KrF TRILAYER RESIST SYSTEM USING AZIDE-PHENOL RESIN RESIST

N. ASAI, A. IMAI, T. UENO, Y. AZUMA*, T. MIYAZAKI*, T. TANAKA and S. OKAZAKI
Central Research Laboratory, Hitachi Ltd., Kokubunji, Tokyo 185
**Hitachi ULSI Eng. Corp. Kodaira, Tokyo 187*

Azide-phenol resin resist is applied to a trilayer resist system for KrF excimer lithography. It was found that smaller size patterning below 0.2- μm -level limit the film thickness to 0.5 μm of bottom layer due to pattern collapse and micro-loading during the dry etching processes. Under such condition, the analysis of multi-interference effect for trilayer resist system leads to a photoabsorptive resist as a top layer. The photoabsorptive resist with extinction coefficient of 0.045 for trilayer resist system gives linewidth variation less than 0.005 μm , resolution limit of 0.15- μm L/S and depth of focus of $\pm 0.8 \mu\text{m}$ for 0.16- μm L/S pattern.

1. Introduction

Trilayer resist systems have been widely investigated to obtain high resolution and precise critical dimension (CD) control. [1] In optical lithography, these systems enable precise CD control to be easily obtained because a thin and uniform top layer (TL) gives high resolution and a thick bottom planarizing layer (BL) can eliminate the reflected light from the substrate. [2] To get the minimum feature size below 0.2 μm , we apply a trilayer resist system for KrF excimer laser lithography using phase-shift mask. However, the aspect ratio of the patterns is limited by pattern collapse and micro-loading in the subsequent etching process [3], leading to relatively thinner BL layer. Since thin BL cannot sufficiently reduce the reflection, it is difficult for a trilayer resist with thin BL to precisely delineate a fine pattern.

This paper discusses a new approach to compensating the reflected light from the substrate for the thin BL with low absorbance. This approach uses a photoabsorptive negative resist as the top layer of trilayer resist systems for KrF excimer laser lithography.

2. Multiple interference in the trilayer resist system

When investigating trilayer resist systems for optical lithography, multiple interference must be taken into account. We define nominal amplitude reflectivity r_{bot} as the amplitude ratio of the total

reflected light from the underlying layers (Middle Layer (ML) and BL) to the incident light on ML. Figure 1 shows a schematic view of the structure of a trilayer resist system.

r_{bot} is defined by the following expressions for monochromatic incident light .

$$r_{bot} = \frac{r_3 + r' \cdot \exp(-id_2)}{1 + r' \cdot r_3 \cdot \exp(-id_2)},$$

$$\text{where } r' = \frac{r_2 + r_1 \cdot \exp(-i\delta_1)}{1 + r_1 \cdot r_2 \cdot \exp(-i\delta_1)}, \quad r_1 = r_{sub} \cdot \exp(i\theta),$$

$$r_2 = \frac{(n_1 - ik_1) - (n_2 - ik_2)}{(n_1 - ik_1) + (n_2 - ik_2)}, \quad r_3 = \frac{(n_2 - ik_2) - (n_3 - ik_3)}{(n_2 - ik_2) + (n_3 - ik_3)}$$

$$\delta_1 = \frac{4\pi \cdot (n_1 - ik_1) \cdot d_1}{\lambda}, \quad \delta_2 = \frac{4\pi \cdot (n_2 - ik_2) \cdot d_2}{\lambda}.$$

r_{bot} corresponds to the bottom interface reflectivity for a single-layer resist system. Here, n_1 , n_2 , and n_3 are the real parts of the refractive indexes of BL, ML, and TL, k_1 , k_2 , and k_3 are the imaginary parts of the refractive indexes (extinction coefficient) of BL, ML, and TL, and d_1 , d_2 , and d_3 are the thicknesses of BL, ML, and TL, respectively. λ is the wavelength of the exposure light, r_{sub} is the amplitude reflectivity at the interface between BL and the substrate, and θ is the optical phase shift at the interface between BL and the substrate.

