Estimation of Remaining Resist Profile without Exposure and Development Simulations in E-beam Lithography

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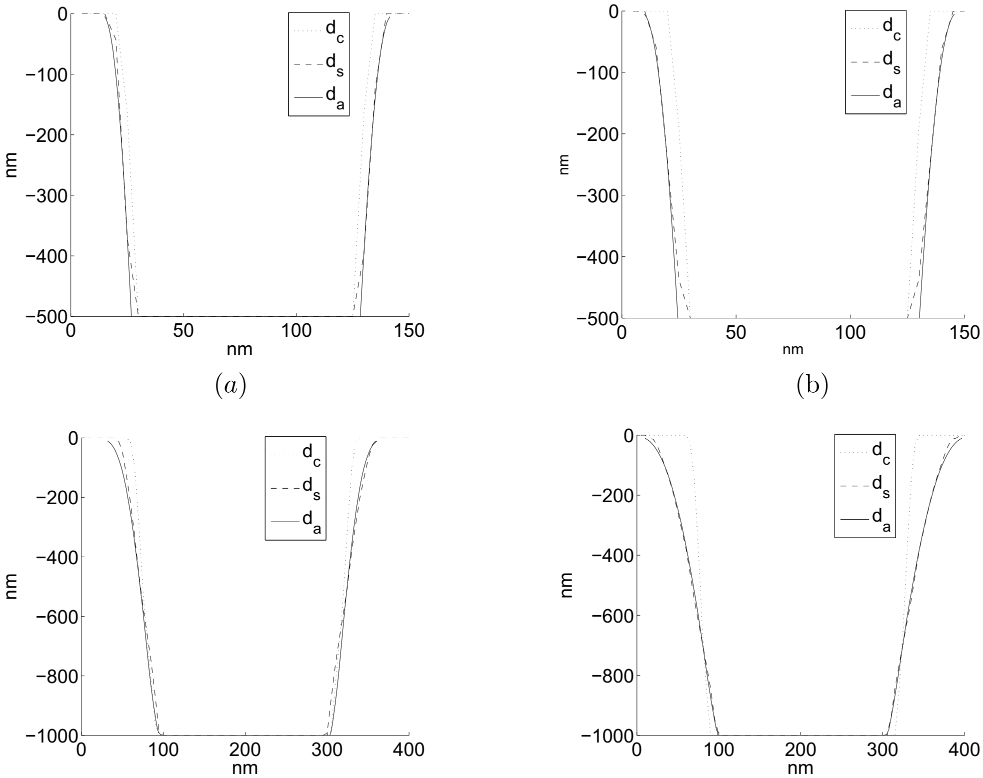
The electron-beam (e-beam) lithographic process consists of selectively exposing resist by e-beam and subsequently developing the resist for pattern transfer. For applications such as predicting the remaining resist profile and e-beam dose control for proximity effect correction, both steps are often simulated. In the first step, the exposure (energy deposited in the resist) distribution is computed by convolution between a circuit pattern and a point spread function (PSF) which depicts the exposure distribution when a single point is exposed. PSF's are usually obtained by theoretical modeling such as a double-Gaussian function or a Monte Carlo simulation. In the second step, the developing rate at each point in the resist is computed based on the corresponding exposure in a given exposure distribution and developing conditions, and an iterative procedure is employed to derive the remaining resist profile. While such simulations are widely used, they have some practical limitations: (*i*) PSF's may not be very accurate, (*ii*) PSF's may not be easily obtained for certain substrate systems, (*iii*) the methods for resist development simulation may not be accurate, and (*iv*) the actual remaining resist profiles vary with the developing condition. Also, such simulations are normally very time-consuming especially for large circuit patterns.

In order to avoid the above-mentioned limitations, a new method is proposed to estimate the remaining resist profiles using a set of experimental results without exposure estimation or development simulation. The idea is to adopt the concepts of *point response*, *line response* and *edge response functions* (*PRF, LRF, ERF*) and properly use them in estimating the remaining resist profile. The *PRF, LRF,* and *ERF* are the remaining resist profiles obtained when a point, a line and an edge (the edge of a large rectangular feature) are exposed, respectively. They are experimentally obtained and, therefore, realistically reflect the development condition. In this paper, L/S (lines/spaces) patterns are employed with a constant e-beam dose for the *binary* lithography to demonstrate feasibility of the method through computer simulation. However, it will be extended to general patterns with a spatially varying dose distribution and the grayscale lithography.

Suppose that a L/S pattern consists of a certain number (N) of long lines where each line is aligned along the Y-axis such that any variation along the Y-dimension may be ignored. Let $d_1(x)$ represent the depth profile of remaining resist when one line in a L/S pattern is exposed in isolation, i.e., line response function. The depth profile, $d_s(x)$, of the L/S pattern may be estimated by combining $\{d_1(x - kI) | k = 0, \ldots, N-1\}$ through the relationship between exposure and developing rate, where I is the line interval. Let the estimated depth profile after this combination step be denoted by $d_c(x)$. However, due to the nonlinearity between exposure and developing rate, and the depth-dependent exposure distribution in the resist, further adjustment to $d_c(x)$ is needed, which results in the final (adjusted) depth profile, denoted by $d_a(x)$. The adjustment is guided by the factors such as the location of feature (line) within a circuit pattern, the relative location of each pixel or layer, resist thickness, beam energy, etc.

In Figure 1, the early results indicating a good potential of the proposed approach are provided, where experimental results, $d_1(x)$ and $d_s(x)$, are replaced by the respective simulation results obtained by the cell removal method. In order to achieve stable estimated results, $d_a(x)$ was derived from $d_c(x)$ by adjusting widths of lines at each layer of the resist. The adjustment (scaling) factor is a function of the layer index with parameters of which values depend on the above-mentioned factors. In this paper, how the *response functions* can be used for estimation of the remaining resist profiles will be described along with the results from an extensive simulation study.



(a) (b)

(c) (d)

Figure 1: Depth profiles of remaining resist: (a) one end and (b) center of a L/S pattern on the substrate of 500 nm PMMA on Si; L/S=100/50 nm, (c) one end and (d) center of a L/S pattern on the substrate of 1000 nm PMMA on Si; L/S= 200/200 nm. The number of lines in the L/S patterns is 100. Refer to the abstract text for descriptions of d_s, d_c, and d_a.