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Characterization of a Newly Developed Contrast Enhancement Material for G-Line Exposure

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A CEL material for g-line exposure using the diazonium compound as the photobleaching dye was developed and several experiments were performed. As a result, submicron resist patterns with steep profile were obtained without the intermixing layer. It was found that the CEL leads to an improvement in the resolution and is very important technology to complement the performance of optical exposure tools.

Introduction

Recently, Griffing and West[1)] introduced the "Contrast Enhanced Photolithography", which is a method of improving the contrast of the resist exposure process that could extend the resolution limits of optical lithography. This method consists of a bi-level structure. The bottom layer is a conventional positive photoresist. The top layer, namely contrast enhancement layer (CEL), contains a photobleachable dye which is sensitive to the exposure wavelength of the optical exposure tools. The regions of the CEL which are exposed to the highest light intensity of the image are bleached more rapidly than regions which are exposed to lower levels of light intensity. Consequently, the ratio of the cumulative energies in the high and low light level regions of the image which transmitted through the CEL is higher than the ratio of the incident light levels.

In this work, we dealt with this technology and examined the properties which the CEL material must have to obtain higher resolution. On the other hand, the commercially available CEL material has the following inherent problems: (1) There is not an appreciable contrast enhancement effect in the g-line (436 nm) exposure wavelength. (2) Tri-level structure must be adopted to avoid the intermixing layer formation. Thus, a CEL material which successfully solved these problems has been newly developed.

In this paper, according to the information of the computer simulation, a new CEL material is proposed and characterized. In addition, improvement in the resolution of optical lithography is demonstrated.

Computer Simulation

A model of the bleaching process was developed and utilized in the evaluation of bleachable materials suitable for use in the CEL. The CEL material was characterized by the A, B and C parameters reported by Dill, et al.[2)] That is, the effective exposure dose transmitted through the CEL, D_{trans}, is given by

$$D_{trans} = \int_0^{t_{exp}} I_{trans}(T_{cel},t)dt \quad , \tag{1}$$

$$I_{trans}(T_{cel},t) = I_0 \exp\{-\int_0^{T_{cel}} [AM(z,t)+B]dz\}, \tag{2}$$

$$\frac{\partial I(z,t)}{\partial z} = -I(z,t)[AM(z,t)+B] \quad , \tag{3}$$

$$\frac{\partial M(z,t)}{\partial t} = -I(z,t)M(z,t)C \quad , \tag{4}$$

were T_{cel} is the CEL thickness, $I(z,t)$ is the light intensity at any depth z in the CEL and exposure time t, I_0 is the intensity of the incident light and M is the relative amount of the photobleaching dye. Parameter A relates to the absorption coefficient of the CEL material before exposure ($M=1$). Parameter B corresponds to the final absorption coefficient of the completely bleached CEL material ($M=0$). Parameter C signifies the bleaching rate of the CEL.

The simulated resist profile of the typical CEL process, assuming that $A=5\ \mu m^{-1}$, $B=0.06\ \mu m^{-1}$ and $C=0.014\ cm^2/mJ$, is shown in Fig. 1. A steep profile can be obtained, and the depend-

