Evaluation of E-Beam Sensitive CARs for Advanced Mask Making

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ABSTRACT

An increasingly tighter set of mask specifications requires new equipment, process improvements, and improved e-beam resist materials. Resist profiles, footing behavior and line edge roughness (LER) have strong impacts on CD-uniformity, process bias and defect control. Additionally, the CD stability of e-beam resists in vacuum contributes to the final CD-uniformity as a systematic error. The resolution capability of the resist process is becoming increasingly important for slot contact like features, which are expected to be applied as clear assist features in contact hole layers at the sub 100nm technology node (1x). Three e-beam sensitive pCAR resists from different vendors were investigated in terms of resolution and pattern quality, PED stability, PEB sensitivity, dose latitude, CD-uniformity and line edge roughness. As reported here, all three pCARs showed improvements in all of these areas. Future work with these pCAR resists will focus on defect density, PCD, and CD uniformity.

Keywords: Positive-tone, Negative-tone, Chemically Amplified Resist, E-Beam, Mask Process

1. INTRODUCTION

E-beam sensitive CARs are widely used in mask making. They offer resolution capabilities down to 35nm and below and make the CAR platform extendable for future technology nodes. The good lithographic performance and stability (post coat delay (PCD) and post exposure delay (PED)) has allowed these CARs to meet requirements of several technology nodes since their introduction. However, there are some characteristics of these CARs that struggle to meet the technical requirements of upcoming nodes like 65nm and beyond. Specifically, the resist profile quality has a major impact on the final CDU performance and etch bias and thus interactions at the resist/CrOx interface need to be tightly controlled to avoid exaggerated resist footing in pCARs or undercut in case of nCARs. In some instances, a small resist foot might be desirable to avoid pattern collapse of dense lines during the development process. Line Edge Roughness (LER) is another resist characteristic that plays an important role at the 65nm technology node. High frequency LER in a CAR might not impact the final mask application in the wafer fab, but makes it more difficult to identify CDU signatures due to the high noise level of measured CD data. PED, especially in vacuum during long write times, is another resist parameter which has a strong impact on the final CDU. Still other resist characteristics are the diffusion of acid molecules created by exposure, the neutralization of quencher by diffusing acid, and the diffusion of quencher caused by the different quencher concentrations in exposed and unexposed areas.

A continuous resist evaluation project was launched at the AMTC in cooperation with IMS Chips, in order to ensure the availability of an e-beam resist with improved characteristics over the current pCAR offerings. During this project it was discovered the development status of e-beam sensitive nCARs is far behind that of pCARs. Therefore this work focused only on the performance of the most recent pCAR samples delivered by different resist vendors. This study investigated some important pCAR resist parameters, which are presented and discussed in this report.

2. EXPERIMENTAL

Three e-beam sensitive pCAR samples from different resist vendors were selected for this evaluation. All three resists are based on the Ethyl-Acetal platform. The samples were investigated on Hoya SHQ 6025 NTAR7 blank material.
The CDU measurements of etched 250nm dense lines were performed on a 36 point array with 1400 e-beam scans for each point with a sub pixel resolution of about 15nm. Cross sections of resist patterns and CD measurements were done for iso lines, dense lines and contact holes at different exposure doses. The resist sensitivity and the contrast were determined using an array of 49 measurement points, each exposed with a different dose differentiated by 0.2µC/cm² increments.

The resist coating and development were both performed at 40% r.H. and 20°C air temperature. The blanks were processed in an amine-controlled environment with an amine concentration below 0.5 ppb. The resist development was done with a Steag HamaTech ASP5000 developer system using 2.38 wt% TMAH with a wetting agent. Developer temperature?

For all baking steps the Steag HamaTech zone controlled hot/coolplate module ABP5000² was used. The bake zones can be individually adjusted to ensure a temperature uniformity of ~1.5 K during the ramping period and 0.2 K at the final temperature.

All substrates were exposed with the variable shaped e-beam writer Leica SB350³. The Leica SB350 operates at 50kV acceleration voltage with a beam current of up to 20A/cm².

Finally, the blanks were etched using the UNAXIS MASK ETCHER III.

The CD measurements and investigations of resist cross-sections were performed in a LEO1560 SEM. This tool includes a CD measurement option that allows the uniformity measurement on the entire mask quality area.

3. RESULTS AND DISCUSSION

The resists have been processed according to initial recommendations from the vendors, but the same developer process was applied for each resist.

