ABSTRACT

In previous study, it has been reported that photo resist erosion after development gets severe as patterns size decreases. The 60nm feature requiring for SRAF(Sub Resolution Assistant Feature) of 45nm technology node, the photo resist erosion after develop on unexposed area was almost 400Å. It will be a serious problem to degrade not only the resist thickness margin for thinner resist to enhance resolution and pattern collapse, but also CD(Critical Dimension) performance capability such as CD linearity and SRAF resolution capability by proceeding dry etching.

In this paper, the effects of photo resist erosion by pattern size on CD linearity performance were studied. The photo resist erosion by pattern size was simulated with the Gaussian blur model before dry etching. The effects of dosage, PEB(Post Exposure Bake) temperature and development conditions were evaluated to reduce blur value before dry etching.

Keywords : Photo resist erosion, CD linearity, Blur before dry etching, Gaussian blur model

1. INTRODUCTION

As wafer lithography continues to scale down to 45nm and below technology, resolution capability of photo mask manufacturing also has become tighten dramatically. Minimum feature size requiring for 45nm technology is 60nm as SRAFs for RET according to 2007 ITRS(International Technical Roadmap for Semiconductors).

In previous study, photo resist erosion by pattern size was observed for isolated line after development. It was almost 400 Å for 60nm feature on FEP171 2000Å thickness. It will be a serious problem not only the resist thickness margin for thinner resist to enhance resolution and pattern collapses, but also CD performance like linearity and SRAF resolution capability by proceeding dry etching.

Photo resist erosion by pattern size already has been known as a result of latent image degradation. Gaussian
distribution has been used for calculating the magnitude of latent image degradation by considering a single standard deviation as a cumulative root-square-sum of each error component. The total blur calculated from measured CD linearity already has been reported, which includes all error components, such as e-beam response chemistry of photo resist, space charge effect and shot noise on e-beam writing, photo acid diffusion during PEB, resist dissolution on develop process and dry etching.\textsuperscript{3} The total blur needs to be reduced for better CD linearity and pattern fidelity.

In this paper, we calculated the blurs from photo resist erosion by pattern size before dry etching and total blur from CD linearity after stripping. The blur added from dry etching could be estimated as deducting the blur before dry etching from the total blur. The CD after development couldn’t be used as blur before dry etching, due to resist shrinkage by CD SEM.\textsuperscript{4}

Effects of blurs before dry etching on CD linearity were studied. The blur contributed from dry etching was increased dramatically, as the blur before dry etching increases. The large blur before dry etching means poor resist slope. In order to improve the total blur, the blur before dry etching should be improved firstly. Finally, we have evaluated how amount of blur before dry etching can be improved by various process factors like dosage, PEB temperature, and develop conditions.

2. EXPERIMENTAL

2.1 Materials and Equipment

Binary COG blanks coated with FEP171 2000Å were used for all experiments. Exposure was conducted on the 50keV VSB e-beam writer and PEB, resist development, dry etching for chrome, resist stripping, and cleaning were followed. CD linearity data were measured on CD SEM. Cross-sectional images were obtained with Hitachi SEM. Remaining resist thickness was measured by AFM.

2.2 Test pattern design

In 50keV e-beam writer, the radius of energy distribution for exposed area called proximity effect is approximately 30µm. When there are some patterns within 30µm, the effective dosages are increased because of backscattered electrons. It can be compensated by PEC(Proximity Effect Correction) depending on pattern density. Also, The shot size for clear pattern in positive resist is compensated with adjusting gain control at VSB e-beam writer.

![Test pattern design](image)

Figure 1. Test pattern design.
Only isolated line patterns were only used for CD linearity and photo resist erosion by pattern size. Isolated lines were designed to be 50\( \mu \)m away from neighbored patterns to eliminate PEC effect. Pattern size designed from 50nm to 200nm by step 10nm and from 300nm to 1000nm by step 100nm. Then, those are arrayed in 11 by 11 on the mask as shown in Figure 1.

2.3 Design of experiment condition.
Dosages were applied top to bottom and increased from 8\( \mu \)C to 10\( \mu \)C by 0.2\( \mu \)C for each chips. Temperature from 110\(^{\circ}\)C to 130\(^{\circ}\)C on PEB was achieved from left to right across mask with zone controllable bake machine.\(^5\) Two develop conditions were applied.

2.4 Gaussian distribution for blur calculation.
In 50keV VSB e-beam writer, the effective amount of radiated e-beam on pattern boundary can be expressed for space pattern like below,

\[
I(x) = \frac{1}{\sqrt{2\pi \sigma_f}} \int_{-\infty}^{\infty} dx' D(x') \exp \left[ -\frac{(x - x')^2}{2\sigma_f^2} \right] + \frac{1}{\sqrt{2\pi \sigma_b}} \int_{-\infty}^{\infty} dx' \eta D(x') \exp \left[ -\frac{(x - x')^2}{2\sigma_b^2} \right]
\]

\[
I(x) = \frac{D_p}{2} B_f(w, x) + \eta \rho D_p B_b(w, x)
\]

\(D_p\): Dosage by local pattern density
\(\rho\): Local pattern density
\(\sigma_f\): Forward scattering
\(\sigma_b\): Backward scattering
\(\eta\): Ratio of backscattering to forward scattering

Where backscattering range is much bigger than pattern width, backscattering energy component can be approximated as a dose background \(\eta \rho D_p\). Gaussian energy distribution can be used for calculating the magnitude of latent image degradation by considering the sigma(\(\sigma_i\)) as a cumulative root-square sum of each error components.

