Novel EUV Resist Development for Sub-14nm Half Pitch

Yoshi Hishiro
JSR Micro Inc.
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- Requirement for sub-14nm HP EUV resist
- JSR strategy for resolution & sensitivity improvement
  - High Tg Resin
  - Short diffusion length PAG
  - Strong acidity PAG
- JSR new high resolution CAR
- Sensitivity improvement by new sensitizer
- Summary
When Will EUV Come in Industry?

ITRS 2013 (MPU Fins and Flash Lines)

<table>
<thead>
<tr>
<th>Year</th>
<th>'14</th>
<th>'16</th>
<th>'18</th>
<th>'20</th>
<th>'22</th>
<th>'24</th>
<th>'26</th>
<th>'28</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min hp after multi. patterning</td>
<td>17nm</td>
<td>14nm</td>
<td>12nm</td>
<td>12nm</td>
<td>11nm</td>
<td>8.4nm</td>
<td>6.7nm</td>
<td>5.3nm</td>
</tr>
<tr>
<td>20 - 30nm ArF Imm DP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 - 20nm ArF Imm QP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 - 15nm ArF Imm QP, DSA, EUV DP, Imprint</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 - 11nm DSA, EUV DP, High NA EUV, Imprint, ML2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 8nm DSA extension, EUV DP, High NA EUV, Imprint, ML2</td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

- EUV will be ready for mass production on 2017-18?
- Sub-14nm resolution will be required for EUV resist.
## Requirements for EUV Resist

<table>
<thead>
<tr>
<th>Source Power</th>
<th>Resist Requirements</th>
<th>Appropriate Platforms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>✓ Super high sensitivity</td>
<td>Super sensitive novel resist</td>
</tr>
<tr>
<td>Middle</td>
<td>✓ RLS balance ✓ Defectivity control</td>
<td>CAR extension</td>
</tr>
<tr>
<td>High</td>
<td>✓ RL improvement ✓ Defectivity control</td>
<td>CAR extension</td>
</tr>
<tr>
<td></td>
<td>✓ Super high resolution ✓ Super low LWR/LER ✓ Defectivity control</td>
<td>Super smooth Non CAR Resist</td>
</tr>
</tbody>
</table>

- Requirement and platform depend on source power.
- In any case, **Resolution** and **Sensitivity** are key requirements.
Strategy for Resolution & Sensitivity Improvement

Requirements for EUV resist

- Low Resolution
- Low LWR
- High Sensitivity
- Low Outgassing
- Suppression of OOB influence
- Defectivity
- etc...

JSR Strategy for Resolution & Sensitivity improvement

<table>
<thead>
<tr>
<th>Item</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin</td>
<td>High Tg resin for acid diffusion control</td>
</tr>
<tr>
<td>PAG</td>
<td>New short diffusion length and strong acidity PAG</td>
</tr>
<tr>
<td>Additive</td>
<td>New sensitizer for high EUV photoabsorption</td>
</tr>
</tbody>
</table>
Acid Diffusion Control by Resin

Berkeley MET, NA0.30

<table>
<thead>
<tr>
<th>Resin</th>
<th>22 nm HP</th>
<th>20 nm HP</th>
<th>Z-factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin 1</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td>2.93E-08</td>
</tr>
<tr>
<td>Resin 2</td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td>2.17E-08</td>
</tr>
<tr>
<td>Resin 3</td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
<td>2.04E-08</td>
</tr>
<tr>
<td>Resin 4</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td>1.74E-08</td>
</tr>
</tbody>
</table>

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

T. Wallow et. Al. SPIE 2008, 69211F

- Acid diffusion control by higher Tg resin is effective approach for improving resolution and Z-factor.

#Detail was published at SPIE 2014 (9048-48)

EUV Workshop, June 17, 2015
Acid diffusion length is one of the important nobs.

New short diffusion PAG enabled the breakthrough performance.

#Detail was published at SPIE 2015 (9422-24)
## High Resolution CAR (BMET)

**Short diffusion length PAG**

<table>
<thead>
<tr>
<th>HP</th>
<th>17nm</th>
<th>16nm</th>
<th>15nm</th>
<th>14nm</th>
<th>13nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>JSR CAR</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>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
</tbody>
</table>

- **JSR CAR**
  - 35.5mJ/cm²

- **13nm HP**
- **12nm HP**

- **Berkeley MET, NA0.30**

- **13nm HP was resolved with short diffusion length PAG on BMET.**
High Resolution CAR on NXE3300

Ultimate resolution of JSR CAR

- 15nmHP LS 37.5mJ/cm² (Resolved)
- 14nmHP LS 45mJ/cm² (Almost resolved)
- 13nmHP LS 45mJ/cm² (Many collapse)

 NXE3300, Dipole45, FT=30nm

➢ Short diffusion PAG almost resolves 14nmHP on NXE3300.
High Resolution CAR on NXE3300

16nmHP LS & 20nm Iso Trench performance

<table>
<thead>
<tr>
<th>JSR CAR FT=30nm</th>
<th>Mask</th>
<th>Dose to Size (mJ/cm²)</th>
<th>Min. CD (nm)</th>
<th>ELmax (%)</th>
<th>DOFmax (nm)</th>
<th>LWR (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16nmHP LS</td>
<td>16L32P</td>
<td>44.8</td>
<td>14.8</td>
<td>18.6</td>
<td>100</td>
<td>4.3</td>
</tr>
<tr>
<td>20nm Iso Trench</td>
<td>22T112P</td>
<td>40.9</td>
<td>18.5</td>
<td>17.7</td>
<td>120</td>
<td>4.2</td>
</tr>
</tbody>
</table>

JSR CAR resist showed good 16nmHP LS & 20nm IT process window.

