Resists for High Throughput Next Generation Lithographies

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157 EUV EPL
MEBDW EBDW X-ray IPL
## IC Technology Roadmap

<table>
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</thead>
<tbody>
<tr>
<td></td>
<td>130 nm DUV</td>
<td>100 nm 193 nm</td>
<td>70 nm 157 nm, EPL, EUV</td>
<td>50 nm EPL, EUV, 157</td>
<td>35 nm EUV, MEBDW, EPL</td>
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</tbody>
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### A. Mask Making Resists

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<tbody>
<tr>
<td>157 nm (5X)</td>
<td>-</td>
<td>-</td>
<td>120 nm</td>
<td>100 nm</td>
<td>-</td>
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<tr>
<td>EPL (4X)</td>
<td>-</td>
<td>200 nm?</td>
<td>160 nm</td>
<td>100 nm ?</td>
<td>-</td>
</tr>
<tr>
<td>EUV(4X)</td>
<td>-</td>
<td>200 nm?</td>
<td>160 nm</td>
<td>100 nm</td>
<td>-</td>
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</tbody>
</table>

### B. Wafer Patterning Resists

<table>
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</thead>
<tbody>
<tr>
<td>157 nm</td>
<td>-</td>
<td>-</td>
<td>60 nm</td>
<td>40 nm ?</td>
<td>-</td>
</tr>
<tr>
<td>EPL</td>
<td>-</td>
<td>-</td>
<td>60 nm ?</td>
<td>40 nm</td>
<td>25 nm ?</td>
</tr>
<tr>
<td>EUV</td>
<td>-</td>
<td>-</td>
<td>60 nm ?</td>
<td>40 nm</td>
<td>25 nm</td>
</tr>
<tr>
<td>MEBDW</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>25 nm ?</td>
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</tbody>
</table>
### NGL Characteristics

<table>
<thead>
<tr>
<th>Property \ Technology</th>
<th>157</th>
<th>EUV</th>
<th>EPL</th>
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</thead>
<tbody>
<tr>
<td><strong>Type &amp; Energy</strong></td>
<td>Optical</td>
<td>Optical</td>
<td>Electron</td>
</tr>
<tr>
<td></td>
<td>7.89 eV</td>
<td>92.4 eV</td>
<td>100,000 eV</td>
</tr>
<tr>
<td>(157 nm)</td>
<td>(13.5 nm)</td>
<td></td>
<td>0.000124 nm</td>
</tr>
<tr>
<td><strong>Electronic Excitations</strong></td>
<td>Molecular,</td>
<td>Atomic,</td>
<td>Atomic,</td>
</tr>
<tr>
<td></td>
<td>Rydberg</td>
<td>Ionizing</td>
<td>Ionizing</td>
</tr>
<tr>
<td><strong>PDUV Resist Absorption</strong></td>
<td>Very High</td>
<td>Mod. High</td>
<td>Very Low</td>
</tr>
<tr>
<td><strong>Resist Thickness, T&gt;45%</strong></td>
<td>60 nm</td>
<td>120 nm</td>
<td>&gt;1000 nm</td>
</tr>
<tr>
<td><strong>PDUV Resist Chemistry</strong></td>
<td>Similar</td>
<td>~ Same</td>
<td>~ Same</td>
</tr>
<tr>
<td><strong>Sensitivity</strong></td>
<td>&lt;10 mJ/cm²</td>
<td>&lt;5 mJ/cm²</td>
<td>~3 µC/cm²</td>
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<tr>
<td><strong>Resolution Target</strong></td>
<td>60 nm</td>
<td>60 nm</td>
<td>60 nm</td>
</tr>
<tr>
<td><strong>Depth-of-Focus</strong></td>
<td>~300 nm</td>
<td>~800 nm</td>
<td>&gt;10,000 nm</td>
</tr>
<tr>
<td><strong>Anti-reflective Coating</strong></td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Low Resist Outgassing</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Hardmask Processing</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Plasma Etch Resistance</strong></td>
<td>= PDUV</td>
<td>= PDUV</td>
<td>= PDUV</td>
</tr>
</tbody>
</table>

