Application of Neural Network to E-beam Dose Control for 3-D Proximity Effect Correction

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One of the major factors that limit the feature resolution in a pattern is the proximity effect caused by electron scattering leading to the "non-ideal" exposure distribution in the resist. In order to be able to achieve a high resolution of nanoscale, it is essential to find proper methods to compensate for it. Almost all proximity effect correction schemes developed so far are based on 2-D models where the exposure variation along the resist depth dimension is ignored. However, when the feature size is reduced down to nanoscale or a certain type of sidewall of the (remaining) resist profile is desired, 3-D exposure distribution needs be considered in order to have fine control of resist profile. Note that the resist profile estimated using a 2-D model can be significantly different from the actual 3-D resist profile. The goal of 3-D proximity effect correction is to determine the 2-D dose distribution which achieves a certain 3-D exposure distribution in the resist. Its inherent difficulty is that one has only 2-D controllability (dose) for 3-D constraints (exposure). An earlier study on a region-by-region dose correction has shown that 3-D exposure distribution may be controlled to some extents. However, such an approach has a fundamental limitation due to the recursive effect of sequential processing of regions and the characteristic of 3-D correction problem, i.e., over-determined. A possible approach to overcoming the limitation is to employ a neural network (NN) of manageable size to determine doses of regions in a window at a time, i.e., the regions are corrected at the same time, not sequentially. The size of window is to be carefully chosen to avoid an excessive amount of computation and achieve an acceptable level of accuracy.

Exposures are linearly related to doses and therefore their relationship can be expressed by linear equations. That is, $Ax = b$ where x is a vector of doses to be determined for regions in the window and b is a vector of exposures (constraints) to be achieved at certain locations in the resist. The element a_{kl} of the matrix A quantifies how much b_k is changed due to a unit change of x_l. An effective way of utilizing NN for 3-D proximity effect correction is to adopt the implementation designed for the least-squares method to solve a system of linear equations. This implementation which minimizes the error $\varepsilon(x) = \|Ax - b\|^2$ is applicable to an over-determined system such as the problem of 3-D proximity effect correction. Each feature in a circuit pattern is partitioned into a set of regions, for each of which a dose is to be determined. This least-squares NN shown in Figure 1 is applied to a set of regions within a window at a time and the sliding window sweeps over the entire circuit pattern. As necessary for convergence of solutions (doses), this process may be iterated. In the current implementation, the window size is set such that all regions generated from a feature are corrected together.

The proposed NN approach to 3-D proximity effect correction has been compared to the previous region-by-region method ("Bin_3D") through simulation in order to examine its feasibility. The substrate system consists of 500 nm PMMA on Si (50 keV) and the resist is modeled by 10 layers. The results in Figure 2 are for 2-D constraints, i.e., a target exposure is specified at a single layer (to be constant at 400 $\mu C/cm^2$ within each feature). It is seen that the NN method achieves the exposure distribution much closer to the target distribution than the Bin_3D method. Also, a 3-D constraint is considered, i.e., the target exposures are given at multiple layers. It is shown in Figure 3 that the exposure distribution achieved by the NN method is significantly better than that by the Bin_3D method. It has been shown that the proposed NN method is able to control 3-D exposure distribution better than the conventional region-by-region correction method and therefore has a good potential to be an effective 3-D proximity effect correction method.

