Development of EUV Resist for 16nm Half Pitch

Ryuji Sugi, Makoto Shimizu and Tooru Kimura*

JSR Corporation, Semiconductor Materials Laboratory,
Fine Electronic Research Laboratories,
100 Kawajiri-cho, Yokkaichi, Mie, 510-8552, Japan

In order to resolve 16 nm half pitch and beyond upon EUV exposure, we have developed new materials for not only resists but also for under layer materials. As for resist, short acid diffusion length photo-acid generator (PAG) was developed for high resolution. As for under layer, new material with high contact angle (CA) improved line collapse margin towards printing of minimum feature size. It was found that CA of under layer was one of the important factors for resolution improvement. Furthermore, effect of development time was investigated to improve resolution. Short development time gained resolution improvement compared with long one. Finally, combination of these results was investigated. As a result, JSR EUV resist showed the potential of 15nm half pitch resolution.

Keywords: 16 nm half pitch, EUV, Photo resist, PAG, Acid diffusion length, under layer, contact angle

1. Introduction

ArF immersion lithography is capable of achieving resolution down to 4x nm half pitch. Double patterning with ArF immersion lithography will extend optical lithography limits to 2x nm half pitch. Furthermore, multiple (triple or quadruple) patterning technology of ArF immersion lithography has the potential to take optical lithography down to 1x nm half pitch nanofabrication process. However, such a complex process will increase device manufacturing cost and negatively impact device yield. From the technical point of view, new lithography process would be necessary for 1x nm half pitch and beyond. Some leading candidates are Extreme Ultra-Violet (EUV) lithography, Directed Self-Assembly (DSA) Technology, and electron-beam (E-beam) lithography [1].

EUV lithography is capable to achieve 1x nm half pitch resolution by single exposure due to its extreme short wavelength (13.5 nm). Therefore, EUV lithography has attractive cost advantage towards HVM device manufacturing. However EUV lithography requires development of new technical processes which is different from traditional optical lithography system. First of all, the extreme short wavelength (13.5 nm) is the remarkable characteristic. To utilize 13.5 nm wavelength, exposure will be performed under vacuum condition with reflective type photo mask instead of transmitting type photo mask since most of the materials absorb 13.5 nm radiation light. In order to apply EUV lithography for device manufacturing, considerable progress has been made in exposure tool, source, mask and related materials in the last few years. However all areas still need further improvement. Photore sist require significant improvement in resolution (R), line width roughness (L), sensitivity (S), and process window simultaneously. We are developing new materials such as molecular glass (MG) [2], photo acid generator (PAG) with short acid diffusion length [2, 3], acid amplifier [2], high absorption resin [4], and many other materials for resist improvement. Along with resist improvements we are exploring novel resist processing methods to achieve RLS requirements simultaneously.

In this paper, we focus on resolution improvement for 1x nm half pitch. We report development of new short acid diffusion length PAG and under layer to achieve 1x nm half pitch resolution. Furthermore, process optimization will be also reported. Finally, performance of state-of-the-art JSR EUV resist is shown.

2. Experimental

2.1. Material

The structures of PAG in this paper are shown in Figure 1. Resist samples were obtained by mixing resin, PAG, quencher, and solvent. The
mixed solution was filtered by 0.02 um PTFE filter prior to evaluation.

\[ \Delta L = 2(D t_{PEB})^{1/2} \text{erfc}^{-1}(E_{crit}/ E) \]  

\( \Delta L \) is the film thickness loss, \( D \) is the acid diffusion coefficient, \( t_{PEB} \) is the PEB time, \( \text{erfc} \) is the error function complement, \( E_{crit} \) is the exposure dose at which film thickness loss was observed for the first time, and \( E \) is the exposure dose in equation (1).

### 3. Result and Discussion

#### 3.1 Material and technology development for 1x nm half pitch resolution

Various PAGs were synthesized [2] in this study and their structures are described in Figure 1. Backbone of anion, functional unit of anion, PAG anion size, and determined acid diffusion length are summarized in Table 1.

<table>
<thead>
<tr>
<th>PAG</th>
<th>Backbone of anion</th>
<th>Functional unit of anion</th>
<th>PAG anion size (Relative value)</th>
<th>Acid diffusion length (Relative value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAG-1</td>
<td>Flexible</td>
<td>None</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>PAG-2</td>
<td>Flexible</td>
<td>Polar unit</td>
<td>170</td>
<td>41</td>
</tr>
<tr>
<td>PAG-3</td>
<td>Ridged</td>
<td>Polar unit</td>
<td>190</td>
<td>14</td>
</tr>
</tbody>
</table>

Anion backbone of PAG-1 and PAG-2 are flexible. On the other hand, anion backbone of PAG-3 is ridged. Anions in PAG-2 and PAG-3 include polar functional unit. Relative value of anion size of PAG-1, PAG-2, and PAG-3 were 100, 170 and 190, respectively. Relative value of acid...
diffusion length of PAG-1, PAG-2, and PAG-3 were 100, 41, and 14, respectively. Many studies have already shown that an increase of PAG anion size and an introduction of polar unit into PAG anion structure makes acid diffusion length shorter. In this study, similar result was obtained about PAG anion size and polar unit. Additionally, PAG-3 with rigid structure shows short acid diffusion length compared to PAG-2 with flexible structure. From this result, the rigid structure of anion is one of the key parameters for obtaining short acid diffusion length.

