Experimental Verification of Achieving Vertical Sidewall for Nanoscale Features in Electron-beam Lithography

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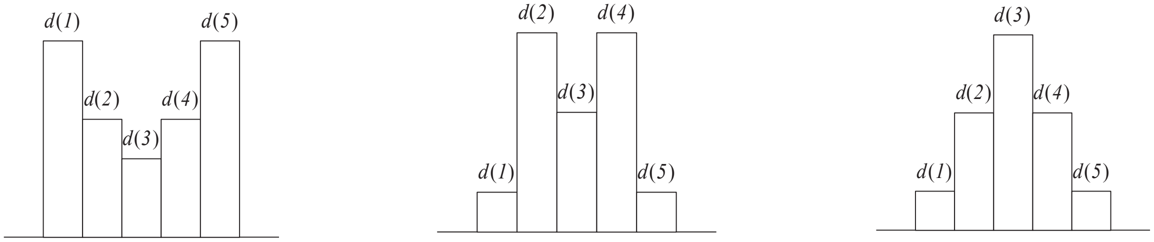
In electron-beam (e-beam) lithography, electron scattering in the resist layer leads to the proximity effect which can make the written pattern significantly different from the target one. Various correction schemes were developed. However, most of the schemes are based on a two-dimensional (2-D) model of resist and therefore do not consider the resist depth dimension during correction. The variation of feature size, such as line width, along the resist depth dimension is not considered. Or equivalently, the feature size averaged along the depth dimension is employed in correction. A 2-D correction might be acceptable for large features since such variation can be negligible compared to the feature size. However, for features of nanoscale, the variation becomes relatively significant such that it cannot be ignored. Therefore, a three-dimensional (3-D) model of resist layer must be employed in order to take the variation of resist profile along the resist depth dimension into account.

A true 3-D correction method introduced earlier minimizes the critical dimension (CD) error in each layer of resist. In this correction procedure, the remaining resist profile is obtained through simulation and the spatial dose distribution is adjusted to reduce the maximum CD error among resist layers. Note that this task of reducing the CD error on each layer as much as possible may be reformulated as minimizing the average CD error with the requirement of vertical sidewall of resist profile. Recently, the issue of achieving vertical sidewall while minimizing the CD error for nanoscale features was considered through an extensive simulation. It is shown that employing a 3-D model allows one to find a spatial dose distribution which minimizes the maximum CD error and achieves a vertical sidewall. Also, the conventional shape of spatial dose distribution, "V-shape (Type-V)" ($d(1) > d(2) > d(3)$ in Fig. 1-(a)), is shown to be not optimal. Two new types of dose distributions, i.e., "M-shape (Type-M)" ($d(2) > d(1), d(3)$ in Fig. 1-(b)) and "A-shape (Type-A)" ($d(3) > d(2) > d(1)$ in Fig. 1-(c)), are more effective than the V-shape distribution in achieving vertical sidewall and minimizing the maximum CD error with a lower total dose required.

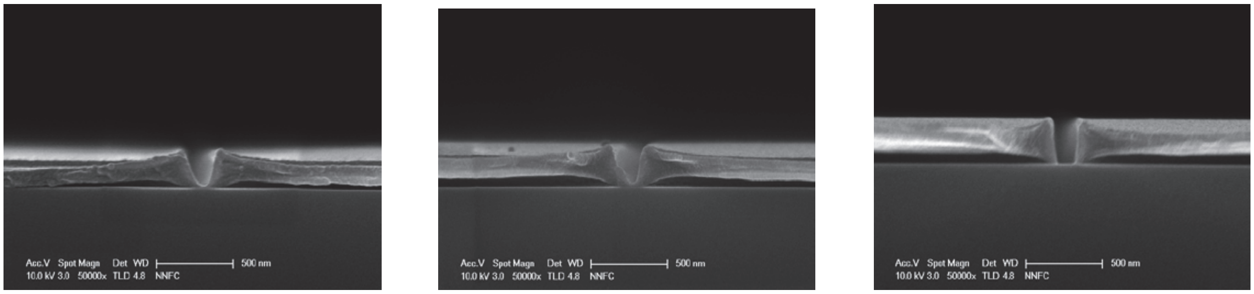
In this study, the simulation results have been verified through experiment. Line features are exposed with different types of dose distribution. Cross-section SEM images of the remaining resist profiles are examined in comparing the new types of dose distribution and conventional types. Different resist types, resist thicknesses, and feature sizes are considered to observe the performance trend of the new types of dose distribution. The experimental results well match with the simulation results.

In Fig. 2, the results (cross-section SEM images of remaining resist profiles) for the resist of 300nm PMMA are provided where the total dose is 290 $\mu C/cm^2$ for all of the uniform, Type-V and Type-M distributions. When the line is exposed with the uniform dose, i.e., no control of spatial dose distribution, a resist profile of overcut was obtained where the line width at the top layer is much larger than the target width of 100nm. The resist profile by Type-V is similar with the one by the uniform dose. However, the Type-M dose distribution was able to achieve a resist profile very close to the target profile, i.e., fully developed with vertical sidewall. In Fig. 3, Type-M and Type-A are compared with the total dose lowered to 275 $\mu C/cm^2$. Due to the reduced dose level, the Type-M dose distribution was not able to get the line fully developed leading to an overcut of resist profile. On the other hand, the resist profile by the Type-A dose distribution is closest to the target profile in terms of line width (CD error) and sidewall shape. It is clear that Type-A not only achieves the target profile with the minimal CD error, but also lowers the total dose required. In this paper, more comprehensive results will be presented with detailed discussion.



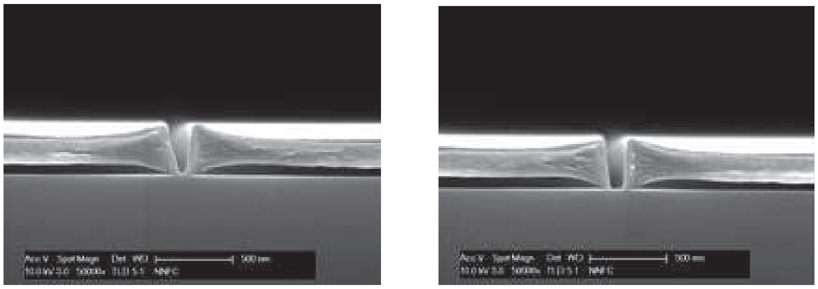
(a) (b) (c)

Figure 1: Dose distribution types: (a) Type-V, (b) Type-M and (c) Type-A.



(a) (b) (c)

Figure 2: Cross-section SEM images of resist profiles on 300nm PMMA on Si with total dose of 290 $\mu C/cm^2$: (a) uniform, (b) Type-V and (c) Type-M.



(a) (b)

Figure 3: Cross-section SEM images of resist profiles on 300nm PMMA on Si with total dose of 275 $\mu C/cm^2$: (a) Type-M and (b) Type-A.