Extended Abstracts of the 17th Conference on Solid State Devices and Materials, Tokyo, 1985, pp. 349-352

Proximity Effect Correction for 1/4 μm Pattern Formation in Electron Beam Lithography

T. Takigawa, E. Nishimura, S. Tamamushi, and Y. Katoh

VLSI Research Center, Toshiba R & D Center, Toshiba Corporation

1, Komukai Toshiba-cho, Saiwai-ku,
Kawasaki, 210, Japan

A proximity effect correction method, which combines high voltage electron beam writing with the GHOST exposure correction, is proposed. At 50kV and 50μC/cm^2 writing for PMMA resist, a pattern size error for 0.5μm patterns, including the isolated line, the line and window, and the isolated window patterns, was 0.22μm. The pattern size error decreased from 0.22 to 0.05 μm by the GHOST exposure correction, while, the pattern size error for a 0.25μm pattern amounted to 0.12μm under this condition. With increasing writing dose, the pattern size accuracy increased. At 50kV and 140μC/cm^2 writing, the 0.25μm pattern was formed with an accuracy of 0.05μm(±0.025μm). At 20kV and 20μC/cm^2 writing, the pattern size error was 0.37μm, which reduced to 0.16μm by the GHOST exposure correction. High voltage writing with the GHOST exposure method is effective for 1/4μm pattern formation.

1. Introduction

Electron beam (EB) lithography is required to write a fine pattern less than 1/2μm for development of future VLSIs. However, a fine pattern formation suffers from the following several problems: (1) poor pattern size accuracy due to the proximity effect, (2) difficulty in forming a resist pattern with vertical walls, (3) poor alignment accuracy when the alignment mark is covered by a thick overlayer, and (4) shaped electron beam blurring. Although high voltage EB writing improves most problems[1], it cannot remove the long range proximity effect[2].

Concerning the proximity effect, several correction methods have been developed; GHOST exposure[3], dose correction[4], pattern shape correction[5] and multi-layer methods[6]. They are effective for up to 1/2μm, but insufficient to fabricate the resist pattern less than 1/2μm.

In this paper, a promixity effect correction, which combines high voltage EB writing with the GHOST exposure method, is proposed. The 1/4μm resist pattern is formed with pattern size accuracy of ±10% using this method.

2. Calculation

In order to estimate pattern size error from the designed value, deposited energy density in the resist at the resist substrate interface was calculated, using two Gaussian approximation method. The deposited energy density, E (r, Zo), at depth Zo from the resist surface and at location r from the electron incident point, is given by

$$E\ (r,\ Zo) = K\ \{\frac{1}{\beta_f'^2} \exp\ (-\frac{r^2}{\beta_f'^2}) + \eta_E \frac{1}{\beta_b'^2} \exp\ (-\frac{r^2}{\beta_b'^2})\}, \quad \text{............ (1)}$$

$$\beta_f'^2 \equiv \beta_f^2 + d^2, \quad \text{.................. (2)}$$

$$\beta_b'^2 \equiv \beta_b^2 + d^2, \quad \text{.................. (3)}$$

where K is a proportional constant, η_E the ratio of total energy deposited in the resist by the back-scattered electrons to that deposited by the forward-scattered electrons, β_f the half width of the forward-scattered electron distribution, β_b the half width of the back-scattered electron distribution, and d the diameter of the Gaussian incident electron beam.

A. Deposited Energy Density without Correction

Figure 1 shows deposited energy density for the 0.25μm pattern, including the isolated window, the line and window, and the isolated line patterns, calculated using parameters indicated in Table 1. At 20kV, the 0.25μm line and 0.25μm window pattern is not resolved due to a large half width of the forward-scattered electron distribution compared with pattern size.

Table 1. Parameters used for calculating deposited energy density.

ACCELERATION VOLTAGE	20kV	50kV
η_e	0.85	1.07
β_b	2.0μm	10.0μm
β_f	0.3μm	0.07μm
BEAM DIAMETER	0.25μm	
RESIST	1μm	

