Latent image formation in chemically amplified extreme ultraviolet resists with low activation energy for deprotection reaction

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The trade-off between resolution, sensitivity, and line width roughness (LWR) has become a serious problem in device manufacturing as the minimum feature size is reduced. To solve this problem, the improvement of pattern formation efficiency is necessary. The efficiency of pattern formation is mainly determined by the absorption efficiency of incident radiation and the acid generation and deprotection efficiency. The deprotection efficiency means how many times an acid can induce catalytic reactions during the diffusion of unit distance. The expected highest efficiency is achieved by a diffusion-controlled reaction. From this viewpoint, low activation energy (E_a) type resists are superior to high E_a type resists. However, high E_a resists have an advantage in the acid-base neutralization. In high E_a resists, acid-base neutralization is once completed before catalytic reactions and start again with the elevation of temperature. The initial neutralization significantly improves the acid image generated upon exposure. However, the neutralization competes against catalytic reactions from the start of exposure in low E_a resists without the image improvement. In this study, we investigated the feasibility of low E_a resists for 22 nm fabrication.

In the simulation, a 22 nm line and space pattern was assumed. The aerial image of incident EUV was assumed to be a cosine function. The initial acid distribution was calculated in accordance with the previously reported formulation based on the sensitization mechanisms of chemically amplified extreme ultraviolet (EUV) resists.[1] The acid and quencher diffusion was calculated under the assumptions that diffusion coefficient is constant or deprotection-dependent.

The representative initial distributions of acid and quencher are shown in Fig. 1. The normalized aerial image of incident EUV is shown in Fig. 1 for comparison. The representative distribution change of protected unit concentration is shown in Fig. 2. Figure 3 shows the latent images (the concentration of protected unit) after all acids are quenched, calculated under the assumption that the diffusion coefficient is constant. Although resist patterns may be still resolved because of the nonlinearity of dissolution kinetics, the latent image is significantly degraded at 5 mJ cm^{-2} exposure. In low E_a resists, acid molecules are considered to diffuse by the relaxation of resist matrix induced by the deprotection reaction. Therefore, the diffusion coefficient depends on the extent of deprotection. This effect may improve the image quality. Under the assumption that the diffusion coefficient is proportional to the extent of deprotection, the latent images were recalculated as shown in Fig. 4. However, the effect was small in this case although the image qualities were slightly improved.

Even when the diffusion-controlled rate is assumed, the efficiency is inadequate for 22 nm fine patterning. For 22 nm fabrication with 5-10 mJ cm^{-2} exposure dose, the increase in acid generation efficiency and polymer absorption is essentially required.

Reference 1. T. Kozawa et al., submitted to Jpn. J. Appl. Phys.

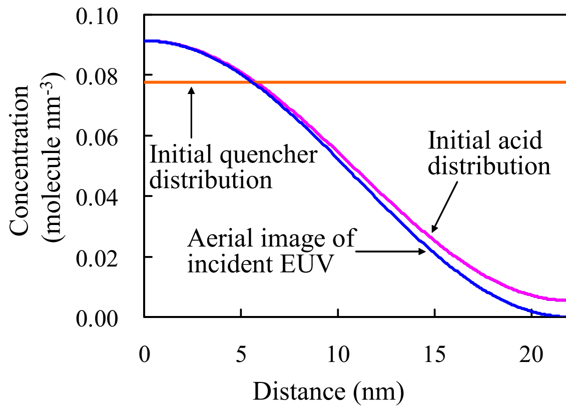

Fig. 1. Aerial image of incident EUV and initial distributions of acid and quencher. 22 nm line & space pattern was assumed. The esposure dose is 10 mJ cm^{-2}. The diviation between the aerial image and acid distribution was caused by secondary electrons. These distributions were used as a boundary condition in the following calculation of acid and quencher diffusion and deprotection reaction.

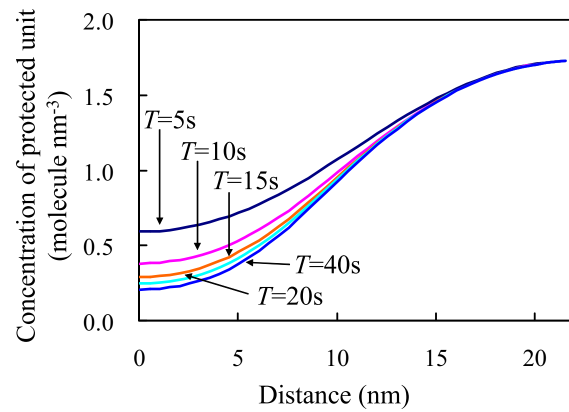

Fig. 2. Representative distribution change of protected unit concentration after EUV esposure with 10 mJ cm^{-2}. All acids were consumed before 40 s after exposure. The diffusion coefficient was assumed to be constant. The quencher concentration was optimized for 22 nm fabrication. The deprotection reaction was assumed to proceed with a diffusion-controlled rate.

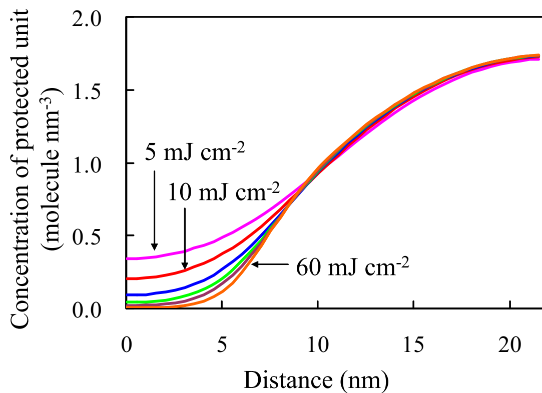

Fig. 3. Dependence of latent image quality on exposure dose. The latent images shown here are ones formed after all acids were consumed. Quencher concentrations are optimized for each exposure dose so that 22 nm patterns can be resolved. The exposure doses are 5, 10, 20, 30, 40, and 60 mJ cm^{-2} from the top line to the bottom line at the origin, respectively.

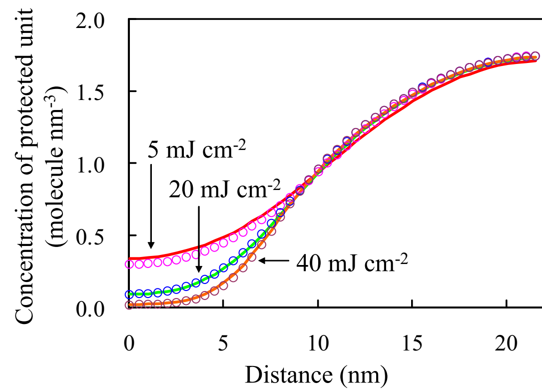

Fig. 4. Difference between constant and deprotection-dependent diffusion coefficient models. The lines represent latent images calculated using a constant diffusion coefficient model. The open circles represent ones calculated using a deprotection-dependent diffusion coefficient model.