EUV Resist Materials
Properties and Performance

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Long Term EUV Resist Targets

Patterning for the 22nm node & Beyond (HVM 2011+)
Tri-ability: Availability, Affordability & Profitability

Resolution: Meet the Design Rules
(updates with generation as device designs are finalized)

LWR (3σ): <10% of min. CD
(updates layer specific, based on device performance results)

Photo Sensitivity: <10 mJ/cm²
(updates based on COO requirements)

Outgassing: $10^{10} - 10^{11}$ m/cm² at E-size
(updates based on optics contamination / cleaning requirements)

Side wall angle: 90° ± 2°
(updates based on etched profiles / device yield / performance)
In addition to meeting the long term goals, resists will also be needed for nearer term experiments.

<table>
<thead>
<tr>
<th>Time</th>
<th>CD</th>
<th>Pitch</th>
<th>LWR</th>
<th>Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1'07</td>
<td>60nm (trench)</td>
<td>150nm</td>
<td>&lt;5nm</td>
<td>&lt;20mJ</td>
</tr>
<tr>
<td>Q1'07</td>
<td>50nm (line)</td>
<td>150nm</td>
<td>&lt;5nm</td>
<td>&lt;20mJ</td>
</tr>
<tr>
<td>Q3'07</td>
<td>40nm (trench)</td>
<td>100nm</td>
<td>&lt;5nm</td>
<td>&lt;20mJ</td>
</tr>
<tr>
<td>Q3'07</td>
<td>40nm (line)</td>
<td>100nm</td>
<td>&lt;5nm</td>
<td>&lt;15mJ</td>
</tr>
<tr>
<td>Q1'08</td>
<td>30nm (trench)</td>
<td>80nm</td>
<td>&lt;4nm</td>
<td>&lt;15mJ</td>
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<tr>
<td>Q1'08</td>
<td>30nm (line)</td>
<td>80nm</td>
<td>&lt;4nm</td>
<td>&lt;15mJ</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20nm (line)</td>
<td>60nm</td>
<td>&lt;2nm</td>
<td>&lt;10mJ</td>
</tr>
</tbody>
</table>

Intel’s EUV resist program aims to both participate in the long term EUV resist research needed to develop HVM compatible solutions, and to supply resists to EUVL research customers in the meantime.
# A Selection of Recent EUV resist patterning results from Intel MET

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Resist Name</th>
<th>Min Resolution for 1:1 Structures (nm)</th>
<th>60nm 1:1</th>
<th>CD DOF (+/-2%) (nm)</th>
<th>Photospeed (mJ/cm²)</th>
<th>LWR (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Resist 1</td>
<td>50</td>
<td>140</td>
<td>5.4</td>
<td>13.9</td>
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<td>11</td>
<td>6.6</td>
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<tr>
<td>A</td>
<td>Resist 3</td>
<td>36</td>
<td>160</td>
<td>9.5</td>
<td>7.9</td>
<td></td>
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<tr>
<td>A</td>
<td>Resist 4</td>
<td>38</td>
<td>120</td>
<td>10</td>
<td>5.5</td>
<td></td>
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<tr>
<td>A</td>
<td>Resist 5</td>
<td>38</td>
<td>120</td>
<td>11.5</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Resist 6</td>
<td>50</td>
<td>175</td>
<td>5.5</td>
<td>11.3</td>
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</tr>
<tr>
<td>B</td>
<td>Resist 7</td>
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<td>80</td>
<td>5.2</td>
<td>13.2</td>
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<tr>
<td>B</td>
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<td>180</td>
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<tr>
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<td>200</td>
<td>7</td>
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<tr>
<td>C</td>
<td>Resist 10</td>
<td>45</td>
<td>350*</td>
<td>11.5</td>
<td>8.4</td>
<td></td>
</tr>
<tr>
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<td>Resist 11</td>
<td>40</td>
<td>350*</td>
<td>11.1</td>
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</tr>
<tr>
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<td>15</td>
<td>7.7</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Resist 13</td>
<td>36</td>
<td>210*</td>
<td>15.5</td>
<td>6.7</td>
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</tr>
<tr>
<td>D</td>
<td>Resist 14</td>
<td>45</td>
<td>210</td>
<td>10.5</td>
<td>7.4</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Resist 15</td>
<td>55</td>
<td>280</td>
<td>10</td>
<td>11.3</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Resist 16</td>
<td>36</td>
<td>300</td>
<td>17.5</td>
<td>4.2</td>
<td></td>
</tr>
</tbody>
</table>
Resist Screening Example
Conventional LAER Formulated for EUV

- 60 nm L/S
- 6.6 nm LWR
- 11 mJ/cm² sensitivity

- 46 nm L/S
- 14 mJ/cm² sensitivity

- 36 nm L/S
- 14 mJ/cm² sensitivity
Process Window

60nm 1:1, 50nm focus steps, 1.5mJ dose steps
Resist Screening Example – CAR + New Additive

50 nm L/S
4.2 nm LWR
17.5 mJ/cm² sensitivity

40 nm L/S
6.1 nm LWR
18 mJ/cm² sensitivity

30 nm CD, 90 nm pitch
14 mJ/cm² sensitivity
Resist Screening Example – New material

Dose to Print ≈ 11mJ

50nm 1:1
LWR ≈ 5 nm

40nm 1:2
LWR ≈ 5 nm

40nm 1:1
Not Resolved

30nm 1:3
LWR ≈ 5 nm
Resist Screening Example – new material / mechanism

Initial results for this resist show promising LWR and good resolution but photospeed of ≈ 35mJ needs improvement.
LWR Complexity

LWR is a multi-factorial phenomenon that can arise from a number of separate causes.