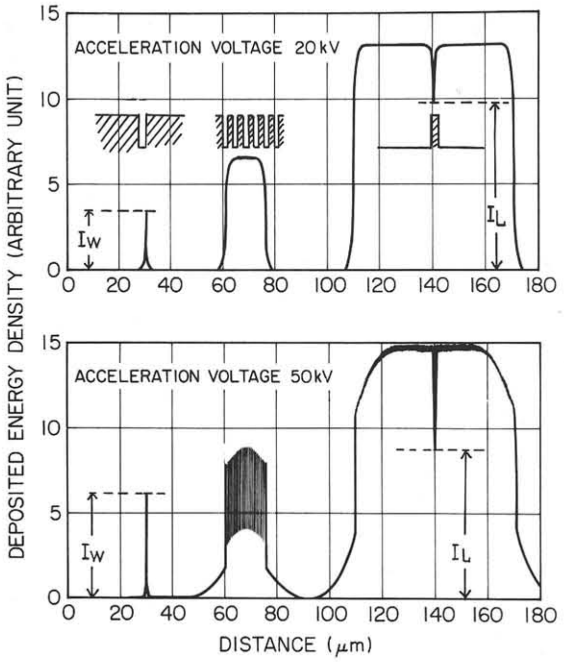

Fig. 1 Calculated deposited energy density for the 0.25μm pattern. Curves on left, middle, and right represent isolated window, 0.25μm line and 0.25μm window, and isolated line patterns.

The intensity of the deposited energy density for the isolated line pattern, I_L (see Fig. 1), is considerably high, because the line pattern area (unexposed area) is fogged by forward-scattered electrons as well as back scattered electrons from the outside of the line pattern area. The intensity of the deposited energy for the isolated window pattern, I_W (see Fig. 1), is low, because considerable numbers of electrons escape from the window pattern area (exposed area) due to the forward scattering. Forward-scattering plays a significant role for 0.25 micron pattern formation in thick resist at 20kV. When the ratio I_L/I_W is less than 1, both the isolated line and the isolated window patterns are formed simultaneously. Since, at 20kV, the ratio I_L/I_W is about 3, the isolated line and the isolated window patterns are not formed simultaneously. At 50kV, the 0.25μm line and 0.25μm window pattern is clearly resolved, due to a small half width of the forward-scattered electron distribution compared with the pattern size of 0.25μm. The forward-scattering effect is not so significant at 50kV as at 20kV. Therefore, the ratio I_L/I_W at 50kV is small, compared with the value at 20kV; that is, I_L/I_W is about 1.4.

B. Deposited Energy Density with Correction

In the GHOST exposure method, the reverse tone of the required pattern is exposed with a beam diameter of $d_c = 2\beta_b/(1+\eta_E)^{1/4}$ and a correction dose $Q_C = Q\,\eta_E/(1+\eta_E)$.[3] Here, Q is the writing dose. Equalization of the background exposure due to back-scattered electrons is achieved by this method. When the forward-scattered electrons play an important role, the GHOST exposure correction is not always effective. Theoretical correction doses are 0.46 Q at 20kV and 0.52 Q at 50kV. With decreasing the correction dose, the resist thickness loss outside the pattern area reduces, which is desirable. Therefore, the correction dose of 0.3 Q was used. Figure 2 shows the deposited energy density corrected by the GHOST exposure method using parameters indicated in Table 1. At 20kV, the correction dose of 0.3 Q is not sufficient for forming both the the isolated line and the isolated window pattern, since the ratio I_L/I_W is about 1.4.

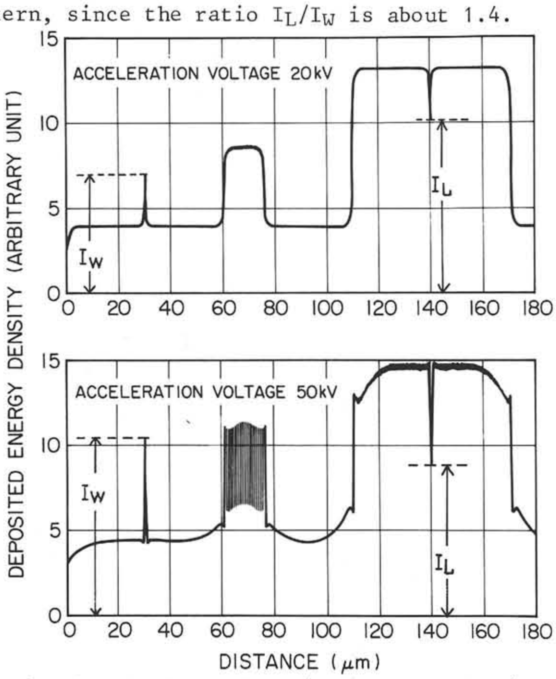

Fig. 2 Calculated deposited energy density corrected by GHOST exposure method.

At 50kV, the 0.25μm pattern is formed, as the ratio I_L/I_W is about 0.8. The GHOST exposure correction is more effective at 50kV than at 20kV for 0.25μm pattern formation in thick resist, which is resulted from the fact that the forward scattering electrons are not significant at 50kV.