3.1. Evaluation criteria

At the beginning of the evaluation a comprehensive table of resist parameters was established from the current resist processes at AMTC. Those resist parameters were compared to the requirements of the upcoming technology nodes. Based on the gap found between current and required resist performance the evaluation conditions and targets were defined. In this work we only focused on following resist parameters:

- Dose-to-clear for pCAR
- Resolution
- Resist profile
- PEB Sensitivity (± 10K of the recommended PEB temperature)
- Influence of post exposure delay in vacuum
- CD-uniformity after chrome etch for 250nm dense lines
- Line edge roughness in absorber

3.2. Process conditions

The evaluated resists were coated on standard Cr/CrO₂ NTAR7 blanks from Hoya. There was a 1-hour dehydration bake at 200°C applied to all blanks prior to the coating step. Resist vendors typically recommend soft bake and post-exposure-bake time and temperature (see Table 1) but for resists used in wafer processing. Those conditions cannot be directly applied to masks due to the higher thermal capacity of thick quartz blanks. In this evaluation we considered the extended temperature ramping curves of the mask blanks and applied 300 sec for all bake steps (PAB and PEB). The film thickness target for the screening experiments was set to 300nm.

During exposure a first approach of the proximity correction was applied in order to reduce the line width difference of the iso dark, iso clear and dense lines within one line width group (i.e., zero iso dense bias). The proximity correction was not adjusted for each specific resist. All patterns were exposed with an undersize of 10nm per feature edge. Also only one developer recipe was applied for all resists using a fixed development time of 60sec and a multiple puddle process.
3.3. Resolution, Resist Profile

The cross section pictures of the resist profiles are summarized in Fig. 1a-c. The 250nm features should reflect the main features of the 65nm node, while 125nm lines and 100nm contact holes have been assessed as the sub resolution assist feature quality. The 80nm dense lines represent the resolution capability of the resist at 300nm film thickness. For all three pCARs a resolution better than 80nm for dense lines was observed. However, the usable resolution is mainly limited by the pattern stability, which in this case seems to depend on the resist profiles. The 100nm contact holes were resolved for all three resists.

Resist B shows the straightest profile, only a slight foot and top rounding. A resist foot can also be seen in Resists A and C. In addition the resist lines are smaller above the foot and wider near the top in Resists A and C. This leads to pattern collapse for smaller line width and limits the usable resolution at this film thickness. The resist foot observed in these pCARs is caused by the well-known interaction between CAR and Cr/CrO$_x$ layer.

3.4. Influence of delays

The PED in vacuum is a very important resist characteristic because exposure times of 10 hours or more are common for advanced reticle patterning including OPC features. Pattern CDs should be stable through the entire writing time in order to meet the tight CD-uniformity specifications. To determine the PED, 7 identical test patterns were exposed with a time gap of 2 hours. The patterns were placed within a small area on the mask to avoid any influences by the global CD-uniformity distribution.

Fig. 2a-c shows the measured CDs for 125nm and 250nm dense lines as a function of the PED time in vacuum. The rate of CD change for all 3 resists in this study is below 0.5nm/h, including the scatter in the measured data, which is an acceptable value for PED stability. Further PED tests with more measurement points on a production type layout need to be done. Additionally, such a PED determination should include a consideration of the linear contribution to CD-uniformity and how this compares to that in the standard process.

3.5. PEB Sensitivity

During the post-exposure-bake step, pCARs undergo a catalyzed deprotection process while nCARs experience a cross-linking reaction. Depending on the resist type the final resist CD correlates with the bake time and temperature. While the baking time can be controlled easily, it is more difficult to ensure a good temperature uniformity, especially during the ramping or heat up period.

The baking time was kept constant in this study and only the baking temperature was varied by ±10K from the supplier’s recommended set point. PEB sensitivity was characterized by measuring 250nm dense line patterns and the results are summarized in Fig. 3a-c. All 3 resists performed similarly and show a gradient of ≤0.5nm/K which means there is a low risk the PEB step for these materials has a large impact on the CD-uniformity performance.

3.6. CD Uniformity and Line Edge Roughness

Finally, the CD-uniformity and LER were investigated after chrome etch. The CD-uniformity characterization was performed in chrome, rather than resist, due to better SEM measurement accuracy. A 90°C hard bake was applied to each pCAR before etching. Chrome etch was performed with a conventional Cl$_2$/O$_2$/He chemistry mixture and a laser endpoint detection was used to determine break-through of the absorber layer. The main chrome etch was followed by a 100% over etch, which for a ~5% pattern density gives an optimum relation between vertical sidewalls and minimum CD over processing. The chrome etch process for all experiments was identical, with the same CDU contribution, allowing an accurate comparison of CDU results between these pCARs.