NGL Characteristics report comparing the properties of three technologies: 157 nm, EUV, and EPL, focusing on their energy levels, electronic excitations, resist absorption, chemistry, sensitivity, resolution, depth-of-focus, and processing capabilities. The table highlights key differences and similarities among these technologies, emphasizing areas where they excel or show compromise.
EUV Resist Development

Principal Needs:
Resolution, Sensitivity, LER, Plasma Etching Resistance

Focus Areas

• Apply learning from DUV lithographic materials & processing.

• Phenolic resin materials
  • Modified high temperature resists based on hydroxystyrene.
  • Modified low temperature processed resists based on hydroxystyrene and new acid-sensitive blocking groups.

• Optimize performance using materials and processing DOEs.
Ultrathin Phenolic Resists

- Based on Positive DUV resist polymers

\[
\text{Base Soluble} + \text{Photo Acid Generator (PAG)}
\]

- Absorbance is ~ 6.8/um
- Thicknesses range from 60-85 nm
- Standard DUV processing
  * PAB 110-140°C and PEB 130-150°C
  * Development: aqueous 0.26N TMAH
Comparison of EUV and DUV Doses @ 100 & 200 nm Size for Modified DUV Resists

- Linear correlations with polymers of a certain type.
- Standard polymer C has highest $E_{size}$ & lowest intercept.
- Modified polymer A is similar to C.
- Modified polymer B has the steepest slope and highest sensitivity.
EUV Resist Lithography and Etch:
100 nm, 1:1 L/S, T=85 nm, NA = 0.088

UV6
Dose >15 mJ/cm²
LER = 9.4 nm

XP98248
Dose = 5.6 mJ/cm²
LER = 6.0 nm

120 nm, 1:2 L/S
Transferred to 50 nm SiON
Hardmask, Resist loss 37%

SEMs courtesy J. Cobb, C. Henderson, EUV-LLC & SNL
XP98248 Imaging in Thicker Films

100 nm 1:2 L/S 100 nm L/S

T = 145 nm

7.5 mJ/cm²

100 nm L/S 100 nm 1:2 L/S

T = 120 nm

6.7 mJ/cm²

SEMs courtesy of C. Henderson & J. Cobb, EUV-LLC
PAG Acid Generation Efficiency vs. Radiation Type and Polymer Type

* Resists exposed with 248 nm light have a slight dependence on polymer.

* Resists exposed with EUV have a dramatic dependence on structure.

* Polymer 3 has a large 30% increase in acid formation.

* Employ Polymer 3 in sensitivity enhancement studies with other techniques.
# Recent High Sensitivity Resist Data

<table>
<thead>
<tr>
<th>Resist</th>
<th>Sensitivity (mJ/cm²)</th>
<th>Resol’n (nm)</th>
<th>LER (nm, 3σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.6</td>
<td>90</td>
<td>7</td>
</tr>
<tr>
<td>B</td>
<td>1.7</td>
<td>90</td>
<td>7</td>
</tr>
<tr>
<td>C</td>
<td>1.6</td>
<td>100</td>
<td>7</td>
</tr>
<tr>
<td>D</td>
<td>1.7</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>XP98248</td>
<td>5.9</td>
<td>80</td>
<td>6</td>
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</table>

Data & SEMs courtesy G. Cardinale, EUV-LLC
E-beam Resist Development

Principal Needs:
Sensitivity, Resolution, LER, Exposure Latitude, Plasma Etching Resistance, Outgassing

Focus Areas

• Phenolic resin materials
  • Modified high temperature resists based on hydroxystyrene.
  • Modified low temperature resists based on hydroxystyrene inhibited by acid-sensitive blocking groups.

• Apply learning from EUV and DUV lithographic performance.

