Effects of Stochastic Exposure on Critical Dimension in Electron-beam Lithography

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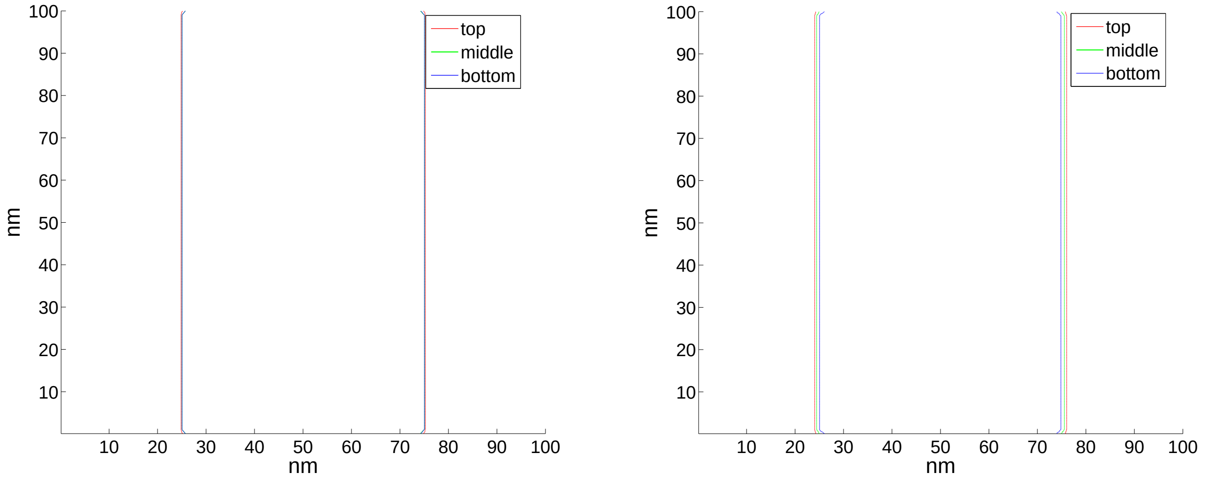
Electron-beam (e-beam) has been widely used in the pattern transfer, especially for a pattern of fine features. However, the electron scattering during the process of exposing a pattern leads to the undesirable shape-distortion of written features, i.e., the proximity effect. There have been many methods developed for reducing the proximity effect, most of which take a computational approach. One of the essential components of the computational lithography needed for the proximity effect correction is the point spread function (PSF) which describes the exposure (energy deposited in the resist) distribution when a point is exposed. The exposure fluctuates, i.e., is stochastic, in reality due to the random nature of electron scattering and shot noise. Nevertheless, the PSF employed in the computational lithography is assumed to be deterministic, equivalently, the average PSF is used, in most cases. In this study, the discrepancy in computational-lithography results, that can be caused by using a deterministic PSF, is investigated.

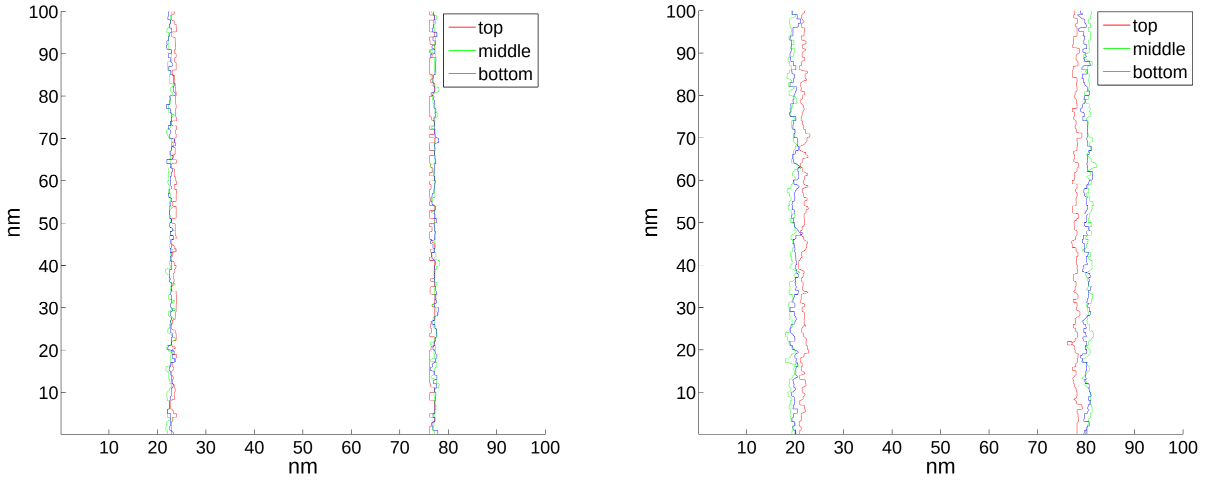
The fluctuation of exposure, coupled with the randomness in the resist-development process, causes the roughness in the feature boundaries, e.g., line edge roughness (LER). The LER which is independent of the feature size limits the minimum feature size and maximum feature density and has been and is being extensively studied. Another effect of exposure fluctuation, which has not received much attention, is on the size of a written feature. Due to the exposure fluctuation, the actual size of a written feature can be substantially different from that estimated based on the deterministic exposure. The reason for this effect is that a point with a lower exposure is helped by the neighboring points with higher exposures in the development process. That is, the effective developing rate at such a point is higher than the nominal value and there can be more such points in the stochastic exposure than in the deterministic exposure. In this investigation, this effect of stochastic exposure on the critical dimension of a feature and its dependency on lithographic parameters are analyzed in detail.

In Fig. 1, the remaining resist profiles of a single line obtained through computer simulation using the deterministic and stochastic exposures are compared at the top, middle and bottom layers of resist. In this comparison, the dose level which achieves the target line-width at the bottom layer in the case of deterministic exposure is determined and then the same dose level is used in generating the stochastic exposure. It can be seen in Fig. 1 that the (average) line-width obtained from the stochastic exposure is larger than that from the deterministic exposure. Therefore, for example, the result from the proximity effect correction obtained using a deterministic PSF may not be realistic. In this paper, results from an extensive analysis will be presented.



(a) 30 keV, deterministic

(b) 10 keV, deterministc



(c) 30 keV, stochastic

(d) 10 keV, stochastic

Figure 1: The feature boundaries (top-down view) at the top, middle and bottom layers of the remaining resist profile for a single line (target line-width of 50nm), obtained from the deterministic exposure ((a) 30 keV and (b) 10 keV) and the stochastic exposure ((c) 30 keV and (d) 10 keV): 100nm PMMA on Si.