Resist A shows a slight radial CD distribution, while Resists B and C have a more random CD distribution (Fig. 4a-c). However, the 3σ CD-uniformities among these pCARs are quite similar at ~12-13nm. While these CDU results are not suitable for current and future technology nodes, improvements in CDU are expected with process optimizations. Top Down SEM images of the etched and stripped 250nm dense lines are shown in Fig. 5a-c for each resist, while the calculated LER and CD-uniformity results are summarized in Table 1. LER was calculated by fitting a linear function to the chrome lines in top down SEM images. LER results are reported in terms of 3σ/mean. On the basis of the absolute values for center distances we were able to run calculating statistics. The 3σ value gives here a
reasonable index for the edge roughness. Need IMS clarification here or delete bold face phrases. The measured LER numbers are very similar for all 3 resists, despite differences in the resist profiles and footing, leading us to conclude the etch process contributes to the final LER.

4. CONCLUSION

Three e-beam sensitive pCAR resists supplied by different vendors were evaluated in this study. The e-beam sensitivity for dense line exposures is similar between these pCARs and in a range that would yield acceptable e-beam write times. The resolution of dense line features was clearly below 80nm for each pCAR however, due to different resist profiles the usable line width-film thickness ratio will vary for each resist. There is almost no difference in the LER measured after the absorber etch between these pCARs while the PED stability in vacuum and low PEB sensitivity of ≤0.5nm/K are very promising. The final CD uniformities measured after absorber etch were all ~12nm 3σ. All three resists might be capable for the 65nm technology node requirements and will depend upon further examinations of defect density, post coat delay, and CD uniformity optimization.

5. ACKNOWLEDGMENTS

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REFERENCES

1 Bryan S. Kasprowicz et al., “CPL Mask Technology for Sub-100nm Contact Hole Imaging,” PHOTOMASK BACUS NEWS, Vol. 20, Issue 11, 2004


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Fig 1a: Resist profiles of Resist A
Fig. 1b: Resist profiles of Resist B

Fig 1c: Resist profiles of Resist C
Fig. 2a: Post Exposure Delay (125nm/250nm) Resist A

Fig. 2b: Post Exposure Delay (125nm/250nm) Resist B

Fig. 2c: Post Exposure Delay (125nm/250nm) Resist C
**Fig 3a: PEB-Sensitivity of 250nm dense line Resist A**

**Fig 3b: PEB-Sensitivity 250nm dense line Resist B**

**Fig 3c: PEB-Sensitivity 250nm Dense-Line Resist C**

**Fig 4a: CDU of 250nm dense lines etched in 70nm chrome Resist A**
### Resist B

**250nm Dense Lines**

<table>
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<tr>
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<th>Value</th>
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<tbody>
<tr>
<td>Mean [nm]</td>
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<tr>
<td>3 sigma [nm]</td>
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<tr>
<td>Max [nm]</td>
<td>221.3</td>
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<tr>
<td>Min [nm]</td>
<td>221.3</td>
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<tr>
<td>Range tot [nm]</td>
<td>12.9</td>
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<tr>
<td>Range tot [%]</td>
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<tr>
<td>Range +/- [nm]</td>
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</tr>
<tr>
<td>Range +/- [%]</td>
<td>3.6</td>
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</tbody>
</table>

Fig 4b: CDU of 250nm dense lines etched in 70nm chrome Resist B

### Resist C

**250nm Dense Lines**

<table>
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<tr>
<th>Metric</th>
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<tbody>
<tr>
<td>Mean [nm]</td>
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<tr>
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<tr>
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<td>Min [nm]</td>
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<tr>
<td>Range +/- [nm]</td>
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<tr>
<td>Range +/- [%]</td>
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</table>

Fig 4c: CDU of 250nm dense lines etched in 70nm chrome Resist C

### Resist A

Fig 5a: 250nm dense lines etched in 70nm chrome Resist A
Table 1: Parameter digest; summary of the screening results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Resist A</th>
<th>Resist B</th>
<th>Resist C</th>
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<tbody>
<tr>
<td>Dose-to-clear</td>
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<tr>
<td>Dose-to-size*</td>
<td>8.1µC/cm²</td>
<td>10.3µC/cm²</td>
<td>9.4µC/cm²</td>
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<tr>
<td>PED vacuum*</td>
<td>0 nm/h</td>
<td>0.16nm/h</td>
<td>-0.9nm/h</td>
</tr>
<tr>
<td>PEB sensitivity*</td>
<td>&lt;1nm/°C</td>
<td>&lt;1nm/°C</td>
<td>&lt;1nm/°C</td>
</tr>
<tr>
<td>Etch selectivity</td>
<td>1:2.34</td>
<td>1:1.88</td>
<td>1:2.28</td>
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<tr>
<td>CD uniformity* (total range)</td>
<td>13.5nm</td>
<td>12.9nm</td>
<td>11.6nm</td>
</tr>
<tr>
<td>LER (3s/mean)*</td>
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<td>3.4%</td>
<td>3.4%</td>
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<tr>
<td>Softbake</td>
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<td>130°C</td>
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<td>Post Exposure Bake</td>
<td>110°C</td>
<td>100°C</td>
<td>110°C</td>
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*Measured at 250nm dense lines