Estimation of Critical Dimension and Line Edge Roughness using Artificial Neural Networks

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Electron-beam (e-beam) lithography is widely used in transferring fine-feature patterns onto a substrate. However, the two main issues are the variation of critical-dimension (CD) due to the proximity effect and the line edge roughness (LER) stemming from the stochastic exposure distribution and developing process. Both impose a limit on the minimum feature size and maximum feature density realizable by the e-beam lithography. In the computational lithography, it is often required to estimate the CD and LER in an effort to minimize the CD error and LER. In our previous study, the e-beam lithographic process was explicitly modeled from SEM images and the model was employed to estimate and minimize the CD error and LER. One drawback of this approach is a long computation time required in the modeling procedure. Also, the modeling needs to be repeated when some of the lithographic parameters such as beam energy are changed. In this study, a new approach of employing an artificial neural network (ANN) has been investigated to overcome the drawbacks.

In the new approach, the neurons and weights between them collectively represent the e-beam lithographic process. An explicit modeling of the e-beam lithographic process can be avoided, which simplifies the modeling so that the applicability is enhanced and possibly the accuracy of estimation is improved. The ANN employed in this study is shown in Fig. 1, which consists of 1 input layer, 3 hidden layers and 1 output layer. The 5 nodes (neurons) in the input layer take the inputs of resit thickness, beam energy, beam diameter, dose, and line-width. Two outputs from the ANN are the CD and LER. The ANN is trained by the mini-batch error back-propagation method using a training set of CD and LER measurements obtained through the simulation. With the trained ANN, the CD and LER can be estimated without the exposure computation and resist development simulation.

A set of preliminary test results is provided in Table 1 where the CD and LER errors obtained in the training and testing are shown in nm and percent. The errors are averaged over all of the cases considered in the testing. It is seen that the trained ANN estimates the CD and LER accurately. In this paper, the ANN designed and its training scheme will be presented with extensive test results.

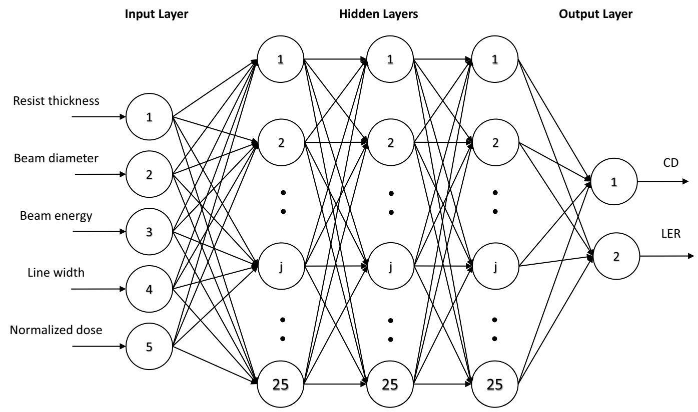

Figure 1: The artificial neural network (ANN) employed for estimating the CD and LER.

Beam energy (keV)	Resist thickness (nm)	Training CD error (nm/%)	Testing CD error (nm/%)	Training LER error (nm/%)	Testing LER error (nm/%)
10	100	0.54/0.52	0.49/0.47	0.03/3.37	0.03/3.80
10	200	0.50/0.49	0.45/0.44	0.04/3.18	0.04/3.36
10	300	0.50/0.50	0.45/0.45	0.03/2.31	0.04/2.54
10	400	0.47/0.50	0.45/0.48	0.02/1.40	0.03/1.71
10	500	0.53/0.61	0.50/0.57	0.03/2.11	0.04/2.39
30	100	0.43/0.43	0.42/0.41	0.02/2.29	0.02/2.57
30	200	0.46/0.46	0.42/0.42	0.04/2.79	0.04/2.91
30	300	0.53/0.53	0.49/0.49	0.05/3.01	0.05/2.98
30	400	0.48/0.49	0.44/0.45	0.04/2.15	0.04/1.89
30	500	0.70/0.75	0.65/0.69	0.05/2.44	0.05/2.19
50	100	0.52/0.54	0.47/0.49	0.03/1.66	0.03/1.64
50	200	0.38/0.39	0.35/0.35	0.03/1.39	0.03/1.50
50	300	0.53/0.55	0.49/0.50	0.03/1.39	0.03/1.43
50	400	0.45/0.48	0.41/0.43	0.04/1.14	0.03/1.07
50	500	0.46/0.48	0.43/0.46	0.03/1.34	0.03/1.24

Table 1: The average CD and LER errors in nm and percent obtained when the ANN in Fig. 1 is employed for the estimation of CD and LER. The substrate system is composed of PMMA on Si and the beam diameter of 5 nm.