Reduction of Exposing Time in Massively-Parallel E-beam Systems

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The existing writing methods for massively-parallel electron-beam (e-beam) systems, e.g., single-row writing (SRW) and multi-row writing (MRW), expose all pixels of features in a pattern mostly with the same dose (uniform dose distribution). However, because of the spaces between features in a pattern and some regions requiring higher dose than others (non-uniform dose distribution) for PEC (proximity effect correction), certain beams, sometimes all, are turned off in several cycles. Consequently, the utilization of beams is reduced considerably. In this study, two different approaches to increasing the beam utilization and thereby reducing the exposing (writing) time are investigated, i.e., lowering the dose difference among regions of a feature during PEC and utilizing the cycles with all beams turned off ("empty cycles").

In a non-uniform dose distribution required for minimizing CD (critical dimension) error and LER (line edge roughness), the maximum dose difference between any two regions may be significant which can lower the utilization of beams substantially. This dose difference can be reduced by decreasing the maximum dose among the regions and increasing doses in the nearby regions as long as the PEC result is acceptable. To utilize the empty cycles in the conventional writing (SRW or MRW) methods while realizing a dose distribution, the deflection angle of the beams can be adjusted so that at least one beam falls on a pixel not having received its target dose yet. The higher the number of empty cycles in a conventional writing method is, the larger the reduction of exposing time becomes. In this study, an extensive simulation is conducted to observe the effect of reducing the dose difference among regions of a feature on the utilization of beams for different dose distribution types, and varying feature size and beam blurring factor. Also, the reduction of exposing time by utilizing the empty cycles of the conventional writing methods is analyzed for L/S patterns, varying the line width (l), space width (s), pattern size (width), beam interval (I_{bx}) and the number of beams (n) in the system.

The results obtained by reducing the maximum dose in an A-type (where the dose is highest in the center region and monotonically decreases toward edge regions) dose distribution are provided in Table 1. It is observed that the beam utilization is increased while the CD error and LER stay within acceptable limits. In Fig. 1, the reduction of exposing time by utilizing empty cycles in realizing the dose distribution with the highest beam utilization in Table 1 is shown for varying pattern size (width). It is seen that the reduction can be significant depending on the pattern, e.g., when $I_{bx} = l + s$.

ΔW (nm)	Dose-distribution ratio	d_{max} reduction (%)	CD error (nm)	Total dose (unitless)	LER (nm)	$U(\%)$
10	1:2:5.3:2:1 (*optimal*)	0.0	0.22	2.16	0.18	42.64
10	1:2.07:5.17:2.07:1	2.5	0.24	2.16	0.18	43.75
10	1:2.13:5.04:2.13:1	5.0	0.27	2.16	0.19	44.84
10	1:2.27:4.77:2.27:1	10.0	0.30	2.16	0.19	47.42

Table 1: CD error, LER and beam utilization (U) obtained by reducing d_{max}, the maximum dose among the five regions in an A-type dose distribution. The total dose is kept constant with the feature width (W) of 50nm and beam blurring factor $\sigma_t = 4$nm. The feature width is reduced by ΔW for PEC and the optimal dose distribution is found minimizing the cost function consisting of CD error and total dose.

(a) (b)

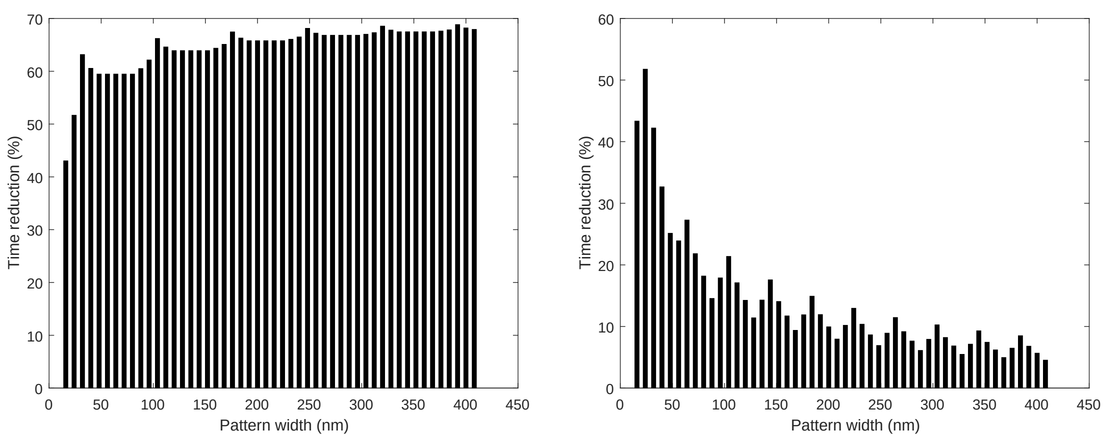

Figure 1: The reduction in the exposing time with respect to the pattern size (width) for the A-type dose distribution with the spatial-dose-distribution ratio of (1:2.27:4.77:2.27:1), compared to the conventional writing method: (a) l =50nm, s =30nm, I_{bx}=80nm ($I_{bx} = l + s$) and $n = 9$, and (b) l =50nm, s =30nm, I_{bx} =90nm ($I_{bx} \neq l + s$) and $n = 10$