Three-Dimensional Proximity Effect Correction for Large-Scale Uniform Patterns

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Abstract

In our recent studies, the limitations of the two-dimensional proximity effect correction (PEC) were analyzed and the need for the three-dimensional (3-D) PEC was well demonstrated for circuit patterns with nanoscale features. In 3-D PEC, a 3-D model of substrate system is employed in order to control the 3-D distribution of exposure (energy deposited in the resist), more specifically, not only the size but also the resist sidewall of feature. The computational requirement of 3-D PEC is extremely high due to the increased dimension of the model and the resist development simulation. Moreover, a feature-by-feature correction procedure would be too time-consuming to be practical, especially for large-scale patterns. Therefore, a 3-D PEC method fast enough to be applicable to realistic-size patterns is required.

In this study, a new method which takes a systematic approach to 3-D PEC in avoiding the feature-by-feature correction without sacrificing the quality of correction result is proposed for large-scale uniform patterns such as a large array of features such as circles, squares and lines. The method consisting of three steps attempts to achieve the target 3-D resist profile of feature with vertical sidewall throughout a large pattern. In the first step of the proposed approach, a single instance of the repeated feature in the pattern is corrected in isolation. The feature is partitioned into regions for each of which a dose is determined using the 3-D model such that the target resist profile is obtained. The (region-wise) dose distribution within the feature is denoted by $d(i)$ and the corresponding exposure distribution by $e(i)$ where i is the region index. The spatial averages of $d(i)$ and $e(i)$ are denoted by D and E, respectively. In the second step, the global distribution of feature-wise dose throughout the pattern is derived by the deconvolution of the target exposure distribution with the PSF (point spread function). The target exposure distribution is a 2-D array where each element corresponding to a location of the feature is assigned the value of E. The PSF is sampled at the interval of the feature size. The output of the deconvolution, which specifies the (average) feature-wise dose distribution required to achieve E at all locations of the feature, is referred to as deconvolution surface. This deconvolution is not computationally intensive since the spatial resolution involved is coarse (feature size). At each location of the feature, $d(i)$ is weighted by the deconvolution surface to results in $d'(i)$. Now, $e'(i)$, corresponding to $d'(i)$, is well balanced throughout the pattern, but the exposure in the unexposed area (referred to as background exposure) may vary with location. The resist profile after development depends on the background exposure as well as $e'(i)$. Hence, in the third step, $d'(i)$ at each of only three critical locations is adjusted such that the deviations from the target resist profile at the top, middle and bottom layers of resist are minimized. Only a small number of iterations is needed since the profile after the second step is already close to the target one. After the final $d'(i)$ is obtained at each critical location, a 2-D interpolation is employed to compute the $d'(i)$ at all other locations according to the deconvolution surface.

The proposed approach to 3-D proximity effect correction for large-scale uniform patterns has been implemented and its performance has been analyzed through simulation. A uniform pattern consisting of 261 lines, shown in Fig. 1, is used for simulation. Each line is 51 μm in length and 50 nm in width, and the gap between adjacent lines is also 50 nm. Each line is partitioned into segments of 3 μm for dose control. The three critical and three test locations are shown in Fig. 1. The substrate system employed in the simulation is composed of 300 nm PMMA on Si. The beam energy is 50 KeV, and the beam diameter is 5 nm. The (cross-section) resist profiles obtained by the 2-D PEC are given in Fig. 2. It can be seen that the 3-D resist profile varies significantly with location. The line width is not uniform and the resist sidewall is not vertical. The resist profiles achieved by the proposed 3-D PEC are provided in Fig. 3. The same total dose is given to the pattern in both 2-D and 3-D PEC's. It is clear that the location-dependent variation of 3-D resist profile has been minimized and the profiles very close to the target one (line width of 50 nm and vertical sidewall) have been achieved not only at the critical locations but also at the test locations. In this paper, a detailed description of the proposed method will be presented with the results from an extensive simulation.