3. Experimental Method

The apparatus used for the experiment was a system remodelled from VL-R1[1], in which the electron beam was deflected in the x direction and the stage moved continuously in the y direction. The acceleration voltage varied from 10 to 50kV in 10kV steps. The beam diameter was 0.22 to 0.24μm, the maximum beam current at 50kV was 300nA, and the deflection width was 60μm. The resist thickness was 1μm. The resist/developer system was PMMA (polymethyl-methacrylate)/IAA (isoamyl acetate), which showed small resist thickness loss in an unexposed region.

Pattern size deviation from the designed value, due to the proximity effect, was evaluated by measuring the SEM image of the cross section of the resist pattern. The pattern size was defined as the distance between the two lines, which are the intersecting lines of the silicon substrate surface and the two tangential surfaces of the resist pattern side walls.

4. Experimental Results

In order to evaluate acceleration voltage dependency of the GHOST exposure correction, pattern size deviation from the designed value was obtained using line and window patterns of various sizes and distances, as shown in Fig. 3. Figure 4 shows the pattern size versus pattern distance at 20kV. The bold dots represent window pattern and the triangles indicate line pattern. Development time was adjusted to accurately form the pattern, whose size was 0.5μm and its distance was 0.5μm, within a pattern size accuracy of ±10%. In the case of non-corrected, the size difference amounted to 0.37μm at 20kV. In this experiment, the GHOST exposure was able to improve the pattern size variation from 0.37 to 0.16μm.

At 50kV, a steep profile resist pattern was obtained. The relationship between pattern size and pattern distance is shown in Fig. 5. Pattern size variation was 0.22μm at 50kV and was almost half of the variation value at 20kV. When correction was made, pattern size variation decreased from 0.22 to 0.05μm. The GHOST

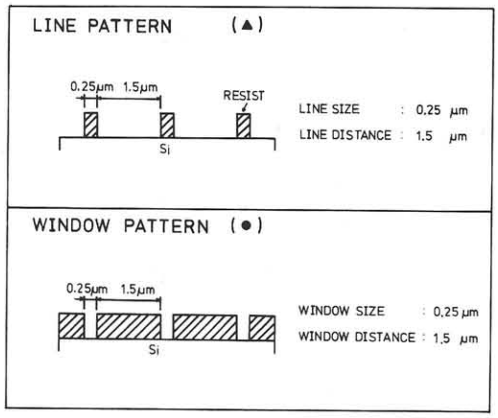

Fig. 3 Definition of the line and window patterns. The line (window) pattern is defined by the line (window) size and the line (window) distance.

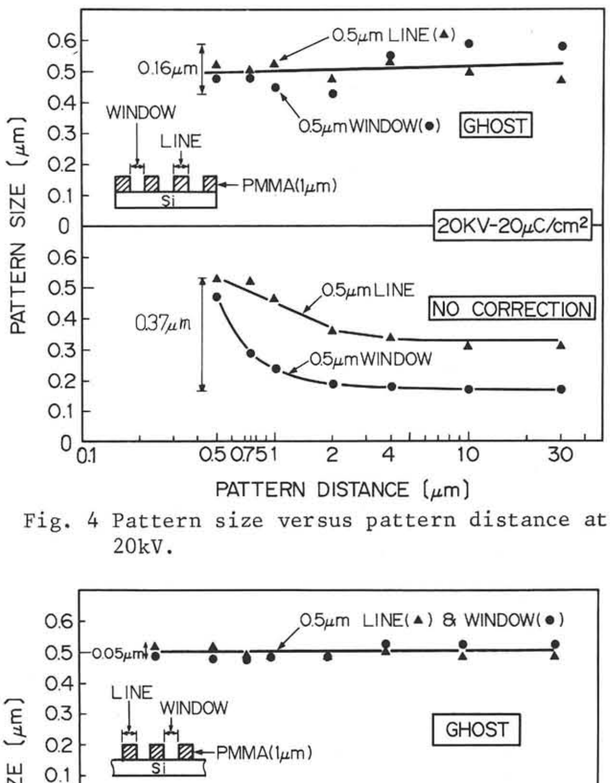

Fig. 4 Pattern size versus pattern distance at 20kV.

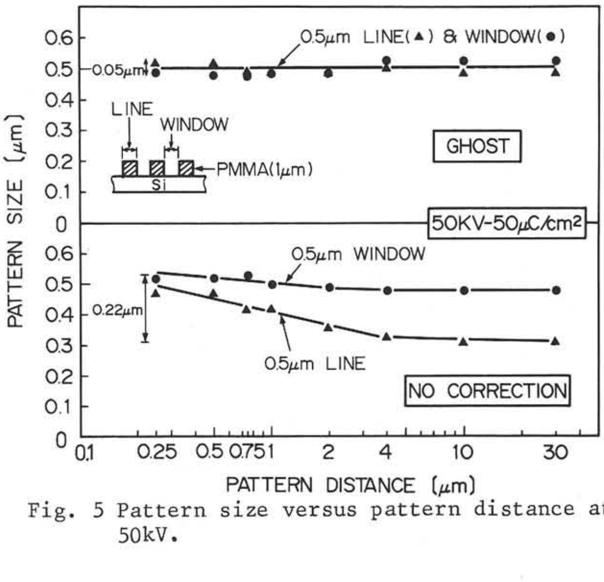

Fig. 5 Pattern size versus pattern distance at 50kV.

exposure correction was more effective at 50kV than at 20kV.