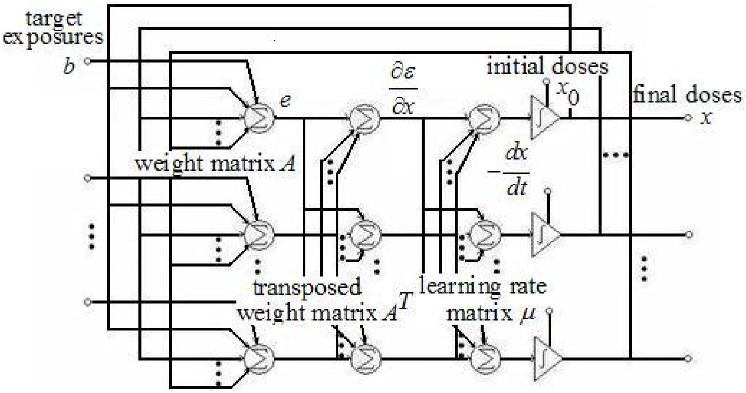
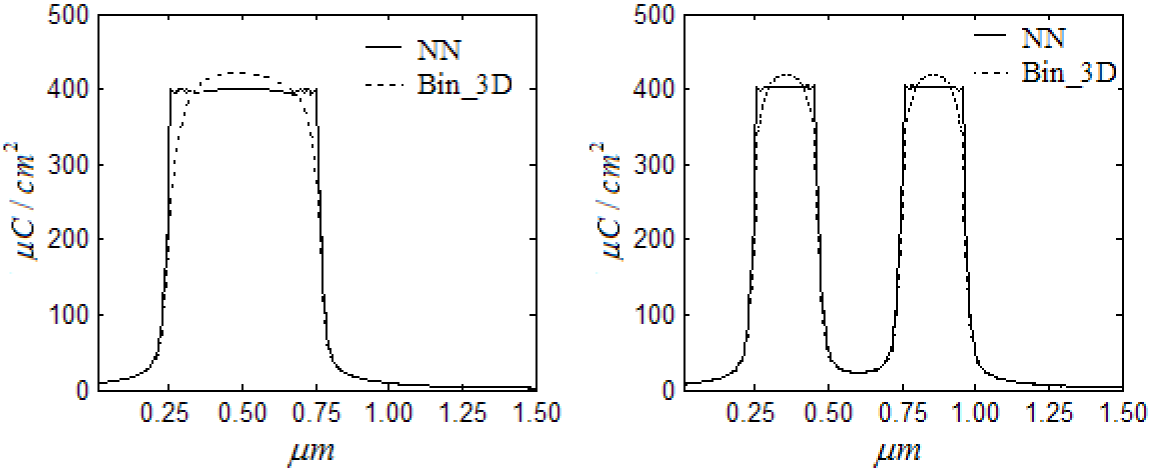
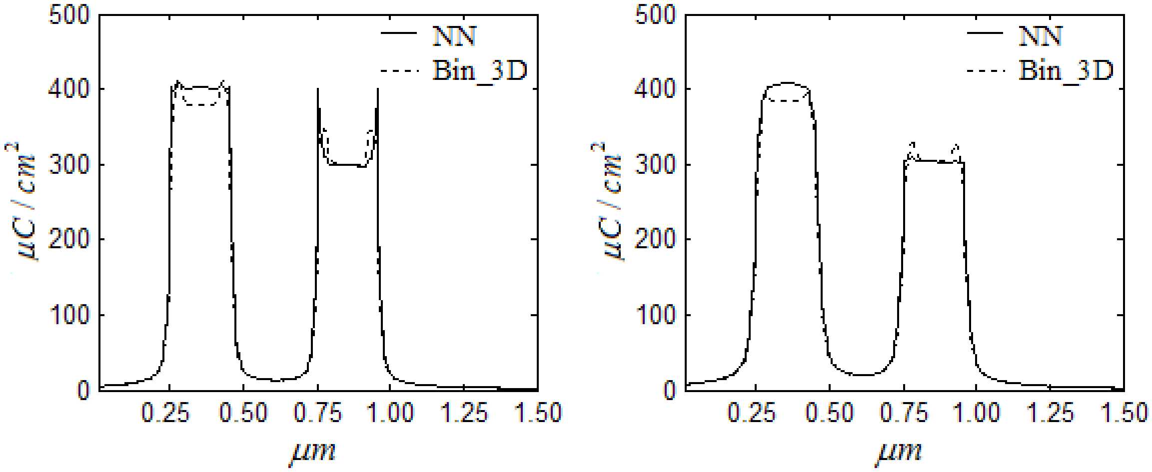


Fig 1 Neural network architecture for solving a system of linear equations (least-squares approach)



(a) (b)

Figure 2. Exposure distributions at the bottom layer of resist: (a) single-line pattern and (b) double-line pattern where the target exposure at the bottom layer for each feature is 400 $\mu C / cm^2$.



(a) (b)

Figure 3. Exposure distributions at (a) the middle layer and (b) the bottom layer where the target exposures at the middle layer for the left feature and the bottom layer for the right feature are 400 $\mu C / cm^2$ and 300 $\mu C / cm^2$, respectively.