Optimization of Spatial Dose Distribution for Controlling Sidewall Shape in Electron-beam Lithography

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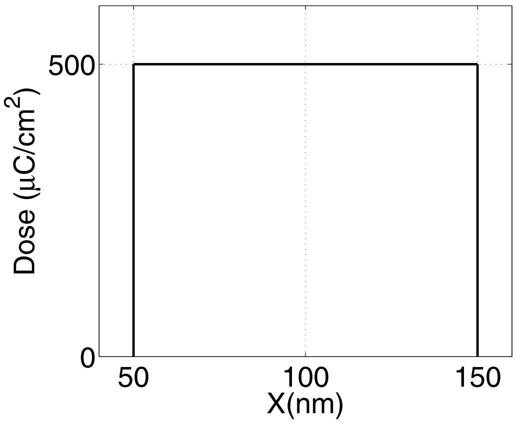
Abstract

Electron-beam (e-beam) lithography is often employed in fabrication of 2-D patterns and 3-D structures. A certain type or shape of sidewall of resist profile may be desired in an application, e.g., undercut for lift-off and vertical sidewall for etching. Also, as the feature size is decreased well below a micron, a small variation of the sidewall slope can lead to a significant (relative) CD error in certain layers. Therefore, it is important to understand effects of spatial dose distribution on sidewall shape and be able to achieve the desired shape. In this study, the relationship among the total dose, spatial distribution of dose, and sidewall shape is analyzed in detail and a method to optimize dose distribution for a given sidewall shape is developed.

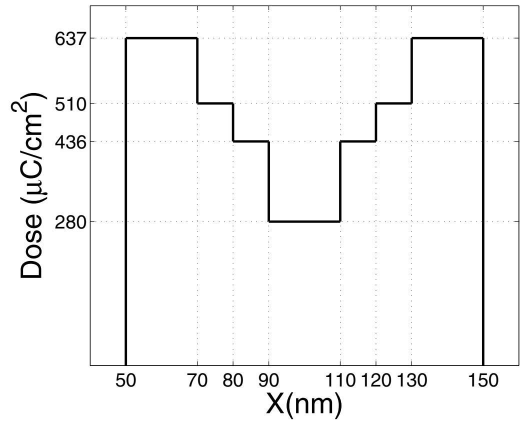
For estimation of resist profile, a 3-D model of resist is employed, which consists of a number of layers, and each layer is modeled by a 2-D array of cubic volumes or cells. Exposure is assumed to remain constant within each cell and computed by layer-by-layer discrete convolution between a dose distribution and a 3-D point spread function (PSF) which describes energy distribution throughout resist when a point on the top surface of resist is exposed. Given a 3-D exposure distribution, the developing rate of each cell is computed according to the rate conversion formula estimated from experimental results. Then, the cell-removal method is used in development simulation to derive the corresponding resist profile after development. This estimation procedure is employed in determining the dose distribution required for a desired sidewall shape.

In this study, a single line which is long enough to ignore any variation of exposure along the length dimension is considered. For such a line it is sufficient to analyze only the cross section of resist, perpendicular to the length dimension. The line is partitioned into long thin regions for each of which a dose is to be determined for achieving a target shape of sidewall. A fundamental difficulty is that the optimal dose for a region has conflict among layers, i.e., the dose required for a layer may be different from that for another layer. Also, the optimal dose for a region depends on the doses of the other regions. Therefore, a general-purpose optimization method is adopted in finding the dose distribution required to achieve a target sidewall shape. It is desired for reducing proximity effect and resist charging that the total amount of dose is minimized. In the optimization of spatial dose distribution, one requiring a lower amount of dose is preferred under the condition that it achieves the target sidewall shape. In this paper, the dose distributions required for three different types of sidewall shapes, overcut, undercut, and vertical, are analyzed and the tradeoff among the total dose, controllability of dose distribution, and developing time is discussed.

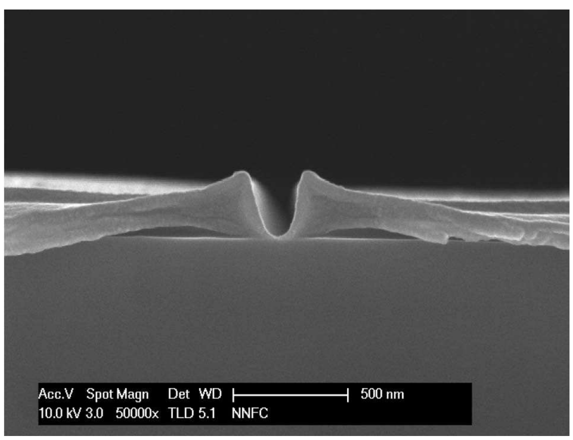
In Figure 1, two different dose distributions with the same total dose and their respective resist profiles are provided from an early experiment. The substrate system consists of 300nm PMMA on Si and the width of line exposed is 100nm. The e-beam accelerating voltage is 50keV. The samples were developed in MIBK:IPA=1:2 for 40 seconds. It can be seen that by controlling the spatial dose distribution one can achieve different shapes of sidewalls though the total amount of dose given to the line remains the same, which well justifies the objectives of this study.



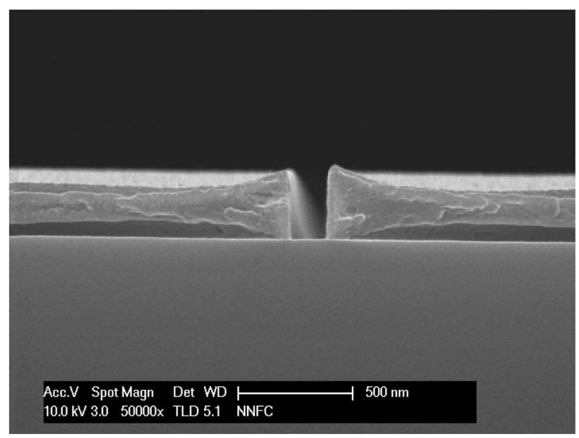
(a)



(b)



(c)



(d)

Figure 1: Dose distributions and sidewalls achieved: (a) & (c) uniform dose and (b) & (d) spatially varying dose distribution. The same total amount of dose (the same average dose of 500 $\mu C/cm^2$) is given to the line in both cases.