In blur calculation, The threshold energy defining resist CD, \(E_{th}\) was firstly adjusted to match well with measured CDs of patterns, and then fixed. The resist sensitivity to dosage intensity was taken by fitting resist contrast curve of FEP171. It was applied for Gaussian blur model to simulate resist profile and thickness remained after development.

3. RESULTS AND DISCUSSION

3.1 Blur calculation and resist profile simulation by Gaussian blur model
The total blur calculated from CD linearity has been already reported, which includes all error components, such as e-beam response chemistry of photo resist, space charge effect and shot noise in e-beam writing, photo acid diffusion at PEB, photo resist dissolution at develop process and dry etching.
The blur before dry etching also can be calculated from photo resist erosion by pattern size as well as CD linearity after development using Gaussian blur model, because they must be a result of latent image degradation from all error components before dry etching.

Once the blur before dry etching is calculated, the blur added by dry etching can be expressed by below equation.

\[ \delta_{\text{blur added during dry etching}} = \delta_{\text{total blur}} - \delta_{\text{blur before dry etching}} \]

A. Total blur from CD linearity

![CD linearity comparison between measured CD and simulation with 32nm blur](image)

Figure 2. CD linearity comparison between measured CD and simulation with 32nm blur

Figure 2 shows the measured CD linearity and simulated one with 32nm blur. Gaussian blur model match well with measured CD linearity as shown in Figure 2.

B. Blur from photo resist erosion by pattern size

The blur before dry etching can be calculated from whether resist CD linearity after development or photo resist erosion by pattern size as explained before.

![CD variations with number of measurements for 1000nm and 100nm line resist patterns by CD SEM](image)

Figure 3. CD variations with number of measurements for 1000nm and 100nm line resist patterns by CD SEM.
So, photo resist erosion by pattern size was used to calculate the blur before dry etching. Figure 4 is simulated photo resist erosion by Gaussian blur model with blur 26nm and measured data. The Gaussian blur model also has matched well with measured photo resist erosion by pattern size.

![Diagram showing simulated and measured resist thickness vs pattern size.](image)

**Figure 4.** Resist erosion comparison between simulation results with blur 26nm and measurement.

### C. Resist profile simulation by Gaussian blur model

Figure 5 are the measured resist images by CD SEM and simulated resist profiles for 300nm and 80nm isolated line by Gaussian blur model with 24nm blur before dry etching, respectively. The height and top corner degradation of simulated resist pattern profiles were matched quite well with experimental data. But, the bottom of profiles wasn’t matched with resist foots because of interaction between resist and chrome substrate.

As for smaller features, the height is decreased and top corner rounding become more serious as shown in Figure 5.

![Resist images after development by vertical SEM and simulation.](image)

**Figure 5.** Resist images after development by vertical SEM and simulation (solid line) by Gaussian blur model with 26nm blur for, (a) 300nm isolated line, and (b) 80nm isolated line.
D. Blur contributed by dry etching

Figure 6. Total blurs from CD linearity and the blurs before dry etching by pattern size, for various process conditions.

Figure 6 is total blurs and the blurs before dry etching for several positions with different process conditions, like dosages, PEB temperatures. Total blurs were always larger than blurs before dry etching. The differences can be regarded as blurs added during dry etching.

In Figure 6, group A was represented for 2 positions with larger blur before dry etching comparatively. Group B was for another 2 positions with smaller blur before dry etching. The blurs added during dry etching of group A were much larger than group B. It means that blur added during dry etching was increased drastically depending on initial blur before dry etching. It will result total blur increase. First of all, we should improve the initial blur before dry etching to improve CD linearity and pattern fidelity.

E. CD linearity change during dry etching

Figure 7. CD linearity change during dry etching, (a) blur before dry etching 24nm, (b) blur before dry etching 35nm
Figure 7 is simulated CD linearity change before and after dry etching, blur before dry etching 24nm and 35nm, respectively. When only CD movement of vertical direction is considered in dry etching, we can obtain the CD linearity after dry etching. The cliff of CD linearity for blur 24nm was shifted little after dry etching. But, It was shifted by 6nm for blur 35nm as shown in Figure 7.6.

Figure 8 shows the simulated resist profiles of 100nm line pattern for blurs before dry etching, 24nm and 35nm. As blur before dry etching increases, photo resist erosion and angle become worse as shown in Figure 8. It must be resulted in CD linearity degradation, depending on blur before dry etching.

**3.2 Effect of process parameters on blur before dry etching**

In this section, effects of dosage, PEB temperatures, and development conditions were discussed to reduce blur before dry etching.