• Optimize performance by materials and processing DOEs.
XP9947A E-beam Resist

Modified DUV chemically amplified resist, high temp process
$E_{\text{size}}$ (50 KeV) = 8.4 µC/cm²
Thickness = 350 nm
Contrast = 18
Resolution = 100 nm 1:1 & 1:3 L/S
Exposure Latitude: >25% Dense, >15% Iso
Coated Shelf-life = > 3 Months

100 nm 1:1 L/S
100 nm 1:3 L/S
XP9947A Soft-Bake Study: 100 nm L/S

60 sec  Baking Time  90 sec

130°C  7.3 μC/cm²  8.0 μC/cm²

140°C  7.7 μC/cm²  8.4 μC/cm²

PEB = 130°C
Actual vs Coded 1:1 Feature Size Linearity for 350 & 200 nm Thickness L/S, IL & CH

200 nm Films

80 nm

90 nm
XP9947A Focus Latitude @ 100 kV, 350 nm Film Thickness & 11 µC/cm²

**SCALPEL Exposures**

80 nm L/S

-20 µm  -10 µm  0 µm  +10 µm  +20 µm

100 nm L/S

SERMs courtesy L. Ocola & A. E. Novembre, Lucent Technologies

gnt-091400
High Sensitivity Results with XP2009-M

100 nm

80 nm

60 nm

2 µC/cm² @ 50 kV
JEOL 9300
(4 µC/cm² @ 100 kV)
PAB 130°C/60sec
PAB 140°C/60sec

Courtesy, L. Ocola & A. E. Novembre, Lucent Technologies

gnt-091400
157 nm Resist Development

Principal Needs:
Absorption, Thickness, Resolution, Outgassing, LER, Plasma Etching Resistance, Sensitivity

Focus Areas

- Apply learning from DUV, EUV and E-beam lithographic materials and extend their use to UTRs for 157 nm tool testing.

- UTR phenolic resin materials
  - Modified high temperature resists based on hydroxystyrene.

- Prepare resins with lower absorbance using fluorine incorporation.

- Study the influence of groups and structure on absorption.

- Optimize lithographic performance using materials, formulation and processing DOEs.
Polymer Absorbance @ 157 nm

R. Kunz, T. Bloomstein, et al, MIT-LL
Thicknes Targets for 157 nm Resists

- Resist absorbance <3.0/\(\mu m\) is difficult.

- Fluorine or other electron withdrawing groups needed.
  - Lower etching resistance
  - Softer resists will have more pattern collapse

- Resist thicknesses using hardmask technology may range from 120-200 nm.

<table>
<thead>
<tr>
<th>Dense Features</th>
<th>% Trans</th>
<th>Thickness</th>
<th>Abs/(\mu m)</th>
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<tbody>
<tr>
<td>45%</td>
<td>0.100</td>
<td>3.468</td>
<td></td>
</tr>
<tr>
<td>45%</td>
<td>0.125</td>
<td>2.774</td>
<td></td>
</tr>
<tr>
<td>45%</td>
<td>0.150</td>
<td>2.312</td>
<td></td>
</tr>
<tr>
<td>45%</td>
<td>0.175</td>
<td>1.982</td>
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</tr>
<tr>
<td>45%</td>
<td>0.200</td>
<td>1.734</td>
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<table>
<thead>
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<th>Isolated Features</th>
<th>% Trans</th>
<th>Thickness</th>
<th>Abs/(\mu m)</th>
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<tr>
<td>30%</td>
<td>0.100</td>
<td>5.229</td>
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<tr>
<td>30%</td>
<td>0.125</td>
<td>4.183</td>
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<tr>
<td>30%</td>
<td>0.150</td>
<td>3.486</td>
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<tr>
<td>30%</td>
<td>0.175</td>
<td>2.988</td>
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<tr>
<td>30%</td>
<td>0.200</td>
<td>2.614</td>
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157 nm Resist Timeline