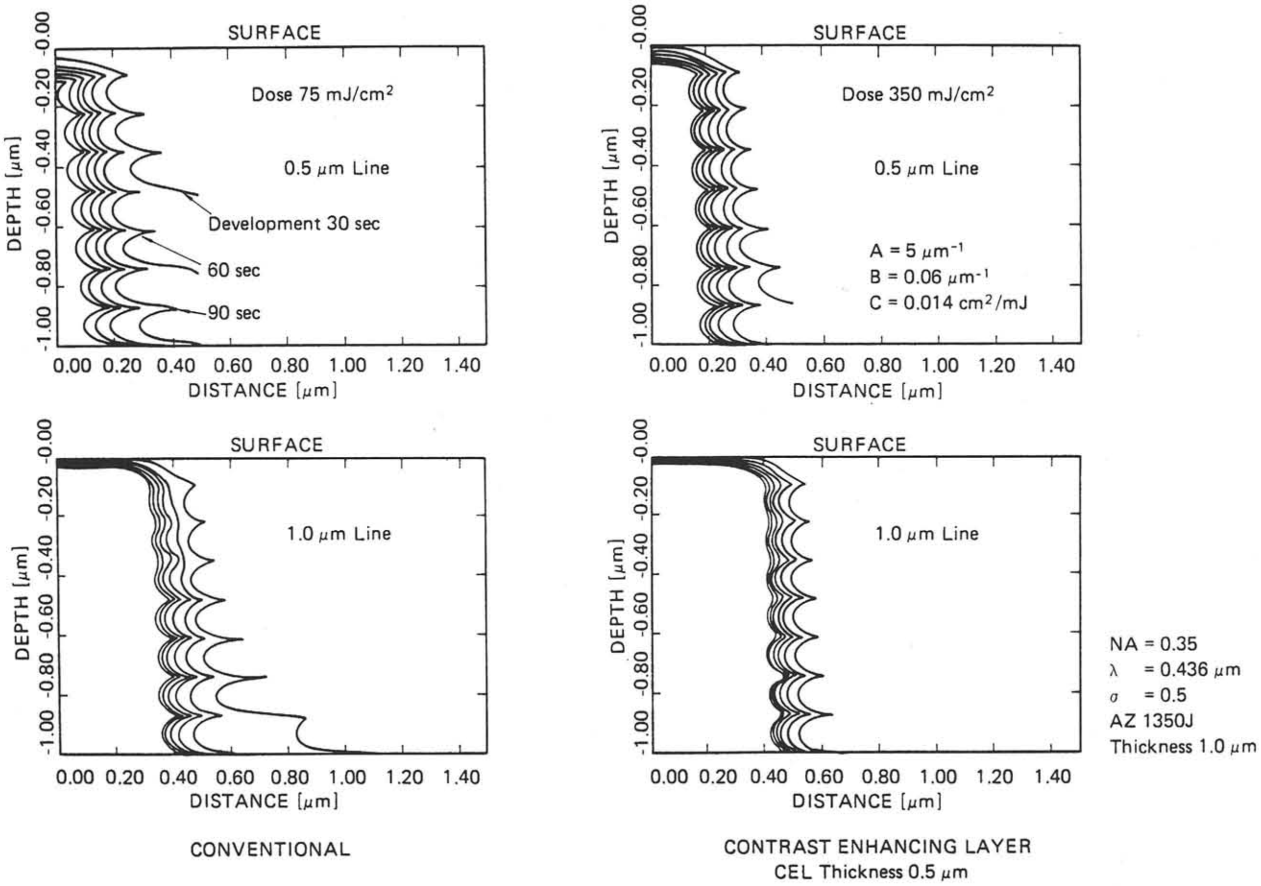


Fig. 1 Simulated resist profiles from a typical CEL process.

ence of the linewidth on the development time decreases with the use of the CEL. Furthermore, it was found from the computer simulation that the contrast enhancement effect is mainly determined by the value of the parameter A[3]. The relation between A and the output dose contrast is shown in Fig. 2. Assuming that the required contrast is 0.8, the A value of more than 3 μm^{-1} is necessary to realize the submicron linewidth printing.

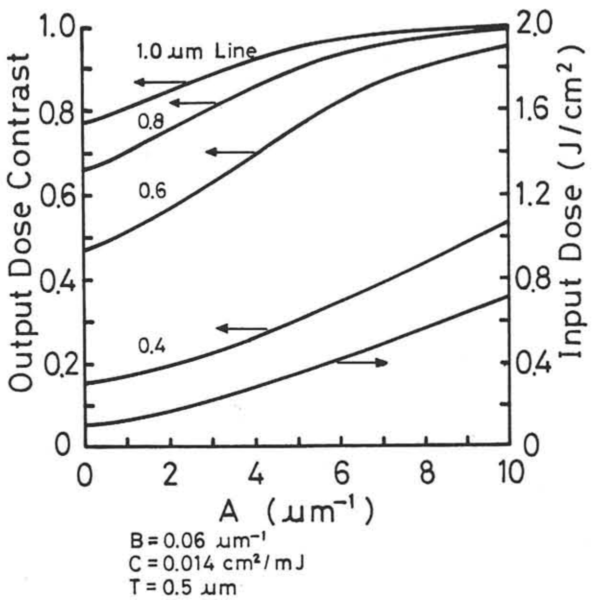


Fig. 2 Dependences of output dose contrast and input dose on parameter A.

Material Characterization

The diazonium compound was used as the photobleaching dye[4], which was reported by Halle. However, the agreement of the absorption wavelength region of the photobleaching dye with the g-line exposure wavelength was inadequate. Then, considering the absorption wavelength region and high molar absorption coefficient of the photobleaching materials, another kind of diazonium compound was selected.

