Acid distribution in chemically amplified extreme ultraviolet resist

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Acid generators are sensitized by secondary electrons in chemically amplified resists for ionizing radiation. As acid generators react with low energy electrons (as low as thermal energy), this sensitization mechanism generates a significant blur and an inhomogeneous acid distribution at the image boundary, which results in line edge roughness (LER) formation. Although the extent of resolution blur has been evaluated in electron beam resists[1], it has been unknown for extreme ultraviolet (EUV) resists because of the difference in the energy spectra of secondary electrons ejected by the ionization. The evaluation of resolution blur intrinsic to the reaction mechanisms is important to develop and optimize resist materials for EUV lithography, especially from the viewpoint of LER.

In this study, we simulated acid generation induced by EUV photons in PHS with 10 wt% TPS-tf and made clear the extent of resolution blur of latent acid images. Figure 1 shows a schematic drawing of EUV-material interaction. When an EUV photon enter materials, it ionizes resist molecules (especially polymers). The ejected electrons with excess energy further induce ionization and excitation. For PHS, the W-value (an average energy required to produce an ion pair) of EUV is approximately same as that of 75 keV electrons, which has been reported to be 22.2 eV.[2] Therefore, 4.2 electrons are generated on average by single EUV photon. After the interaction with molecules, the energy of electrons reaches an equilibrium with thermal energy. The thermalized electrons migrate in resist matrix and react with acid generators.

The electron trajectories after EUV absorption were calculated using a modified form of Bethe equation with the parameters calculated using values of the electron energy loss function. Figure 2 and 3 show the initial probability distribution of radical cations (ionization point) and thermalized electrons, respectively. EUV photons are absorbed at the origin. Because the inelastic mean free path of <90 eV electrons is shorter than the thermalization distance, the electron distribution is significantly wider than the radical cation distirubiton. For EB resists, an average distance between electron-cation pairs is approximately 30 nm on the incident electron trajectory. However, for EUV resists, radical cations are clustered around the origin. This cluster (the average number: 4.2) exerts a stronger Coulomb force on surrounding electrons than single cation. The subsequent electron migration and the reaction with acid generators were calculated according to the previously reported procedure.[3] Figure 4 shows an acid probability distribution. The average distance from EUV absorption point (resolution blur) is 6.3 nm. The resolution blur is slightly increased from that of electron beam (5.6 nm) because of the difference in initial electron energy ejected by incident radiation. The acid generation efficiency per ionization is decreased from 0.74 (EB) to 0.62 (EUV) because of the electric field produced by the clustered cations. The acid generation efficiency per EUV photon is 2.6.

References 1. T. Kozawa et al., J. Appl. Phys. **99**, 054509 (2006). 2. T. Kozawa et al., J. Vac. Sci. Technol. **B24**, 3055 (2006). 3. T. Kozawa et al., J. Vac. Sci. Technol. **B22**, 3489 (2004).

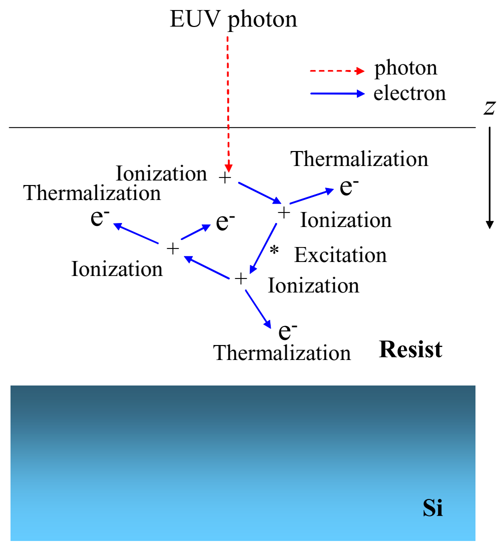

Fig. 1. Schematic drawing of EUV-material interaction.

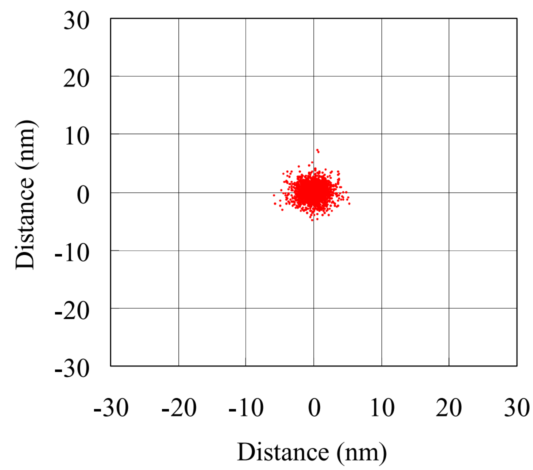

Fig. 2. Initial probability distribution of radical cations (proton source).

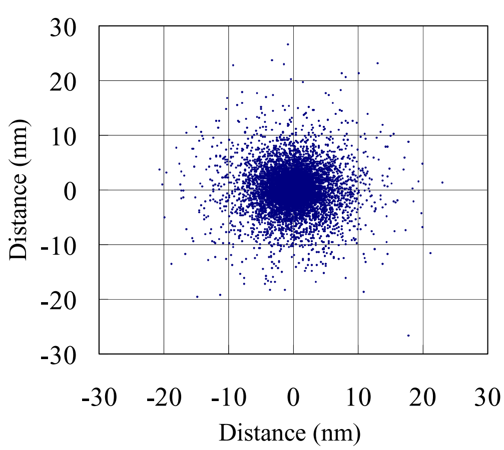

Fig. 3. Initial probability distribution of thermalized electrons.

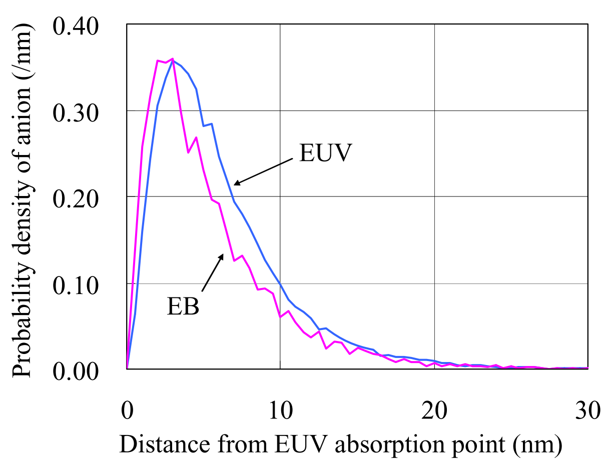

Fig. 4. Probability distribution of anion generated in PHS with 10 wt% TPS-tf by an EUV photon. The distribution generated by EB was normalized for the comparison.