NXE3300, Dipole90
Strong acidity PAG is effective for sensitivity improvement. But LWR and sensitivity are trade-off.
PAG Development
(Diffusion length and Acidity)

New PAG enables breakthrough performance

- JSR new short diffusion & high acidity PAG

Exposed at PSI

<table>
<thead>
<tr>
<th></th>
<th>PAG A</th>
<th>PAG C</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAG-A ratio</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>(Weak)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAG-C ratio</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>(Strong &amp; Low ADL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sen. (mJ/cm²)</td>
<td>36.1</td>
<td>19.4</td>
</tr>
<tr>
<td>(16nmHP)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LWR (nm)</td>
<td>7.2</td>
<td>5.3</td>
</tr>
<tr>
<td>(16nmHP)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
JSR EUV Resist for 16nm HP

【JSR EUV Photoresist】

16nm L/S ED window

34mJ 35mJ 36mJ 37mJ 38mJ 39mJ

+40nm +20nm 0nm -20nm -40nm

[Process Conditions]
- Substrate: Organic UL
- Resist FT: 35nm
- Exposure: NXE:3300B, NA0.33, Dipole45X

Exposure Courtesy of ASML and imec

✓ JSR EUV photoresist showed certain process window at 16nm HP.

EUV Workshop, June 17, 2015
**JSR High Resolution Resist**

**on NXE3300**
- Dipole90X
  - 16nm LS
  - LWR=5.2nm
  - EL >15%
  - 39.2mJ/cm²

**on NXE3300**
- Dipole45X
  - 15nm LS
  - 40.4mJ/cm²
  - 14nm LS
  - 36.8mJ/cm²
  - 13nm LS
  - 38.6mJ/cm²

**on PSI**
- 12nm LS
  - 40.5mJ/cm²
- 11nm LS
  - 33.6mJ/cm²

✓ **13nm HP (NXE3300) and 12nm HP (PSI) resolution was achieved by JSR EUV photoresist.**
Concept of New Sensitizer

- **EUV photoabsorption is key factor for efficient secondary electrons generation.**
- **JSR developed new sensitizer using high EUV photoabsorption atom.**
### Sensitivity Improvement: New Sensitizer

**Berkeley MET, NA0.30**

<table>
<thead>
<tr>
<th></th>
<th>Conventional CAR</th>
<th>CAR + New Sensitizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEM Image Mask: 18L36P</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Sensitivity (mJ/cm²)</td>
<td>54.2</td>
<td>45.8</td>
</tr>
<tr>
<td>CD (nm)</td>
<td>17.5</td>
<td>18.0</td>
</tr>
<tr>
<td>LWR (nm)</td>
<td>2.7</td>
<td>2.8</td>
</tr>
</tbody>
</table>

- **JSR new sensitizer improves EUV resist sensitivity with keeping resolution and roughness at sub-20nmhp.**
- **Outgassing of new CAR + Sensitizer system:** CC=3.29nm

**EUV Workshop, June 17, 2015**
## Sensitivity Improvement: New Sensitizer

<table>
<thead>
<tr>
<th></th>
<th>Conventional CAR</th>
<th>CAR + New Sensitizer</th>
<th>Sensitivity improve</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resist A</strong></td>
<td>![Image]</td>
<td>![Image]</td>
<td>16%</td>
</tr>
<tr>
<td>18nmHP</td>
<td>54.2mJ CD=17.5 LWR=2.7</td>
<td>45.8mJ CD=18.0 LWR=2.8</td>
<td></td>
</tr>
<tr>
<td><strong>Resist B</strong></td>
<td>![Image]</td>
<td>![Image]</td>
<td>9%</td>
</tr>
<tr>
<td>22nmHP</td>
<td>20.0mJ CD=23.7 LWR=8.2</td>
<td>18.3mJ CD=23.7 LWR=4.1</td>
<td></td>
</tr>
<tr>
<td><strong>Resist C</strong></td>
<td>![Image]</td>
<td>![Image]</td>
<td>13%</td>
</tr>
<tr>
<td>17nmHP</td>
<td>52.5mJ CD=19.1 LWR=5.3</td>
<td>45.9mJ CD=19.3 LWR=6.4</td>
<td></td>
</tr>
</tbody>
</table>

➤ *New sensitizer system is applicable for various resists.*

*EUV Workshop, June 17, 2015*
Summary

✓ Material development for breakthrough CAR performance
  • Short diffusion length PAG
  • Short diffusion length and strong acidity PAG

✓ JSR new high resolution CAR
  • Good 16nmHP LS & 20nm IT process window on NXE3300
  • 13nmHP resolution on NXE 3300
  • 12nmHP resolution on PSI

✓ New sensitizer development
  • Sensitivity improvement with keeping resolution & roughness
  • Applicable for various resist

Target of 2015
Resolution: 13nmHP, Sensitivity: 20mJ/cm², LWR: 2nm
Investigation of various approaches to improve litho performance
Collaboration with imec and partners for NXE exposure
Acknowledgement

The author gratefully thanks to:

**SEMATECH**
for the exposure support on MET

**ASML**
for the NXE3300 exposure and valuable discussion

**imec**
for the close collaboration and discussion
Thank you for your attention!!

2007
40 nm LS, ArFi

2008
26 nm LS, ArFi DP

2010
19 nm LS, EUV

2015
13nm LS, EUV