Study of Line-Edge Roughness in ZEP Resist Nanopatterns from Electron Beam Lithography by Numerical Modeling

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Optimization of line-edge roughness (LER) and line-width roughness (LWR) is critical for fabrication of structures and devices at the nanometer scale by electron beam lithography (EBL). Here we propose a novel approach to estimate LER and LWR in a positive-tone EBL resist numerically. The factors which determine LER include pattern roughness of the mask, fluctuations in local exposure dose along the line edge, physico-chemical properties of the resist, etc. [1]. In the present work we explore the impact of the non-uniformity of local exposure on the observable LER. The impact of a thin electron beam on a resist layer can be characterized by a three-dimensional (3D) point spread function (PSF), which conventionally represents the distribution of deposited energy [2]. In our previous works, we adopt a somewhat different interpretation of PSF, as a spatial distribution of the yield of scissions (broken bonds) as a result of interaction of electrons with a positive tone resist [3,4]. Here we have found that because of the stochastic nature of the electron scattering processes, and for practically applicable exposure dose regimes, the local PSF levels vary across the resist, thereby providing a contribution to LER. We have investigated, how large a contribution to LER these fluctuations of exposure can produce for a ZEP resist under the exposure conditions typically used in EBL. For this purpose, we first computed a nominal continuous exposure distribution with our original EBL simulation tool [3,4] as shown in Fig. 1. Next, we introduced fluctuations in the distribution such that the number of broken C-C bonds per unit volume is always an integer number, whereas the averaged yield of scissions is equal to the local nominal level. This accounting for the fluctuations is close to that in Ref. [2], but it is more efficient since modeling of the detailed structure of the resist is avoided, yet it still provides a molecular-level treatment of the scissions through the corresponding local yields. Figs. 2a and b present examples of computed development profiles in a periodic grating structure with a 60 nm pitch, and Figs. 3 and 4 illustrate the predicted dependencies of the line width (LW) and LER on the average line dose. The LW dose dependence on Fig. 3 comprises three parts, two nonlinear ones (for doses below 100 pC/cm and higher than 220 pC/cm) and one linear where LW increases in proportion to the dose. A similar behaviour of LW versus dose was recently reported in [5] for PMMA. Interestingly, the dose dependence of LER in Fig. 4 has a profound minimum around 150 pC/cm, i.e. close to the middle of the linear portion of the LW curve, which emerges as an optimal exposure dose for ZEP. Our predicted LER for dose 100 pC/cm (1.28 nm) is in good agreement with our benchmark experiment [6], which gives a 1.3 nm LER for ZEP exposed at similar conditions. Our further analysis has also shown that LER and LWR are normally uncorrelated, and therefore the well-known relationship for the standard deviations is applicable, $\sigma_{LWR} = \sqrt{2}\,\sigma_{LER}$. Further tests of the model are in progress.

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5. N. Tsikrikas et al., Japanese Journal of Applied Physics **47**, 4909-4912 (2008).
6. M. A. Mohammad et al., Japanese Journal of Applied Physics (2011) submitted.

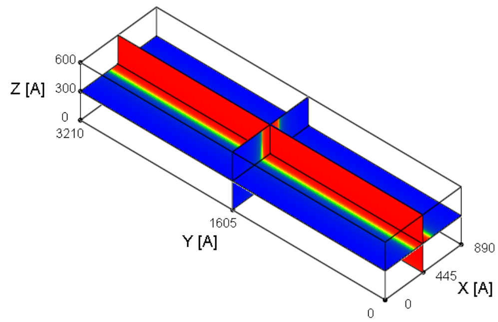

Figure 1 Example of a continuous nominal distribution of the yield of scission in a segment of a periodic grating with a 60 nm pitch in a layer of ZEP-520 resist on a Si substrate, computed using model 2 from Ref [4], without accounting for fluctuations. Red color corresponds to high scission yield and the blue stands for low yield. The size of 3D segment of periodic structure used for the calculation is 321nm×60nm×89nm. The electron energy of exposure is 10 keV.

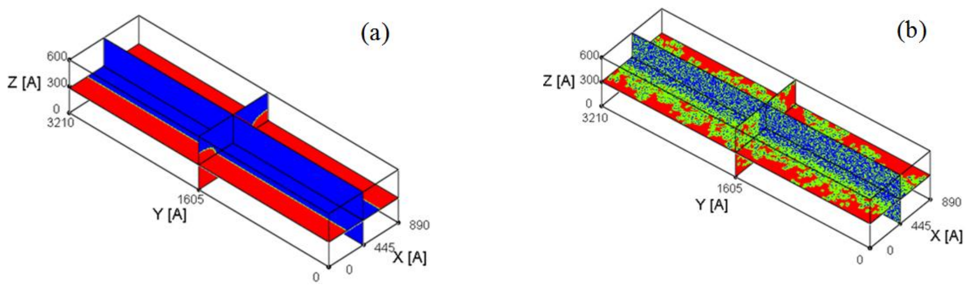

Figure 2 Examples of computed development profile in a segment of a periodic grating with a 60 nm pitch in ZEP-520 resist, (a) – without fluctuations, (b) –with fluctuations. Blue and green colors represent fully or partially developed areas, and red indicates totally undeveloped areas. Fluctuations of the scissions distribution taking into account the stochastic nature of PSF were introduced (see Fig. 2b). After this, development during 5s in ZED-N50 developer at temperature of 22°C was simulated employing the kinetic model from Ref.[6].

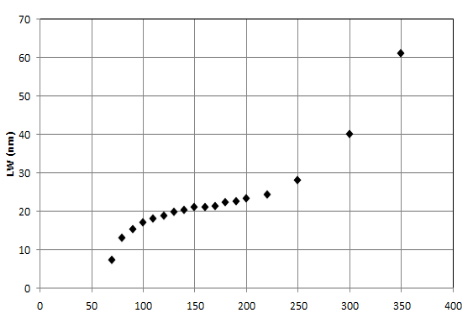

Figure 3 Line width as a function of line dose calculated for the periodic grating in ZEP resist with fluctuations. The conditions of exposure and development as well as the simulation geometry are as in Figs. 1 and 2.

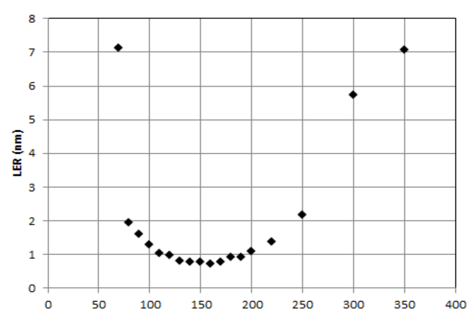

Figure 4 Line-edge roughness (the standard deviation) as a function of the dose for the periodic grating in ZEP. The conditions of exposure and development as well as the simulation geometry are as in Figs. 1 and 2.