Novel EUV Resist Materials and Process for 16 nm Half Pitch and Beyond

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\textsuperscript{1}JSR Micro Inc, \textsuperscript{2}JSR Corporation
Contents

- Challenge for EUV Resist & JSR approaches
- Development of new materials and process for Resolution, LER and Sensitivity (RLS) improvement
- Combination of materials and process
- Sub 22 nm CH patterning with EUV lithography and Directed Self-assembly (DSA) process
- Summary
Challenge for EUV Resist

The most difficult technical requirement is simultaneous improvement in resolution, LWR, and sensitivity (RLS).
JSR Approach for EUV Resist RLS Improvement

Resist Materials
- Short acid diffusion length PAG
- High Tg resin
- High absorption resin

Related Materials
- Under-layer
- Top-coat

Process
- Rinse agent
- DSA

➢ EUV Resist RLS improvement with combination of materials and process
EUV Resist RLS Improvement
-Resist Materials-

Resist Materials
- Short acid diffusion length PAG
- High Tg resin
- High absorption resin

Related Materials
- Under-layer
- Top-coat

Process
- Rinse agent
- DSA
## RLS Improvement: Resist Materials

<table>
<thead>
<tr>
<th>Short acid diffusion length PAG</th>
<th>High Tg resin</th>
<th>High absorption resin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid diffusion control</td>
<td>Acid diffusion control</td>
<td>High acid yield</td>
</tr>
<tr>
<td>LWR &amp; Resolution</td>
<td>LWR &amp; Resolution</td>
<td>Sensitivity</td>
</tr>
</tbody>
</table>

- Improvement of RLS performance of resist with short acid diffusion length PAG was demonstrated
- Effect of resin glass transition temperature (Tg) and absorption was investigated in detail

**Figure**: Elemental absorption cross-sections at 13.4 nm wavelength. Elements commonly found in photoresist materials are H, C, N, O, F, and S.

*P. Dentinger et al.*

Effect of Tg on LER

Comparison of Tg Results

- In general, LER gets worse at higher Tg.
- Since Tg is a function of thickness, this may partially explain LER degradation.
- As Tg increases, the φ for 36-nm lines improves while the φ for 50 nm lines gets worse.

Brian Cardineau et al. 2011 International Symposium on EUVL

➢ JSR started to develop resin with higher Tg to understand the effect on LWR
### Development of High Tg Resin

<table>
<thead>
<tr>
<th>Resin Composition</th>
<th>Std. resin</th>
<th>High Tg resin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhesion unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protecting group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Tg unit</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tg (°C)</th>
<th>Std.</th>
<th>Std. + 20 C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid diffusion length (Relative value)</td>
<td>100</td>
<td>60</td>
</tr>
</tbody>
</table>

- **High Tg EUV resin was prepared by incorporating high Tg monomer unit into standard resin**
  - Tg increased by 20 C by adding high Tg monomer to std. resin
  - Acid diffusion length become short by 40% by applying high Tg resin.
### Resin Tg Impact on RLS Performance

<table>
<thead>
<tr>
<th>Resist</th>
<th>Resist A</th>
<th>Resist B</th>
<th>Resist B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin Tg (°C)</td>
<td>Std</td>
<td>Std + 20</td>
<td>Std + 20</td>
</tr>
<tr>
<td>PEB</td>
<td>Std</td>
<td>Std</td>
<td>High</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>16.7 mJ/cm²</td>
<td>18.6 mJ/cm²</td>
<td>15.4 mJ/cm²</td>
</tr>
<tr>
<td>LWR</td>
<td>6.2 nm</td>
<td>4.6 nm</td>
<td>5.0 nm</td>
</tr>
<tr>
<td>Z-factor</td>
<td>5.68E-08</td>
<td>3.56E-08</td>
<td>3.32E-08</td>
</tr>
</tbody>
</table>

26 nm hp

- Resist with high Tg resin shows good LWR than std resist
- Combination of high Tg resin and high PEB improved RLS performance
Resin including high absorption atom was developed to improve sensitivity

Figure 1: Elemental absorption cross-sections at 13.4 nm wavelength. Elements commonly found in photoresist materials are H, C, N, O, F, and S.