Resist A, B, and C containing PAG-1, PAG-2, and PAG-3, respectively, were exposed using an EUV exposure tool (NA0.3, Annular). Table 2 shows ultimate resolution data of these resists. Ultimate resolution of Resist A, B, and C were 32 nm half pitch, 26 nm half pitch, and 24 nm half pitch, respectively. These results suggest that acid diffusion suppression provides a good way to improve resolution.

Table 3 shows resolution, LWR, sensitivity, and Z-factor of Resist A, B and C. Z-factor helps in quantifying resist performance and is calculated with equation (2) [7].

\[ Z\text{-factor} = (\text{Resolution})^3 \times (\text{LER})^2 \times (\text{Sensitivity}) \]  

\[ \text{eq. (2)} \]

Among them, Resist C with short acid diffusion length showed the best LWR and Z-factor. From these results, it is suggested that PAG with short acid diffusion is one of the key item for improvement of total resist performance and not only resolution improvement.

3.1.2 Under layer
Pattern collapse is one of the leading causes of resolution limit of advanced EUV resists. Various under layers were evaluated in this study with the aim in improvement of collapse margin. From the view point of wider pattern collapse margin, we focused on contact angle of under layer. Contact angle of under layers are shown in Table 4. Relative values of contact angle of UL-A, UL-B, UL-C, and UL-D were 100, 104, 106, and 109, respectively.

Table 4. Contact angle of under layers

<table>
<thead>
<tr>
<th>Contact angle (relative value)</th>
<th>UL-A</th>
<th>UL-B</th>
<th>UL-C</th>
<th>UL-D</th>
</tr>
</thead>
<tbody>
<tr>
<td>UL-A</td>
<td>100</td>
<td>104</td>
<td>106</td>
<td>109</td>
</tr>
</tbody>
</table>

Table 5. Effect of under layer on ultimate resolution. (NA0.3, dipole)
Table 5 showed ultimate resolution data on EUV exposure tool (NA0.3, dipole) when using UL-A, UL-B, UL-C, and UL-D as a under layer. Ultimate resolution of UL-A, UL-B, UL-C, and UL-D were >30 nm half pitch, 28 nm half pitch, 28 nm half pitch, and 26 nm half pitch, respectively. From these results clear correlation is found between the contact angle of under layer and collapse margin. Furthermore, under layer with the highest contact angle, UL-D, showed the best resolution by improvement of pattern collapse. It is thus suggested that contact angle of under layer is the key parameter for resolution improvement via manipulation of under layer. Development of under layer with higher contact angle is underway.

3.1.3 Development time
Suppression of resist pattern swelling during development process affects ultimate resolution significantly. Shorter contact time of developer on resist surface should reduce amount of swelling of resist pattern. Therefore, ultimate resolution was evaluated with various development times on EUV exposure tool (NA0.3, 18 nm dipole). Ultimate resolution data with various development times are summarized in Table 6. The short development time shows 20 nm half pitch resolution with improvement in pattern collapse margin. From these results, it is found that shorter development time improves resolution via improvement of pattern collapse. We postulate that short development time inhibits pattern swelling during development process.

Figure 3 shows process window data of 30 nm half pitch on EUV exposure tool (NA0.3, Quadrapole). It was found that shorter development time shows large process window with improvement of pattern collapse margin.

![Fig. 3. Effect of development time for process window (NA0.3, Quadrapole)](image)

Table 6. Effect of development time on ultimate resolution (NA0.3, 18 nm dipole)

<table>
<thead>
<tr>
<th>Development time</th>
<th>26 nm half pitch</th>
<th>24 nm half pitch</th>
<th>22 nm half pitch</th>
<th>20 nm half pitch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2 Combination of material and technology

Figure 4 shows ultimate resolution data of JSR EUV resist on EUV exposure tool (NA0.3, Pseudo PSM). JSR EUV resist has the potential to achieve 15nm LS resolution. From this result, practical application of EUV lithography has taken a great step forward with the realization of 1x nm level pattern formation.

4. Conclusion

In this study, we demonstrated that 15 nm half pitch resolution with new materials and process optimization. Results of this study are hoped to push EUV resist implementation for mass production at 1x nm half pitch generation.

Acknowledgments

The authors are greatly indebted to imec, Selete, Sematech, and CXRO for their support on evaluation on EUV exposure tool.

References

1. ITRS website, http://www.itrs.net/