**Date**

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<tr>
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<th>4/00</th>
<th>7/00</th>
<th>10/00</th>
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<th>4/01</th>
<th>7/01</th>
<th>10/01</th>
<th>1/02</th>
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<tr>
<td>UTR, T ≤100nm</td>
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<tr>
<td>HT-UTR, T ≥ 100 nm</td>
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<td>SLR, T &gt; 200nm</td>
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<tr>
<td>Organic ARC</td>
<td>AR 19</td>
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<td>ARC 1</td>
</tr>
</tbody>
</table>

**Process Details**

- **UTR, T ≤100nm**
  - CHO
  - 90nm+
  - PSM 70nm+

- **HT-UTR, T ≥ 100 nm**
  - Moderate C-F
  - 100nm+
  - PSM 70nm+

- **SLR, T > 200nm**
  - High C-F
  - 150nm+
  - 100nm+

**ARC Details**

- **Organic ARC**
  - AR 19
  - ARC 1
Ultrathin Phenolic Resists

- Based on Positive DUV resist polymers

- Absorbance is ~ 6.8/um
- Thicknesses range from 60-85 nm
- Standard DUV processing
  * PAB 110-140°C and PEB 130-150°C
  * Development: aqueous 0.26N TMAH
Contrast Curve: Crosslinking Effect
Factors Involved in UTR Resolution

- Modified Phenolic Resins
  * Monomers with low crosslinking.
  * Optimum dissolution properties, low UFTL.

- Modified Formulations
  * Revised to give enhanced deprotection.
XP2332C Imaging @ 4 mJ/cm²

70 nm Thick
NA = 0.6
Binary Mask
90 nm, I:1.5 L/S
PAB = 130°C/60sec
PEB = 130°C/90sec
0.26N TMAH/45sec

SEM courtesy Georgia Rich, SEMATECH

gnt-091400
Ultrathin Film Imaging of XP2332C

Thickness = 70 nm
NA = 0.60, dipole
70 nm, I:1.5 L/S
PAB = 130°C/60sec
PEB = 130°C/90sec
0.26N TMAH/45sec
LER ~ 7 nm, 3σ

SEM courtesy Stephan Hien, SEMATECH
# Resist Outgassing

<table>
<thead>
<tr>
<th>Resist</th>
<th>Type</th>
<th>Outgassing Rate @ 6 mJ/cm² (Molecules/cm²·sec)</th>
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</thead>
<tbody>
<tr>
<td>UV6</td>
<td>DUV</td>
<td>2.0E11</td>
</tr>
<tr>
<td>XP2452D</td>
<td>157</td>
<td>2.0E11</td>
</tr>
<tr>
<td>XP98248D</td>
<td>EUV</td>
<td>6.0E10</td>
</tr>
<tr>
<td>XP2332B</td>
<td>157</td>
<td>4.0E10</td>
</tr>
</tbody>
</table>

Measurement by R. Kunz & D. Downes, MIT-LL
Conclusions

• Making progress in the three NGL resist technologies targeting the 70 nm node for production.

• Some achievements.

  157
  * Sensitive UTR XP2332C resolves 70 nm in 70 nm films.
  * Work just being initiated on lower absorbance polymers for EUV.
  * XP98248 resist has best resolution (80 nm) and LER.
  * XP2008B resist is 3X faster at almost equal performance.

  E-beam
  * XP9947A resist has excellent overall properties, but is somewhat insensitive for optimum EPL throughput.
  * New XP2008A has 100 kV sensitivity of ~4µC/cm² and resolution approaching 60 nm for isolated lines.

Future focus: 50 nm resolution and improved processes & characteristics
Acknowledgments

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  EUV-LLC

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  Erik Anderson  
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  Etec Systems  
  LBNL  
  DARPA/SPAWAR  
  Lucent Technologies  
  MIT-LL

- **157 nm**
  
  Kim Dean, Georgia Rich, Stephan Hein  
  Ted Fedynyshn, R. Kunz  
  Olga Vladimirsky, Chen Lu  
  SEMATECH  
  MIT-LL  
  SVG-L