An Approach to 3-D Modeling of Electron-beam Lithographic Process from SEM Images for Minimization of CD Error and LER

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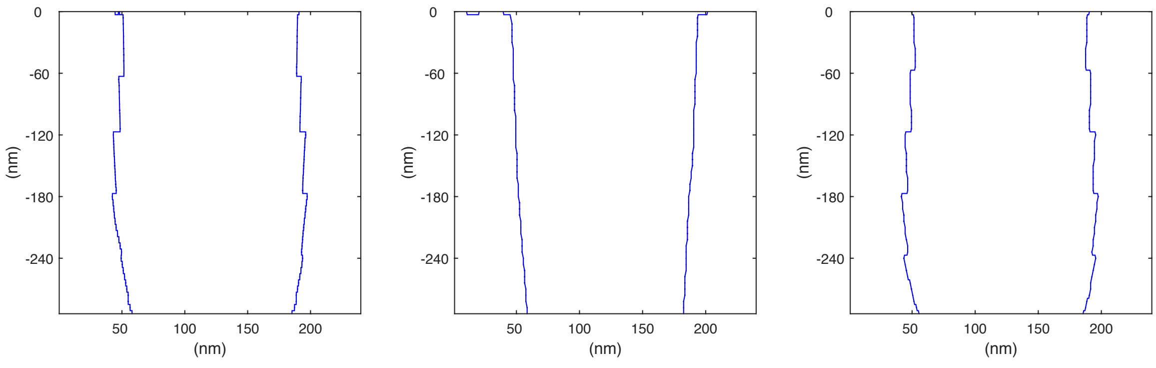
Electron-beam (e-beam) lithography is widely employed in the pattern transfer. Two of the main issues which limit the minimum feature size and maximum feature density achievable by the e-beam lithography are the proximity effect and line edge roughness (LER). Various methods have been developed in the efforts to correct the proximity effect and reduce the LER. In the computational lithography, such efforts are based on a model representing the lithographic process where a typical model consists of three components, i.e., the point spread function (equivalently line spread function: LSF), exposure-to-developing rate conversion, and noise (exposure fluctuation). In our previous study, a practical approach to deriving the three components directly from SEM images was proposed. One of the advantages of the approach is that results from the proximity effect correction and LER minimization can be more realistic since the model is derived from real results of SEM images. However, in the previous study, a 2-D model was employed for the simplicity of modeling. That is, the variation of exposure along the resist-depth dimension was not considered.

In this study, the possibility of improving the model is investigated by taking into account the dependency of exposure on the resist depth (layer). In order to minimize the computational complexity, the LSF is first modeled for the middle layer of resist and then the LSF's at other layers are derived from the middle-layer LSF according to the layer dependency of the LSF obtained from the Monte Carlo simulation (CASINO). In the iterative modeling procedure, a "fraction factor" is involved to allow for a deviation from the layer dependency of the CASINO LSF. The fraction factor of 0 corresponds to the 2-D model (i.e., the LSF does not vary with the depth dimension) and that of 1 to the case where the layer dependency of the modeled LSF is identical with that of the CASINO LSF. The three components of the 3-D model are estimated such that the CD and LER measured from SEM images are as close to the modeled CD and LER as possible.

For the accuracy analysis, "reference resist profiles" are created through simulation. In Fig. 1, the resist profiles estimated using the 2-D and 3-D models for a single line are compared. It can be seen that the resist profile by the 3-D model is closer to the reference profile than that by the 2-D model. The estimated profiles are quantitatively compared with the respective reference profiles in terms of CD and LER errors (differences), and the average errors are provided in Table 1. It is clear that the 3-D model enables a more accurate estimation of resist profile than the 2-D model. In this paper, a detailed description of the 3-D model and optimization procedure will be presented with simulation results.



(a) (b) (c)

Figure 1: Cross-section of the remaining resist profile of a line, (a) reference profile, (b) profile estimated with 2-D model, and (c) profile estimated with 3-D model: 300nm PMMA on Si, beam energy of 10 keV, beam diameter of 6nm, and line width of 120nm.

Resist thickness (nm)	Voltage (kV)	Beam diameter (nm)	Ave CD error ($nm/\%$)		Ave LER error ($nm/\%$)	
			2-D	3-D	2-D	3-D
100	20	3	0.79/0.74	0.61/0.58	0.22/18.58	0.22/18.33
200	20	3	1.80/1.69	1.07/1.00	0.52/38.33	0.47/34.07
300	10	6	8.31/7.42	3.31/2.95	0.47/19.06	0.48/19.52

Table 1: Average CD and LER errors (difference between reference and estimated profiles) where a set of different reference profiles are used for accuracy analysis in each case. Note that both absolute and percent errors are provided.