Figure 2 shows the dependence of nominal reflectivity r_{bot} on the BL extinction coefficient, k_1 . We assumed 0.5- μm -thick BL, 0.06- μm -thick ML, 0.2- μm -thick TL and a perfectly reflective substrate. This figure indicates that the reflectivity r_{bot} has a minimum value around $k_1 = 0.2$. Curve (a) shows the calculated reflected r_{bot} in the case of optical index matching at all interfaces in the resist system. Under this condition, the minimum r_{bot} is 0.1. Curve (b) shows r_{bot} in the case of assuming a spin on glass (SOG) as ML, which gives the minimum r_{bot} of 0.18.

The effective exposure dose change ratio (swing ratio) to average dose, E_S , caused by the multiple interference effect is given by the following equation. [4]

$$E_S = 4 \cdot r_{sur} \cdot r_{bot} \cdot \exp(-4\pi k_3 d_3 / \lambda), \quad (1)$$

where r_{sur} is the amplitude reflectivity of the air/TL interface. As the refractive index of TL is around 1.8, r_{sur} is about 0.286. Transparent TL gives the minimum dose swing of $\pm 11\%$ from Eq (1) when TL, ML and BL refractive index are matched. When SOG is used for the ML, the swing is $\pm 20\%$. Therefore, when a transparent resist for the TL is used, the multiple interference effect gave significant the pattern size variations even for optical index matching at all interfaces. On the other hand, it is expected that use of photoabsorptive resist for the TL can change, the multiple interference

effect. When the extinction coefficient of TL, k_3 , is 0.05, the exposure swing, E_s , in a 0.2- μm -thick TL is 40% smaller than that of a completely transparent resist.

Fig. 1. Schematic view of exposure light rays in a trilayer resist system.

Fig. 2 Dependence of BL extinction coefficient k_1 on nominal reflectivity r_{bot} . The following conditions are used : (a) $n_1=1.8$; $n_2=1.8, k_2=0.0$; $n_3=1.8, k_3=0.0$ (b) $n_1=1.92$; $n_2=1.47, k_2=0.0$; $n_3=1.8, k_3=0.0$

3. Experimental

The resist material prepared for this work was a crosslinking type negative resist composed of 4,4'-diazide-3,3'-dimethoxy biphenyl sensitizer and poly(hydroxystyrene). [5] The resist was prebaked at 80°C for 2 min. The extinction coefficient of the TL was 0.045 for a resist thickness of 0.2 μm . Other optical indexes of the trilayer resist system are listed in Table 1. A 0.505- μm -thick BL was spun onto a Si substrate.

Exposure was done using a KrF excimer stepper and a phase shifting mask. The numerical aperture (NA) of the lens was 0.45, and the coherency factor (σ) was chosen to be 0.3. The bandwidth of the laser was less than 2.4 pm (FWHM). The resist was developed in a 0.48% tetramethylammonium hydroxide (TMAH) aqueous solution for 125 s and rinsed in de-ionized water. An ellipsometer (MOSS, Sopra Corp.) was used for complex refractive index measurement. Measurements of linewidth and observations of fabricated micropatterns were done on a scanning electron microscope (SEM) S800 and S900 (Hitachi Ltd.).

Table 1 Optical indexes of trilayer resist in the experiment

($\lambda = 248 \text{ nm}$)			
Layer	Real part of the refractive index	Extinction coefficient	Thickness (μm)
TL	1.80	0.045	0.2
ML	1.70	0.26	0.06
BL	1.92	0.13	0.505

4. Experimental Results and Discussion

Multiple Interference - Figure 3 shows the dependence of the linewidth variation on the TL resist thickness for fixed exposure dose. The linewidth swing range was about 0.005 μm , which was only 2.5% of the designed linewidth. The linewidth swing range and the effective exposure dose swing ratio, E_s , were simulated using the exposure dose latitude data. The swing ratio, E_s , in the experimental resist system, which was calculated on the basis of the data shown in Table 1 using Eq.(1), is approximately 0.03. The exposure dose latitude parameter A is defined as

$$L = A \log I + B, \quad (2)$$

where L is linewidth, I is exposure dose and B is a constant parameter. From Fig. 4, it can be seen that A is 0.33 μm in the case of this experimental resist. From Eq. (2), the linewidth change, ΔL , is derived as

$$\Delta L = \frac{A}{\ln 10} \cdot \frac{\Delta I}{I}.$$

As the $(\Delta I / I)_{\max}$ is E_s , the simulated linewidth swing, $2\Delta L$, for the resist system was $0.008 \mu\text{m}$, and this value agrees well with the experimental data of $0.005 \mu\text{m}$. From these experimental results, we conclude that the photoabsorptive resist is quite effective in reducing the unwanted light reflection.

