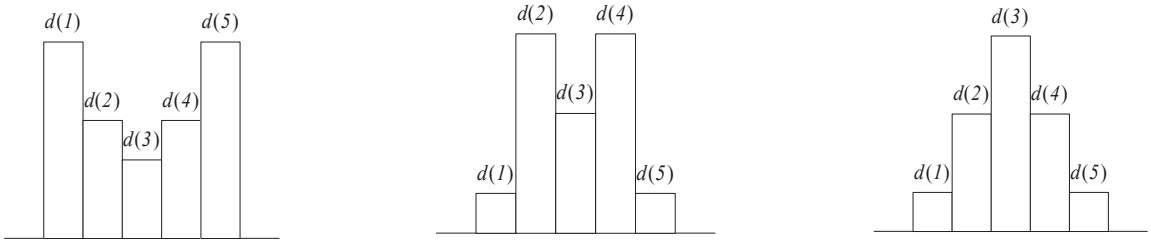
Optimization of Spatial Dose Distribution for Vertical Sidewall of Resist Profile Minimizing Total Dose in Electron-beam Lithography

Q. Dai and S.-Y. Lee
Department of Electrical and Computer Engineering, Auburn University, Auburn, AL 36849
Fax: (334) 844-1809, *leesooy@eng.auburn.edu*
S.-H. Lee, B.-G. Kim, and H.-K. Cho
Samsung Electronics, Photomask Division, 16 Banwol-Dong, Hwasung, Kyunggi-Do, Korea

A typical two-dimensional (2-D) proximity effect correction (PEC) scheme does not take into account the variation of exposure along the resist depth dimension, and deconvolves the 2-D target exposure distribution by the point spread function (PSF) to derive a correction result, i.e., the required dose distribution. For a target exposure distribution which is constant and zero within and outside a feature, respectively, the required dose distribution is of "V-shape," i.e., the dose is highest at the edge and gradually decreases toward the center of a feature, to be referred to as Type-V (see Fig. 1-(a)). However, our earlier studies have shown that such 2-D PEC does not lead to realistic results especially for nanoscale features and therefore true three-dimensional (3-D) PEC is needed. Moreover, it has been demonstrated that in order to minimize any deviation from a target resist profile, a 3-D PEC scheme must check the estimated resist profile during the dose optimization procedure. One practical issue of such an approach to 3-D PEC is that a time-consuming resist-development simulation needs to be carried out in each iteration of the dose optimization.

