The Impact of Isofocal Dose-Based Proximity Effect Correction on Effective Process Blur Tolerance

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Proximity effect is a ubiquitous challenge in electron beam lithography (EBL). It is well known that designs patterned using EBL can have overexposed dense features and underexposed sparse features. To resolve these uniformity issues, dose-based proximity effect correction (PEC) convolves the pattern with a point spread function (PSF) to evaluate the absorbed energy distribution, and then physically fractures the pattern, assigning the shapes a dose factor to deposit the appropriate energy so they develop to size. This work demonstrates the impact of isofocal dose-based PEC using 300 nm line-space tower patterns with the following pattern densities: 0%, 25%, 50%, 75% and 100%. PEC is applied with a ~2.5% dose accuracy, and each tower pattern is centered in the main field using BEAMER by GenISys. The patterns are exposed on a silicon substrate spun with a 200 nm thick ZEP520A resist layer (from ZEON CHEMICALS), using an Elionix ELS-7500EX 50 keV EBL tool with a fixed 20 MHz clock at 200 pA with a 30 μm final aperture and a 20 nm beam step size. The pattern is exposed with a focused beam and again with a defocused beam for comparison. Samples are developed using o-xylene for 70 seconds at 21˚C, then soaked in IPA at 21˚C for 30 seconds followed by an N_2 blow dry. The patterns are then transferred 100 nm into the Si using an Oxford 80 Plus reactive ion etcher (RIE) using tetrafluoromethane (CF_4) at 20 sccm with a process pressure of 65 mTorr and an RF power of 150 W for 155 seconds.

The isofocal dose in EBL is defined as the dose that results in the desired feature size independent of the effective process blur ($blur_{eff}$). In other words, if the $blur_{eff}$ changes, the target CD is still obtained by the same dose for a specific pattern density. For this experiment, the dominant component of the $blur_{eff}$ is the electron beam as opposed to temperature.[1] By comparing measurements from tower patterns exposed with a focused beam with those from a defocused beam, the resulting (and very different) $blurs_{eff}$ manifest themselves in the exposure latitude as a change in slope for each pattern density (Figure 1). Superimposing the exposure latitudes from each $blur_{eff}$ at a specific pattern density, the intersection of said curves indicates the pattern density dependent isofocal dose of the resist process (Figure 2). Despite the difference in the $blur_{eff}$, the response to the correction remains invariant when the density dependent isofocal doses are aligned properly using a tunable PEC algorithm (Figure 3). This means that if an isofocal PEC is applied, the desired feature sizes are consistently attainable across all pattern densities regardless of the beam focus accuracy. In the text that follows, we will discuss the techniques used to empirically identify the pattern density isofocal doses and the algorithm employed to correct the pattern based on these findings.

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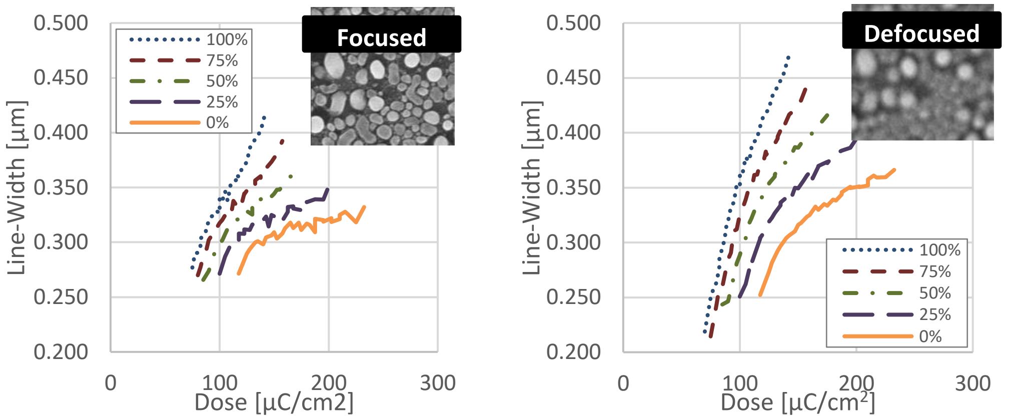
[1] C. M. Eichfeld and G. G. Lopez, J. Vac. Sci. Technol., B 32, 6 (2014).



