Modeling Strategies for the Incorporation and Correction of Proximity Effects in High-Resolution Electron-Beam Lithography

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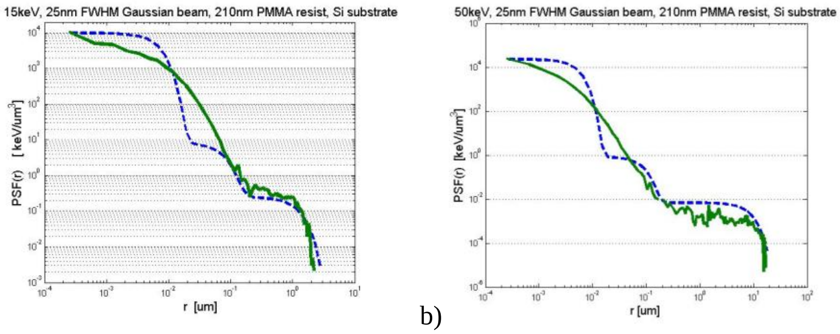
As the micro-electronics industry continues to shrink the size of the devices in integrated circuits, electron beam lithography is used more extensively either for direct wafer write or for mask fabrication [1-3], hence proximity effect correction (PEC) in e-beam lithography (EBL) for large layouts and masks is becoming more urgent. The most critical issue in the e-beam simulation work is to understand the interaction between the electrons and the resist. Several different models to describe this interaction have been developed previously based on the Point Spread Function (PSF) convolution using PSF fit models such as multiple Gaussians [4], analytically derived PSF from transport theory [5], and Monte Carlo modeling [6]. The major disadvantage of the Monte Carlo approach is that it requires large amounts of CPU time in order to obtain a result with sufficiently small statistical fluctuations, especially in the case of a multilayer substrate with many boundary conditions. An alternative to the Monte Carlo method is an analytical representation of the PSF using a Gaussian fit model of electron scattering in resist.

However, there are still some problems before EBL may be deployed in high-volume manufacturing. One of the critical problems is how to quickly estimate the PSF parameters such as forward scattered electron exposure distribution - α and backscattered exposure distribution - β for aerial image formation to allow Proximity Effect Correction (PEC) to compensate for EBL effects. Usually for parameter determination special patterns are exposed, for which the proximity function can be solved analytically, allowing one to fit experimental results. This EBL process is also influenced by the development process. This could be one of the reasons for the widespread measured parameters for identical conditions [7]. In general, the forward scattered electrons exposure distribution, the backscattered exposure distribution, and their ratio are determined by cross section of elastic and inelastic scattering of fast electrons in a resist and a substrate, thus, depend on electron energy E, atomic number, atomic weight, density, resist thickness, etc. Exact values of the parameters are needed for successful correction of the proximity effect in EBL.

In this study a method will be described that illustrates how to determine the optimized PSF for proximity effect corrections in e-beam lithography. The combination of all effects (EBL proximity effect, substrate, energy, resist, development process and etc.) forms the final developed pattern of non-corrected layout. The main idea behind the method is model-based analyses and interpretation of non-corrected representative patterns generic pattern distortions in order to achieve the best possible matching of these effects with extracted empirical data. The modeling will use 3 or more Gaussian PSF convolution with representative patterns and resist development model. This study presents optimized algorithms for e-beam proximity effects which enable the creation of both fast and accurate full-chip process models for EBL. Model fits for various EBL effects will be demonstrated. Algorithms used to create these fits will also be discussed.



a) b)

Fig.1. Exposure energy distribution on silicon substrate at 15keV (a) and 50keV (b) obtained by "S-Litho ebeam" software package using Monte Carlo Simulation. The dotted line indicates the fitted triple Gaussian point spread function.

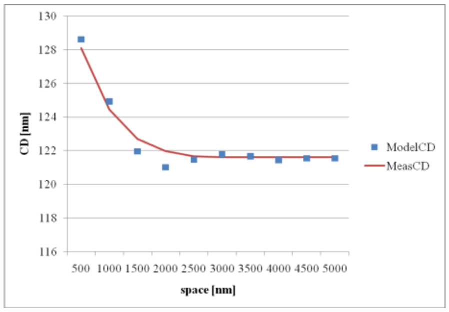


Fig.2. An Example of modeled CD.

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