Both the diazonium compound and a base resin were dissolved in organic solvent. The absorption spectrum of the CEL film in the UV-visible region is shown in Fig. 3. The CEL material shows good photobleaching characteristics in the g-line wavelength region. Figure 4 shows the relations between the diazonium concentration and the A, B and C parameters at g-line exposure, which were derived from the transmittance characteristics of the CEL film[2]. The parameter A increases with increasing the diazonium concentration. On the contrary, the parameters B and C are kept constant in the region above certain values of the concentration. In the case of 4 m mol/g diazonium concentration, the parameters A, B and C are 3.8 μm^{-1}, 0.22 μm^{-1} and 0.04 cm^2/mJ, respectively. Therefore, it is suggested from Fig. 1 that the resolution of less than 0.8 μm can be obtained.

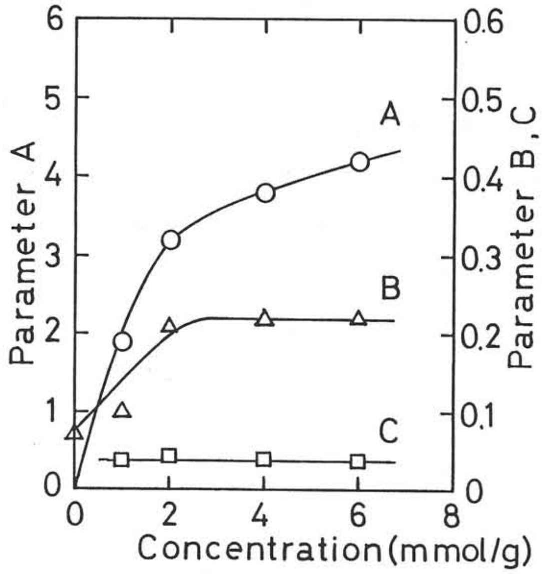


Fig. 4 Relations between diazonium concentration and A, B, C parameters.

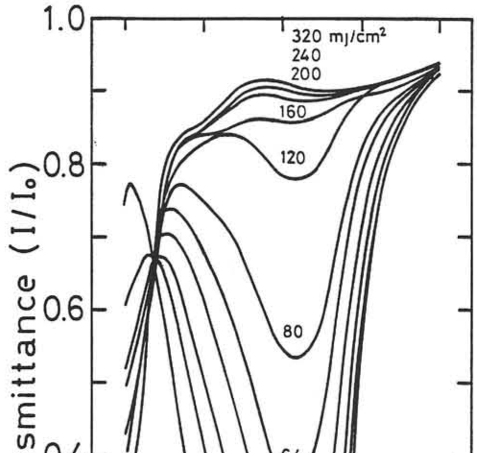
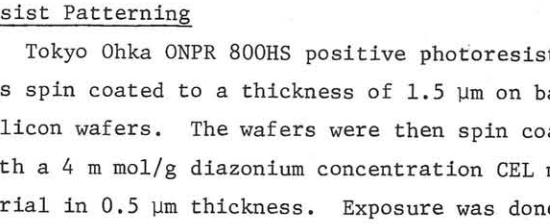


Fig. 3 Absorption spectrum of the CEL film with exposure dose as a parameter.

Resist Patterning

Tokyo Ohka ONPR 800HS positive photoresist was spin coated to a thickness of 1.5 μm on bare silicon wafers. The wafers were then spin coated with a 4 m mol/g diazonium concentration CEL material in 0.5 μm thickness. Exposure was done on a Nikon 5:1 wafer stepper with g-line lens having a numerical aperture of 0.35. The CEL coated wafers required additional exposure about three times compare with the control wafers. After exposure, the CEL was removed in an appropriate solvent and the resist was spray developed for 40 seconds in Tamakagaku TM-3 developer. At this time, the scum of the resist film was not observed.

Figure 5 shows resist patterns with and without the CEL. Fine resist patterns are obtained



conventional CEL

Fig. 5 SEM photographs of a 0.8 μm lines and spaces resist pattern.

without the intermixing layer, and the reduction in the resist thickness decreases compared with the conventional process.

Conclusions

The contrast enhancement effect of the CEL process was examined by the computer simulation. According to the information, a CEL material for g-line exposure which consists of the diazonium compound and the base resin was developed, and several experiments were performed. As a result, using the composed CEL material and g-line wafer stepper, submicron resist pattern with steep profile was obtained without the intermixing layer, and the reduction in the resist thickness decreased. CEL is very important technology to complement the performance of optical exposure tools.

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