### Development of High Absorption Resin

<table>
<thead>
<tr>
<th>EUV Resist with Std Resin</th>
<th>HP</th>
<th>22 nm HP</th>
<th>20 nm HP</th>
<th>19 nm HP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sensitivity</strong></td>
<td></td>
<td>17.2mJ/cm²</td>
<td>17.2mJ/cm²</td>
<td>17.2mJ/cm²</td>
</tr>
<tr>
<td><strong>LWR</strong></td>
<td></td>
<td>5.8nm</td>
<td>5.5nm</td>
<td>-</td>
</tr>
<tr>
<td><strong>Image</strong></td>
<td></td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EUV Resist with High absorption resin</th>
<th>HP</th>
<th>22 nm HP</th>
<th>20 nm HP</th>
<th>19 nm HP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sensitivity</strong></td>
<td></td>
<td>15.0mJ/cm²</td>
<td>15.0mJ/cm²</td>
<td>15.0mJ/cm²</td>
</tr>
<tr>
<td><strong>LWR</strong></td>
<td></td>
<td>5.5nm</td>
<td>5.8nm</td>
<td>-</td>
</tr>
<tr>
<td><strong>Image</strong></td>
<td></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
</tbody>
</table>

- **Sensitivity improved by 15 % with high absorption resin**
EUV Resist RLS Improvement
-EUV lithography related materials-

- Resist Materials
  - Short acid diffusion length PAG
  - High Tg resin
  - High absorption resin

- Related Materials
  - Under-layer
  - Top-coat

- Process
  - Rinse agent
  - DSA

- Rinse agent
- DSA
Development of Under Layer (UL) – Si-HM

✓ Si-HMs in different contact angle were evaluated to understand the effect of Si-HM composition on resist pattern line collapse
**Si-HM Impact on Resolution**

<table>
<thead>
<tr>
<th>Si-HM</th>
<th>30 nm HP</th>
<th>28 nm HP</th>
<th>26 nm HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si-HM-A</td>
<td><img src="Si-HM-A_30nm.png" alt="Image" /></td>
<td><img src="Si-HM-A_28nm.png" alt="Image" /></td>
<td><img src="Si-HM-A_26nm.png" alt="Image" /></td>
</tr>
<tr>
<td>Contact angle: 100 (relative value)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si-HM-B</td>
<td><img src="Si-HM-B_30nm.png" alt="Image" /></td>
<td><img src="Si-HM-B_28nm.png" alt="Image" /></td>
<td><img src="Si-HM-B_26nm.png" alt="Image" /></td>
</tr>
<tr>
<td>Contact angle: 104 (relative value)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si-HM-C</td>
<td><img src="Si-HM-C_30nm.png" alt="Image" /></td>
<td><img src="Si-HM-C_28nm.png" alt="Image" /></td>
<td><img src="Si-HM-C_26nm.png" alt="Image" /></td>
</tr>
<tr>
<td>Contact angle: 106 (relative value)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si-HM-D</td>
<td><img src="Si-HM-D_30nm.png" alt="Image" /></td>
<td><img src="Si-HM-D_28nm.png" alt="Image" /></td>
<td><img src="Si-HM-D_26nm.png" alt="Image" /></td>
</tr>
<tr>
<td>Contact angle: 109 (relative value)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Higher contact angle of Si-HM improves resist pattern collapse
- Surface property is the key factor for improvement of pattern collapse
Si-HM impact on Sensitivity

<table>
<thead>
<tr>
<th>HP</th>
<th>32 nm HP</th>
<th>30 nm HP</th>
<th>28 nm HP</th>
<th>26 nm HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>16.0mJ/cm²</td>
<td>16.0mJ/cm²</td>
<td>16.0mJ/cm²</td>
<td>16.0mJ/cm²</td>
</tr>
<tr>
<td>LWR</td>
<td>4.1nm</td>
<td>3.7nm</td>
<td>4.3nm</td>
<td>-</td>
</tr>
</tbody>
</table>

Image

- Sensitivity improved by 15% with Si-HM.
EUV Resist RLS Improvement

-Process-

**Resist Materials**
- Short acid diffusion length PAG
- High Tg resin
- High absorption resin

**Related Materials**
- Under-layer
  - Top-coat

**Process**
- Rinse agent
- DSA
## FIRM™ Rinse* Process Impact for Pattern Collapse

### Without FIRM™ rinse

<table>
<thead>
<tr>
<th>Dose (mJ/cm²)</th>
<th>28.9</th>
<th>30.7</th>
<th>34.2</th>
<th>36.0</th>
<th>37.8</th>
<th>39.5</th>
<th>41.3</th>
<th>43.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD (nm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 nm HP</td>
<td><img src="20nmHP.png" alt="Image" /></td>
<td><img src="20nmHP.png" alt="Image" /></td>
<td><img src="20nmHP.png" alt="Image" /></td>
<td><img src="20nmHP.png" alt="Image" /></td>
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<td><img src="20nmHP.png" alt="Image" /></td>
<td><img src="20nmHP.png" alt="Image" /></td>
<td><img src="20nmHP.png" alt="Image" /></td>
</tr>
</tbody>
</table>