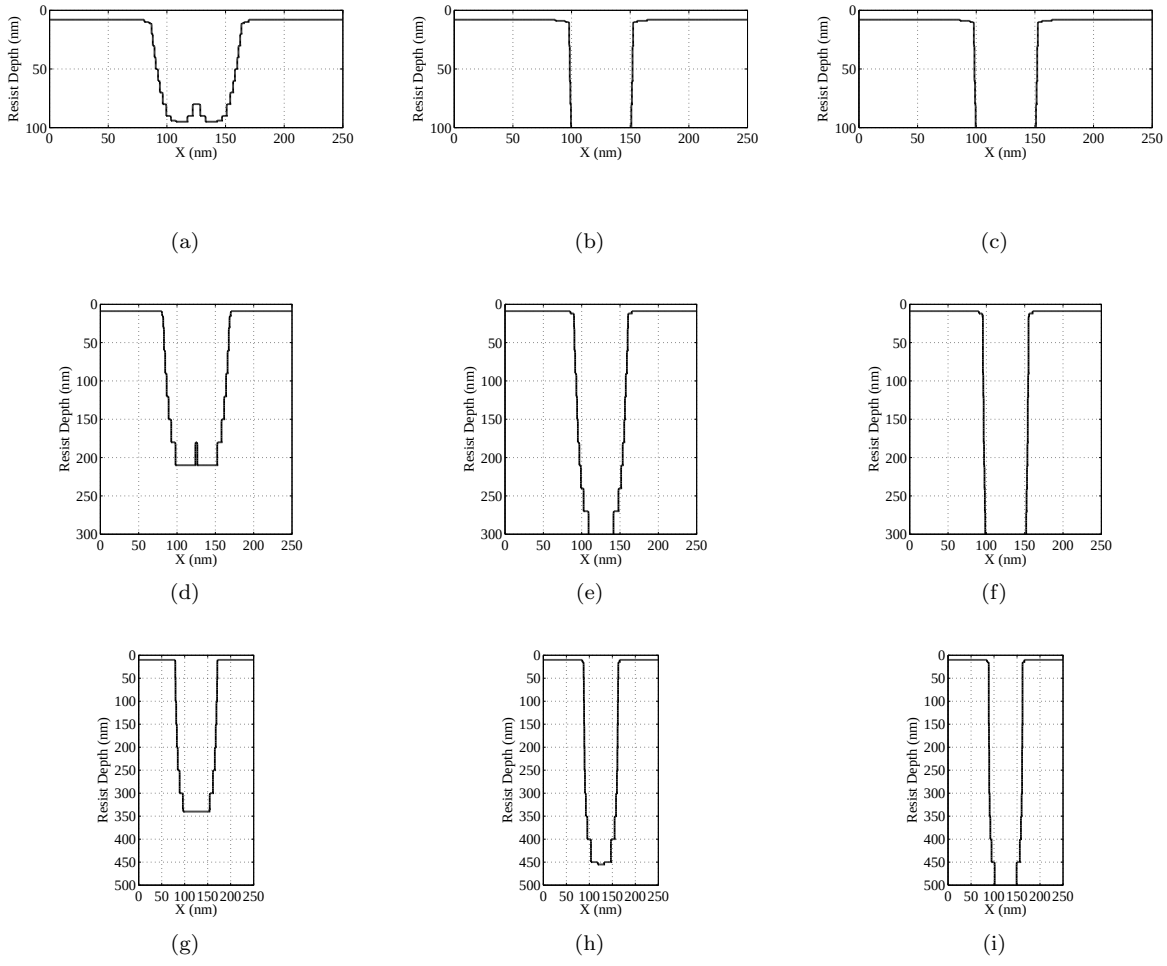
In this study, an efficient dose optimization scheme which does not require a direct resist-development simulation while achieving a target 3-D resist profile has been developed. Also, it is shown that the dose distribution of Type-V is not optimal for realizing a vertical sidewall of the resist profile, especially when the total dose is to be minimized. Note that a higher total dose worsens the charging effect and lengthens the exposing time. The sidewall of resist profile for a line feature is considered in this investigation. In order to avoid a high complexity of the optimization procedure and also have a sufficient spatial control of dose distribution, the line feature is partitioned into 5 regions along its length dimension and a dose $d(i)$ is determined for each region i where i=1, $\cdots$, 5 as shown in Fig. 1. The doses of the 5 regions are updated through iterations in each of which the resist profile is estimated and the dimension error, i.e., the deviation from the target resist profile, is computed. The doses are adjusted such that the error is decreased. For estimating the resist profile, a fast path-based method has been developed instead of employing a time-consuming cell-based method. It traces critical paths in the resist to derive the boundaries of developing process where the critical paths are set depending on the shape of dose distribution. The systematic dose updating procedure coupled with the fast resist development simulation makes the dose optimization scheme fast and effective. The most noteworthy result from this study is that in order to achieve a vertical sidewall of nanoscale feature with the minimum total dose, one has to use a dose distribution different from that of Type-V. This is due to the fact that the lateral development of resist becomes comparable to the vertical development for nanoscale features and the exposure (energy deposited) varies along the depth dimension with high and low contrasts at the top and bottom layers of resist, respectively. These enable the dose distributions of Type-M ("M-shape" shown in Fig. 1-(b)) and Type-A ("A-shape" shown in Fig. 1-(c)) to achieve the target resist profile of vertical sidewall minimizing the total dose. This new finding would not have been possible without using our 3-D model and PEC.

The new 3-D PEC scheme has been implemented and its performance has been analyzed through simulation. A set of typical results is provided in Fig. 2 where the beam energy and diameter are assumed to be 50 keV and 5 nm, respectively. The substrate system is composed of PMMA on Si with the three different thicknesses of PMMA (100, 300 and 500 nm) considered. The width and length of a line feature are 100 nm and 3 μm, respectively. The target 3-D resist profile, i.e., the cross-section of (remaining) resist profile, is of vertical sidewall with the width of 50 nm. The best dose distribution for each type of dose distribution is derived with the constraint that the total dose for the line feature is the same for all three types. While the resist profiles by Type-V are significantly deviated from the target profile, i.e., sidewall shape of overcut and not fully developed, those by Type-M and Type-A are very close to the target profile. Hence, it is believed that, for ultra-fine features of nanoscale, Type-M or Type-A needs to be employed to achieve a vertical sidewall with a minimal total dose. In the paper, the detail of the dose optimization scheme will be presented with more results and explanation.



(a) (b) (c)

Figure 1: Types of spatial dose distribution cross a line: (a) Type-V, (b) Type-M and (c) Type-A.



(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Figure 2: Cross-section resist profiles after 3-D PEC with (a) Type-V, (b) Type-M and (c) Type-A with total dose of 440 $\mu C/cm^2$ for 100 nm PMMA on Si; (d) Type-V, (e) Type-M and (f) Type-A with total dose of 560 $\mu C/cm^2$ for 300 nm PMMA on Si; (g) Type-V, (h) Type-M and (i) Type-A with total dose of 700 $\mu C/cm^2$ for 500 nm PMMA on Si.