Temperature Dependent Effective Process Blur and Its Impact on Process Latitude and Lithographic Targets Using E-Beam Simulation and Proximity Effect Correction

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It is well known that cold development yields higher contrast and improved process latitude particularly for ZEP520 from Zeon Chemicals.[1] In this paper, we quantify the effective process blur by exposing a dose matrix of 200nm line-space patterns with a 50% duty cycle in ZEP520 on Si; each pattern is large enough so that its center sits atop backscattered electrons. Samples were developed using n-amyl acetate for 3 minutes at various temperatures, then soaked in IPA at 21˚C for 30 seconds followed by a N_2 blow dry. Figure 1 shows the CD response to a change in dose (process latitude) by charting the measurements taken at the center of each line-space pattern using the Analyze_Stripes[2] macro for ImageJ. Using simulation with the process latitude measurements and a backscatter point spread function (PSF) (α= 5 nm, β= 30 µm and η= 0.6), the effective process blur is characterized at 10nm, 42nm and 71nm for developer temperatures at -12˚C, 21˚C and 30˚C, respectively. Blur and developer temperature are directly proportional to one another. A process with a large effective blur (71nm) exhibits a CD response that has a higher sensitivity to a change in dose when compared to a smaller blur (10nm).

Optimizing e-beam exposure time is always desired while maintaining a target CD and shape fidelity. In particular, the exposure time can be dominated by shape overhead delays stemming from the over digitization of curved shapes within a pattern. As such, it is better to expose a pattern with the least number of shapes as possible while maintaining shape fidelity. Here, e-beam simulation can be used to determine the optimal conditions to obtain a target shape fidelity while minimizing the shape count. For example, a wavy line pattern can be generated from repeating 2 sized rectangles with sharp corners (Figure 2a). As the effective blur increases, the sharp corners within the pattern become rounded, which is desired (Figure 2b-2c). Since a 71nm process blur has a limited process latitude, using proximity effect correction (PEC) with a backscatter PSF convolved with a 71nm effective FWHM process blur aids in the CD uniformity from center to corner (Figure 3). Consequently, the target shape fidelity with rounded corners is also achieved using fewer shapes, optimizing writing time.

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[1] Ocola L and Stein A. J Vac Sci Technol B 24(6): 3061, 2006.
[2] J. Bickford, Automatic Stripe Analysis Tool. Adelphi, MD: ARL, May 2013. (U.S. ARL Tech Report #6469) http://imagejdocu.tudor.lu/doku.php?id=macro:analyze_stripes

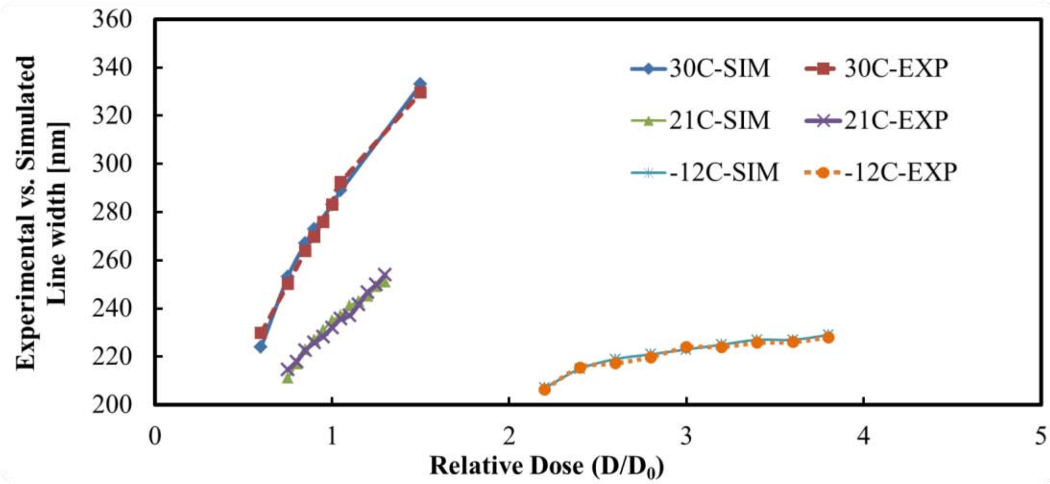
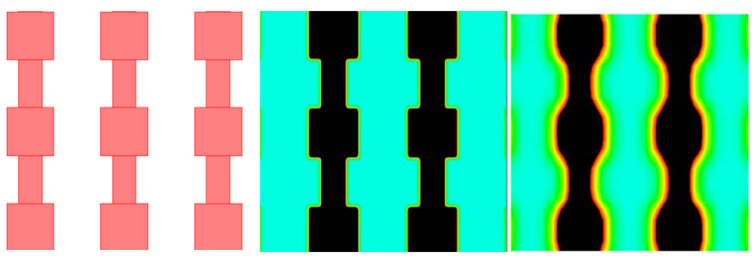
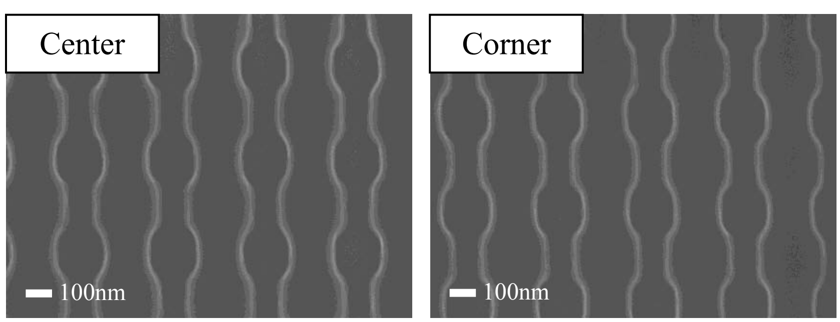


Figure 1: Process Latitude and E-Beam Simulation: The graph shows the empirical dependence of process blur to developer temperature. Good agreement is found using e-beam simulation, which characterizes the effective process blur at 10nm, 42nm and 71nm for developer temperatures at -12˚C, 21˚C and 30˚C, respectively, using a backscatter PSF . Unlike higher temperature development, cold development (-12˚C) requires a higher base dose which explains why the curves do not converge to 200nm as the relative dose decreases.



(a) *(b)* *(c)*

Figure 2: E-Beam Simulation: The original pattern *(a)* is simulated at the center of a 150μm by 150μm square array. Simulating a 10nm blur (-12˚C) in *(b)* exhibits sharp corners. The desired shape fidelity *(c)* utilizes a larger blur (71nm at 30˚C) and limited process latitude. Black indicates where the resist is cleared.



(a) *(b)*

Figure 3: SEM of Proximity Effect Corrected (PEC'd) Pattern with a Large Effective Process Blur of 71nm: The target shape fidelity with rounded corners is achieved using a large blur. However, to maintain CD uniformity with a limited process latitude, the pattern was PEC'd with a 71nm blur. As shown above, the center of the pattern *(a)* is in good agreement to the corner of the pattern in *(b)*.