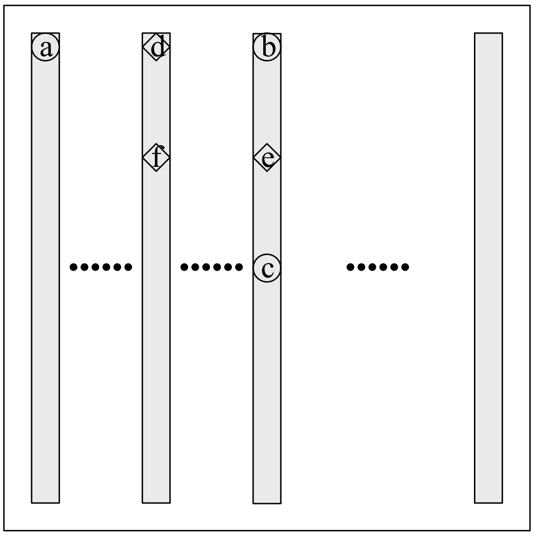
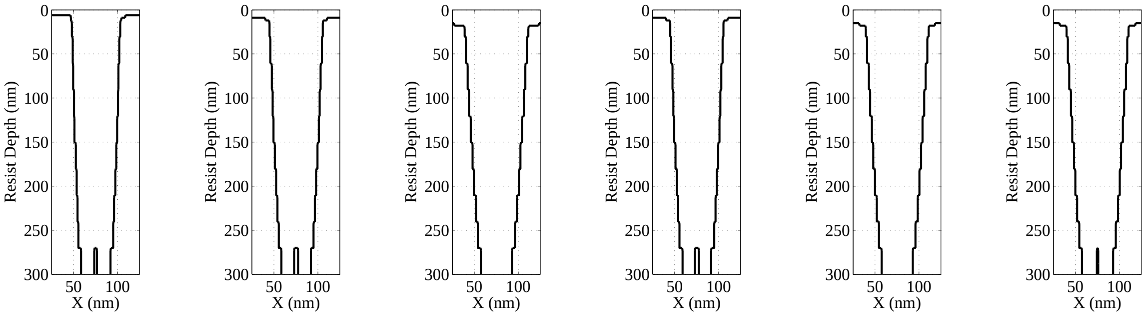
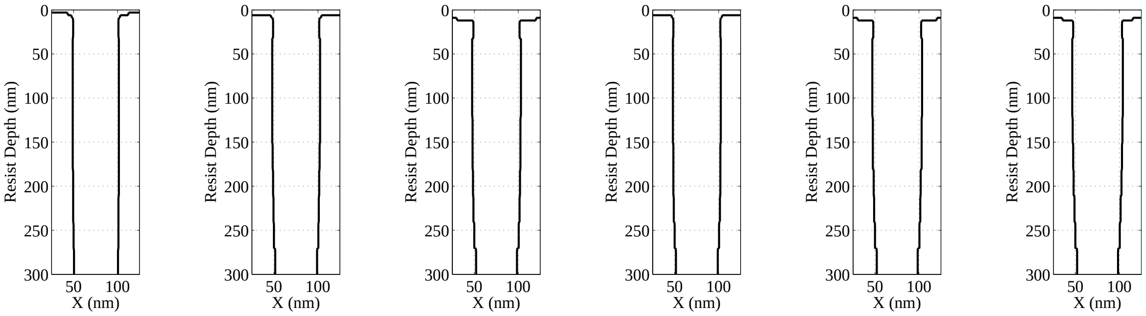


Figure 1: Critical locations (marked by ○) and test locations (marked by ◇) in the line pattern.



(a) (b) (c) (d) (e) (f)

Figure 2: Cross-section resist profiles after 2-D correction at the critical locations ((a) corner, (b) edge and (c) center; refer to Fig. 1) and the test locations ((d), (e) and (f); refer to Fig. 1).



(a) (b) (c) (d) (e) (f)

Figure 3: Cross-section resist profiles after 3-D correction at the critical locations ((a) corner, (b) edge and (c) center; refer to Fig. 1) and the test locations ((d), (e) and (f); refer to Fig. 1).