(a) *(b)*

Figure 1: Exposure Latitudes: The exposure latitude curves for pattern densities 0%, 25%, 50% 75% and 100% using a beam that is (a) focused and (b) defocused. SEM images of a gold reference sample from the (a) focused and (b) defocused beam used during exposure are shown. The data is plotted using the same range in X and Y to show the impact of slope from a focused to a defocused beam. As expected, a steeper slope is seen for the defocused beam in (b).

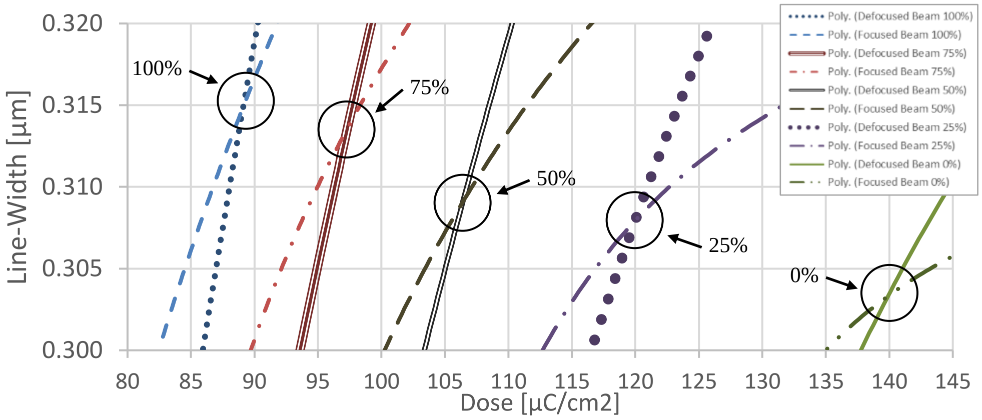
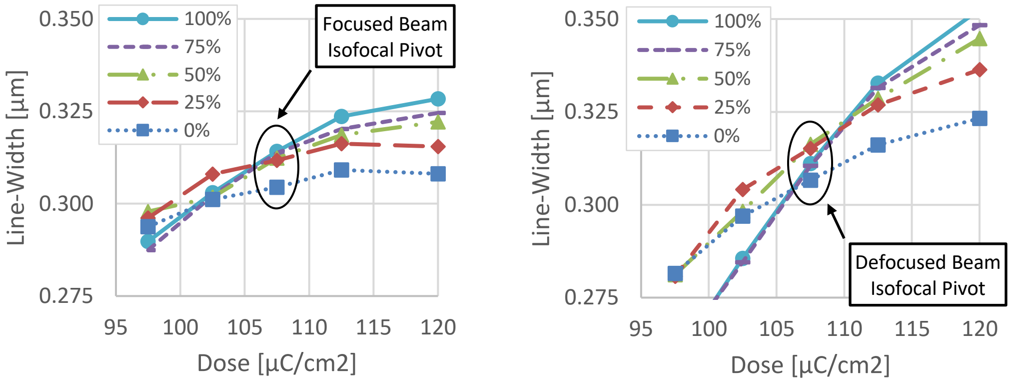


Figure 2: Pattern Density Dependent Isofocal Dose: The isofocal doses are found from the crossover points for each pattern density. As expected isolated features require higher dose. Also note that an isofocal bias increases with pattern density possibly from lateral development in the resist. The pattern dependent isofocal doses are roughly 140, 120, 106.5, 97.5 and 89 µC/cm^2 for 0%, 25%, 50%, 75% and 100% pattern densities, respectively.



(a) *(b)*

Figure 3: Results from an Isofocal PEC: The pivot for an isofocal PEC is indifferent to a (a) focused and a (b) defocused beam. A job dose of 107.5 µC/cm^2 was modulated to the approximate isofocal dose of each pattern density with the response exhibiting tolerance to the $blur_{eff}$ and therefore isofocality.