Image Contrast Slope and Line Edge Roughness of Chemically Amplified Resists for Post-Optical Lithography

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The topography of patterned resist surface such as line edge roughness (LER) or line width roughness (LWR) has become a problem in device manufacturing as the minimum feature size is reduced. Requirement for LWR is projected to be less than 1.7 nm at the 32 nm technology node. As LER has been intensively investigated, the details of LER are getting clear. Many factors have been reported to affect LER formation as shown in Fig. 1. LER is formed through three stages ([i] acid image formation during exposure, [ii] latent image formation, [iii] development and rinse). Because beam optics and lithography process have been well investigated, only a missing link in a series of LER formation processes had been an acid generation process for the post-optical lithography. For photoresists, the initial acid distribution corresponds to the aerial image of incident light. In chemically amplified EB and EUV resists, acid generators are mainly sensitized by secondary electrons generated by primary electrons or EUV photons. The problem is in the fact that acid generators react with low energy electrons near thermal energy. Although this sensitization mechanism leads to efficient acid generation,[1] it simultaneously causes significant resolution blur, namely, the degradation of image contrast.[2]

An accurate process simulation including LER formation requires a precise prediction of image contrast. In particular, the prediction of acid concentration is important because a statistical effect play an essential role in LER formation.[3] We propose a formulation for the calculation of image contrast slope based on the sensitization mechanisms of chemically amplified resists for post-optical lithography. The advantage of this method is an accurate prediction for the initial acid distribution, which determines the following LER formation.

The aerial images of incident radiation and initial acid distribution are shown in Fig. 2 with image profiles after neutralization. The distribution changes of the temporal integration of acid concentration are shown in Fig. 3. Figure 4 shows the concentration of protected unit. The intermediate region where unprotected and protected polymers coexist has been reported to lead to LER formation.[4] The image contrast slope in Fig. 4 is initially improved and then degraded during PEB. Because the image contrast slope depends on targeted patterns and many factors as shown in Fig. 1, minimizing LER (finding a process parameter set to maximize the image contrast) requires the accurate prediction of latent images. Also, these results were compared with LERs of molecular and polymer type resists.

References 1. T. Kozawa et al., J. Vac. Sci. Technol. **B24**, L27 (2006). 2. T. Kozawa et al., J. Appl. Phys. **99**, 054509 (2006). 3. T. Kozawa et al., J. Vac. Sci. Technol. **B23**, 2716 (2006). 4. W. Hinsberg et al., J. Vac. Sci. Technol. B 16, 3689 (1998).

Initial acid distribution

Aerial image including reflection from substrate and flare
Acid concentration
- Exposure dose — **Process factor**
- Acid generation efficiency — **Material factor**

Shot noise
Specific to EB and EUV
Reaction of acid generator with low energy electron (~0eV)

Catalytic chain reaction (acid diffusion and reaction)

- Pre-baking and post-exposure bake conditions (temperature and period) — **Process factor**
- Diffusion constant of acid and base quencher — **Material factor**
  - Glass transition temperature of polymer
  - Size of acid counter anion and base quencher
  - Residual solvent
- Base quencher concentration
- Activation energy for catalytic reaction

Development and rinse

- Development time — **Process factor**
- Temperature of developer
- Strength and molecular size of solvents
- Rinse
- Molecular weight — **Material factor**
- Molecular dispersion
- Rigidity of polymer structure
- Polymer aggregation
- Crystallization

Fig. 1. Factors to affect LER formation.

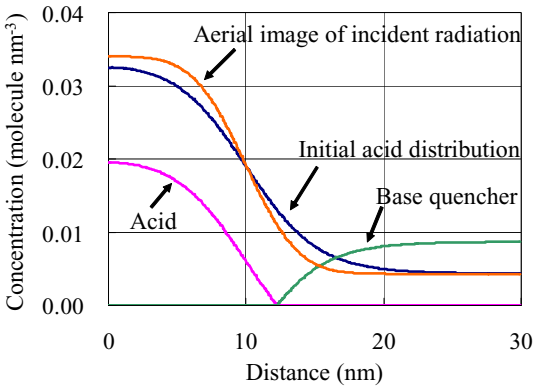

Fig. 2. Aerial image of incident radiation and initial acid distribution. 30 nm line & space pattern is assumed. Acid and base quencher profiles after neutralization are also shown.

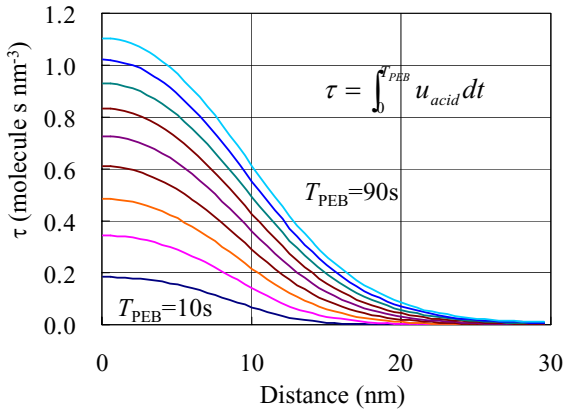

Fig. 3. Profiles of the temporal integration of acid concentration, τ. In the equation, u_{acid} and T_{PEB} are the acid concentration and PEB time, respectively. T_{PEB} ranges from 10 (bottom line) to 90 s (top line) with the time interval of 10 s.

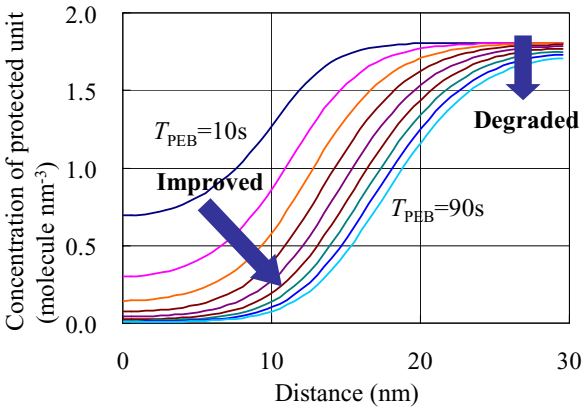

Fig. 4. Temporal changes of profiles of the concentration of protected units during PEB. PEB times range from 10 (left line) to 90 s (right line) with the time interval of 10 s.