### With FIRM™ rinse

<table>
<thead>
<tr>
<th>Dose (mJ/cm²)</th>
<th>28.9</th>
<th>30.7</th>
<th>34.2</th>
<th>36.0</th>
<th>37.8</th>
<th>39.5</th>
<th>41.3</th>
<th>43.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD (nm)</td>
<td>21.5</td>
<td>20.9</td>
<td>20.1</td>
<td>20.0</td>
<td>19.0</td>
<td>18.3</td>
<td>16.8</td>
<td>-</td>
</tr>
<tr>
<td>20 nm HP</td>
<td><img src="20nmHP.png" alt="Image" /></td>
<td><img src="20nmHP.png" alt="Image" /></td>
<td><img src="20nmHP.png" alt="Image" /></td>
<td><img src="20nmHP.png" alt="Image" /></td>
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<td><img src="20nmHP.png" alt="Image" /></td>
<td><img src="20nmHP.png" alt="Image" /></td>
<td><img src="20nmHP.png" alt="Image" /></td>
</tr>
</tbody>
</table>

*FIRM™ Extreme™ 12

- **FIRM™ rinse process improves pattern collapse margin**

**FIRM™ Rinse** Process Impact for Resolution and LWR

<table>
<thead>
<tr>
<th>HP</th>
<th>20 nm HP</th>
<th>19 nm HP</th>
<th>18 nm HP</th>
<th>17 nm HP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Without</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FIRM™ Rinse</td>
<td>LWR:3.4 nm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>With</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FIRM™ Rinse</td>
<td>LWR:2.8 nm</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Higher resolution observed with rinse process
- LWR improved by 15% with rinse process

*FIRM™ Extreme™ 12*
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Exposure result on SEMATECH Berkeley MET

**LS Ultimate resolution**
- 16nm LS
- 15nm LS
- 14nm LS
- 13nm LS

**CH Ultimate resolution**
- 20nmC40nmP
- 20nmC60nmP

Berkeley MET, NA0.3, Pseudo PSM
Sensitivity: 44mJ/cm²

Berkeley MET, NA0.3, Quadrupole
Sen. 63mJ/cm²
Sen.105mJ/cm²

➢ JSR EUV resist has the potential to achieve of 14 nm LS and 20 nm CH patterns
Exposure result on imec NXE:3100

**LS Performance**

22nm LS

- Sensitivity: 13.5mJ/cm²
- LER: 3.1nm

20nm LS

- Sensitivity: 13.8mJ/cm²

**CH Performance**

28nm CH

- Sensitivity: 16.2mJ/cm²
- LCDU: 1.0nm

26nm CH

- Sensitivity: 16.8mJ/cm²
- LCDU: 1.0nm

Imec’s NXE3100, NA0.25, Dipole60X

With FIRM™ rinse.

LER: 3σ

- JSR EUV resist shows good RLS and LCDU performance for 2x nm generation

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*2012 International Symposium on Extreme Ultraviolet Lithography  Oct. 1, 2012*
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- Summary
# EUV Lithography with DSA

<table>
<thead>
<tr>
<th>Polymer phase separation</th>
<th>Blend type (PolymerA/PolymerB)</th>
<th>BCP type (PS-b-PMMA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No specific dimension, morphology, or periodicity</td>
<td>Intrinsic dimension and predetermined morphology</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CH Shrink</th>
<th>Guide pattern Less polar polymer Polar polymer</th>
<th>Guide pattern PMMA PS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Polar polymer remains for pattern shrink and less polar polymer is removed</td>
<td>PS remains for pattern shrink and PMMA is removed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Development</th>
<th>Organic solvent</th>
<th>Dry development UV irradiation with polar solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>120 -150 °C</td>
<td>200 -250 °C</td>
</tr>
</tbody>
</table>
EUV Lithography with DSA

- Guide pattern (EUVL)
- Polymer blend coating
- Annealing
- Wet Development

✓ Polymer blend DSA material was investigated for CH shrink process
EUV Lithography with DSA

<table>
<thead>
<tr>
<th></th>
<th>EUV lithography</th>
<th>EUV + DSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>105 mJ/cm²</td>
<td>32.1 mJ/cm²</td>
</tr>
<tr>
<td>LCDU</td>
<td>4.6 nm</td>
<td>4.9 nm</td>
</tr>
</tbody>
</table>

- **EUV lithography followed by polymer blend DSA process achieved 20 nm contact hole patterns**
- **EUV+DSA process improves resist sensitivity**
Summary

✓ Material & process development for RLS improvement
  • New high Tg or high absorption resin shows good balance between LWR and sensitivity
  • Si-HM UL improves resolution and sensitivity
  • Rinse agent improves resolution and LWR
  • EUVL with polymer blend DSA process improves sensitivity for CH process

✓ Combination of material and process for ≤ 22 nm hp patterning
  • JSR EUV resist achieved 14 nm LS and 20 nm CH resolution on SEMATECH Berkeley MET
  • JSR EUV resist shows good RLS and LDCU performance for 2x nm hp generation on imec NXE:3100.
Acknowledgment

*The authors gratefully thank imec, SEMATECH, and CXRO for the close collaboration*
Thank you for your attention!!