At 50kV and 50μC/cm^2 writing, the pattern size variation for a 0.25μm pattern amounted to 0.12μm. The variation of 0.12μm is too large for 0.25μm pattern formation. Since a pattern size error of ±10% is required, pattern size variation has to be smaller than 0.05μm (±0.025μm) for a 0.25μm pattern. It was found that pattern size variation reduced with increasing writing dose. Figure 6 shows the SEM image of the 0.25μm pattern. Steep and precise resist patterns of 0.25μm were obtained when the writing dose was 140μC/cm^2 and the GHOST exposure dose was about 40μC/cm^2. Figure 7(a) shows pattern size versus pattern distance. All kinds of patterns with sizes ranging from 0.25 to 0.75μm were formed with an accuracy of 0.05μm (±0.025μm). Figure 7(b) indicates pattern size versus pattern distance without correction. The pattern size variation was about 0.20μm, which is nearly the same as the value at 50μC/cm^2 writing.

The proximity effect reduction for 1/4μm was basically achieved for the PMMA resist on a flat substrate surface composed of only one material.

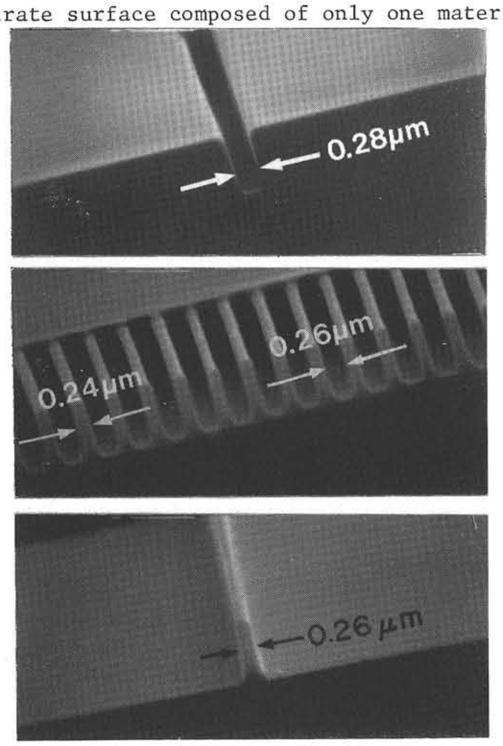

Fig.6 SEM image of 0.25μm pattern. Upper; isolated window pattern. Middle; line and window pattern. Lower; isolated line pattern.

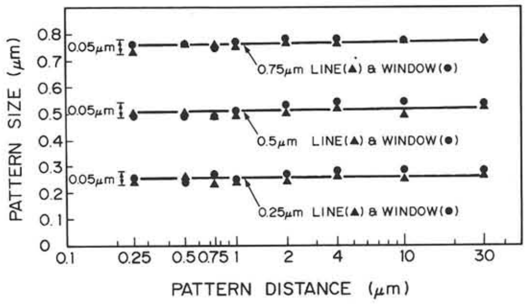

Fig.7(a) Pattern size versus pattern distance for 50kV and 140μC/cm^2 writing with the GHOST exposure correction.

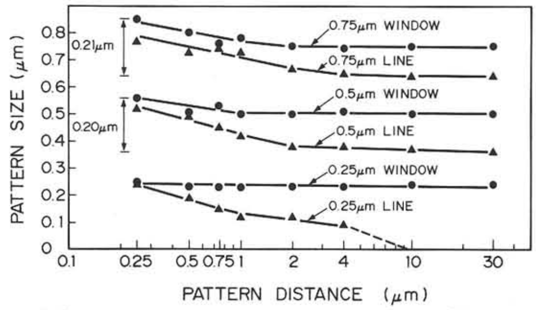

Fig.7(b) Pattern size versus pattern distance for 50kV and 140μC/cm^2 writing without correction.

5. Conclusion

High voltage writing with the GHOST exposure correction is effective for proximity effect reduction. A 1/4μm pattern is formed with a pattern size accuracy of ±10% using this method.

Acknowledgment

The authors wish to thank Dr. Y. Horiike for his helpful and stimulating discussions.

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