**A. Dosage effect**

Figure 9(a) shows blur before dry etching for dosage 8μC and 10μC. Figure 9(b) is PEB latitude for dosage 8μC and 10μC. As lowering dosage by 2μC, the blur before dry etching was improved by 9nm. PEB latitudes are 0.31nm/°C for 10μC and 0.47nm/°C for 8μC, respectively. Lower dosage(8μC) should be used for blur improvement. As for stable CD control, it’s needed to use higher dosage(10μC).
B. PEB temperature effect

Figure 10. (a) Blur before dry etching for PEB 110°C and 130°C with 8µC dosage and develop condition A. (b) Dosage latitude for PEB 110°C and 130°C with develop condition A.

Figure 10(a) shows blur before dry etching for PEB 110°C and 130°C. Figure 10(b) is the dosage latitude for PEB 110°C and 130°C. As for lower PEB 110°C, the blur was reduced by 4nm. Dosage latitudes were 19nm/µC for 110°C and 17.1nm/µC for 130°C.

So, lower PEB temperature was preferable to higher PEB temperature for blur improvement before dry etching. However, higher PEB temperature was better for CD control. Trade-off relation between blur improvement and dosage latitude was observed as like dosage effect in above.

C. Develop condition effect

The effects of develop conditions A and B was evaluated. Figure 11(a) shows the blur reduction before dry etching by the develop conditions. Figure 11(b) is for PEB latitude and Figure 11(c) is for dosage latitude.

Figure 11. (a) Blur before dry etching for develop A and B with 8µC dosage and PEB 110°C. (b) PEB latitude for develop A and B with 8µC dosage. (c) Dosage latitude for develop A and B with PEB 110°C.
The blurs before dry etching by develop conditions were 22 nm for develop A and 23 nm for develop B, respectively. Dosage latitudes were 19.0 nm/µC for develop A and 18.9 nm/µC for develop B, respectively. PEB latitudes were 0.69 nm/°C for develop A and 0.47 nm/°C for develop B, respectively. Blur improvement and dosage latitude were not effective by develop conditions. Develop A for only PEB latitude is preferable to develop B. Comparing to dosage and PEB effect, develop condition for blur improvement has been seen insignificantly.

3.3 Result summary

1) Blur before dry etching could be calculated from photo resist erosion and also matched with experimental data quite well. The resist CD linearity was not suitable due to different resist shrinkage by pattern size at CD SEM measurement.

2) Blur added during dry etching could be estimated by deducting the blur before dry etching from total blur, which estimated from CD linearity after stripping. As blurs before dry etching increase, blur added during dry etching becomes increased drastically. Therefore, blur before dry etching must be improved firstly to improve total blur, which degrades CD linearity and pattern fidelity.

3) Resist profiles could be predicted by Gaussian blur model. The height and top corner degradation of resist profiles were matched well with experimental data. However, The bottom of predicted profiles weren’t matched with resist foots because of interaction between resist and chrome substrate.

4) When CDs movement of vertical direction is only considered in dry etching, CD linearity degradation after dry etching could be predicted approximately, depending on magnitude of blurs before dry etching.

5) Effect of dosage, PEB temperature, and development conditions has been investigated on blur improvement before dry etching as summarized in below,

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<tbody>
<tr>
<td>1</td>
<td>Dosage</td>
<td>8 10</td>
<td>130 130</td>
<td>A A</td>
<td>26 35</td>
<td>Increase</td>
<td>Decrease</td>
<td>9</td>
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<td>2</td>
<td>PEB</td>
<td>8 8 8 8</td>
<td>110 130</td>
<td>A A</td>
<td>22 26</td>
<td>Increase</td>
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<tr>
<td>3</td>
<td>Develop</td>
<td>8 8 8</td>
<td>110 110</td>
<td>A B</td>
<td>22 23</td>
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To improve blur before dry etching, dosage and PEB temperature should be lowered. But, the process window of this condition will be narrowed. They were trade-off relation between blur improvement and process window. Dosage was the most effective on blur improvement before dry etching. Comparing to dosage and PEB effect, development conditions for blur reduction has been seen insignificantly.
4. CONCLUSION

In advanced photo mask manufacturing, smaller blur before dry etching must be required for better CD linearity, pattern fidelity and high resolution. Good resist profiles corresponding smaller blur before dry etching are indispensable. Blur calculation from resist CD linearity was not suitable due to resist shrinkage by pattern size at CD SEM measurement. So, the resist erosion by pattern size has been used for simulation of blur before dry etching with Gaussian blur model. It has shown good agreements with experimental data. Also, it enables the resist profile simulation matching well with experimental resist profile.

To improve the blur before dry etching, dosages, PEB temperatures and develop conditions have been evaluated as well as for process margin. The results say that dosage and PEB temperature should be lowered and develop conditions have seen to be insignificant. However, improvement of blur before dry etching shows the trade-off relation with process margin. The photo mask processes for 45nm and below technology have to be focused on blur improvement with the expense of process margin even though blur before dry etching are mostly contributed from e-beam equipments and materials rather than process parameters.

5. REFERENCE