal dose would be obtained by both methods in each case, which demonstrates the accuracy of the new analytic method. In this paper, the detailed complete description of the new analytic method for deriving and minimizing the LER (and CD error) will be provided with more results.



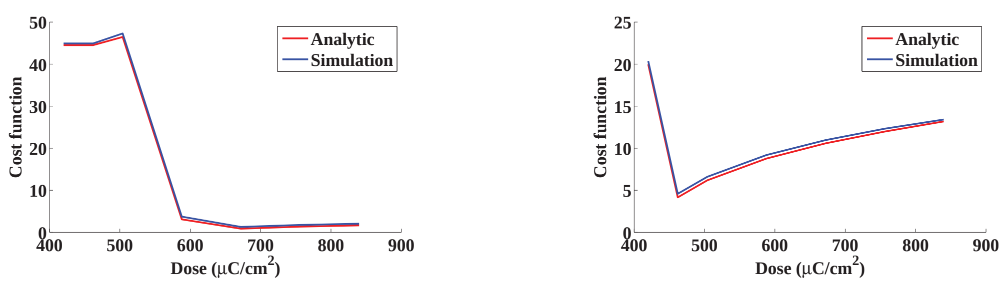
(a) (b)

Figure 1: (a) A substrate system on which a long line feature is exposed, and (b) the cross-section of the remaining resist profile along the line-width dimension where a developing path is illustrated.



(a) (b)

Figure 2: The LER as a function of the edge location, evaluated by the analytic method and direct simulation: (a) 300 nm PMMA on Si and beam energy of 50 keV, and (b) 100 nm PMMA on Si and beam energy of 30 keV.



(a) (b)

Figure 3: The cost function (the sum of CD error and 3×LER) as a function of dose, evaluated by the analytic method and direct simulation: (a) 300 nm PMMA on Si and beam energy of 50 keV, and (b) 100 nm PMMA on Si and beam energy of 30 keV.