Fig. 3 The dependence of a top layer resist thickness on the Critical Dimension. The design pattern was a $0.16 \mu\text{m}$ L/S pattern. Exposure dose was $81 \text{ mJ}/\text{cm}^2$. The linewidth swing range was about $0.005 \mu\text{m}$.

Fig. 4. Dependence of exposure dose on Critical Dimension. The design pattern was a $0.16 \mu\text{m}$ L/S pattern.

Other lithographic features of the experimental resist are summarized as follows.

Resolution - Figure 5 shows SEM photographs of delineated line-and-space (L/S) patterns using phase shifting lithography. $0.15\text{-}\mu\text{m}$ L/S and $0.16\text{-}\mu\text{m}$ L/S patterns can be clearly delineated. The exposure dose was $81 \text{ mJ}/\text{cm}^2$.

Focus Latitude - Resist pattern profiles under various focus conditions are shown in Fig. 6. The measured CD-focus curve for $0.16\text{-}\mu\text{m}$ L/S patterns is shown in Fig. 7. A defocus tolerance of $\pm 0.8 \mu\text{m}$ for 10% CD change was obtained.

Fig. 5. Delineated TL patterns. Exposure dose was 81 mJ/cm². TL film thickness was 0.2 μm .

Fig. 6. Defocus characteristics of experimental resist patterns. The design pattern was a 0.16 μm L/S pattern. Exposure dose was 81 mJ/cm². TL film thickness was 0.2 μm .

Fig. 7. CD-focus characteristics. The design pattern was a 0.16 μm L/S pattern. Exposure dose was 81 mJ/cm^2 . TL film thickness was 0.2 μm .

Thickness Dependence- Figure 8 shows cross sectional views of the TL pattern with 0.2- μm -thick and 0.3- μm -thick resist under the same exposure and development conditions. There is no significant difference between the 0.2- μm -thick resist pattern and the 0.3- μm -thick pattern.

Fig. 8. Resist thickness dependence of TL patterns. The design pattern was a 0.16 μm L/S pattern. Exposure dose was 81 mJ/cm^2 .

BL pattern - Figure 9 shows a cross sectional view of the 0.16- μm L/S BL pattern after pattern transfers by dry etching processes. It shows that a vertical wall pattern was obtained without any pattern collapse.

Fig. 9. Delineated BL patterns of 0.16- μm L/S BL pattern.

5. Conclusion

A trilayer resist system for KrF excimer exposure optimized for thin BL (0.5 μm) was investigated. A photoabsorptive negative resist (an azide-phenol resin resist with 0.045 extinction coefficient) as TL for trilayer resist system can avoid the problem of light reflection, which enables 0.16- μm -level pattern for KrF excimer laser lithography. The linewidth variation of the resist was less than 0.005- μm , which is half that of a transparent resist. The resolution limit of the experimental resist was 0.15- μm L/S patterns, and the depth of focus was $\pm 0.8 \mu\text{m}$ for 0.16- μm L/S patterns. According to these results, this photoabsorptive resist is very suitable for the trilayer resist systems with thin BL.

Acknowledgment

The authors would like to thank Mr. Hiroshi Kamiyama of SEIKA Corp. for carrying out the optical index measurement.

References

- [1] J. M. Moran and D. Mayden, *J. Vac. Sci. Technol.*, **16**, 1620 (1979)
- [2] T. Tanaka, N. Hasegawa, S. Okazaki and Y. Azuma, *J. Vac. Sci. Technol. B*, **10**, 723 (1992)
- [3] Y. Gotoh, T. Kure and S. Tachi, *Jpn. J. Appl. Phys.*, **32**, 3035 (1993)
- [4] T. Brunner, *Proc. SPIE*, **1466**, 297 (1991)
- [5] M. Toriumi, N. Hayashi, M. Hashimoto, S. Nonogaki, T. Ueno and T. Iwayanagi, *Polym. Eng. Sci.*, **29**, 865 (1989)