Possible source of LWR:
• Phase separation between protected and de-protected polymer
• Polymer inhomogeneity, colloid redeposition, and Mw/Pd
• PAG density and PAG/base ratio effects
• Polymer ‘grain’ size

Intel confirmed
• Photospeed: the slower the resist, the lower LWR
• Aerial image: the better the NILS, the lower LWR
• Tool NA: the higher NA, the lower LWR
• Acid diffusivity: the higher diffusivity, the lower LWR
• LWR has a strong impact on several device performance parameters

Further work is needed to characterize effects on device performance by layer, as a function of frequency and through correlation of litho and etched LWR
Collaborations

Making progress towards our goals through fundamental understanding, new materials, metrology, process and equipment research

New Resist Materials
- **Molecular Glasses** – Both new materials and low Mw analogues of existing platforms
- **Inorganic resists** - Photosensitive thin, dense, pore free, EUV sensitive films
- **Chain Scission** – Both CAR and non-CAR materials, QSPR screening, radical trap materials
- **New PAGs** – Non-PHOS and polymer-bound PAG (anion and cation) development
- **Resist Suppliers** – Screening and component development with suppliers and sub-suppliers

Process / Equipment Development
- **Smoothing** – LWR reduction through post develop processing (chemical, thermal, photo, etc.)
- **SCCO2 Developer** - Reduced line collapse for high aspect ratios features, plus LWR reduction
- **EUV IL Tool** – Equipment for resist research and screening
- **CDSAXS** – Resist LWR and cross section profile using small angle x-ray scattering
- **Outgassing** – Measurement & characterization of resist outgassing under EUV

Resist Fundamentals
- **EUV Photochemistry** – Modeling reaction mechanisms in EUV and e-beam resists
- **LWR Fundamentals** – Measuring the extent of CAR deprotection and PAG concentration
- **Resist Simulations** – Molecular resists, LWR characterization and simulation
- **Material LWR** – Understanding the material sources of LWR
- **CFM** – Mapping surface chemical distributions
Resist Morphology

Photoresist is a mixture of large (5nm) & small (0.5 nm) molecules. Aggregation and gradients emerge as meso-scale anisotropy in the resist. Anisotropy results from molecular forces interacting.
Harnessing Molecular Anisotropy

Engineering molecular functionality is “preorganization” (Cram, Nobel-'87) Chemicals systems with emergent, long-range structure are “self assembling”

Intel’s Molecules for Advanced Patterning Program (MAPP) designs preorganization & self assembly into lithographic materials

Uniform

Chaotic

<table>
<thead>
<tr>
<th>Class</th>
<th>Types</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>APPAG</strong></td>
<td>Long &amp; Short Diffusion helps DOF &amp; profile</td>
<td>Improved DOF &amp; profile of footed process; undercut with square profile process</td>
</tr>
<tr>
<td><strong>Advanced Developer</strong></td>
<td>Varied nonionic and ionic additives</td>
<td>Enables improved photospeed, margin, and diffusion</td>
</tr>
</tbody>
</table>
| **Scissionable Steroidal Dendrimer** | Scissionable Host for PAG Guest  
6 kinds of G0 made  
G1 made in June | G0 <5mJ/cm**2 EUV;  
G0 & G1 <0.5 μ e-beam;  
working on increased PEB |
| **Scissionable Quencher Backbone** | Preorganized quencher directs acid to protection  
6 copolymers | 10mJ/cm**2 EUV, <0.5 μ e-beam; working on increased temperature PEB |
Fate of Light in Resist

Catalyst precursor absorbs light making acid pattern

Other resist components absorb light too (thermal noise)

Light is pattern information, so...

... more information (acid) is presented on top...

... and catalyst precursor can only make less acid on bottom.

Lithography process and materials are challenged to compensate

Some substrates also deplete acid (SiN, SiON)

Feet didn’t dissolve!
Preorganized interfaces

HMDS tunes wafer surface energy to match resist surface energy
This adhesioin promoter glues resist to wafer in current processes
Can a light sensitive adhesion promoter boost interfacial contrast?

“Smart Interfaces: improving pattern fidelity with the gain enhancing underlayers, APPAG”, J. Macromolecular Sci., 45(6), 2006
APPAG DUV and EUV

DUV (1/4 μ) experiment shows depth of focus improvement
EUV experiment shows lower PEB enabled for process
APPAG tunes substrate surface pH and hydrophobicity
Other functional groups and ion pairs under study

![Graph showing CD nm vs Defocus μ with APPAG, APPAG9, APPAG6, Control, and BARC]

-1.5  -0.9  -0.26  +0.38  +1
Defocus, μ

![Graph showing Focus Å vs CD nm with EUV: 11, 10, 9 & 8mj/cm², 80 degree PEB, HMDS, and APPAG6]

EUV: 11, 10, 9 & 8mj/cm²
80 degree PEB
HMDS
APPAG6

CD, nm
Defocus, μ
Focus, Å
Developer additives found that smooth features Photospeed accelerating additives noted too For investigation: • Additives (size, shape, functionality) • Ions (concentration, activity & size)
Scissionable Steroid Dendrimer

PAG preorganized by branches

Branches are cut then ionized by PAG

G0 shows E0 of 5mJ/cm**2
Scissionable Bound Quencher

Preorganized base steers protons

Main chain is cut proximal to base

Lower Tg restricts PEB & limits resolution
Conformational restriction

- Rings raise glass transition 2 ways
- Rigid and bulky
- Scale-up underway

Larger “R group” has smaller vibrational cone (pinacol, ring)
Summary

• Resist screening continues on Intel MET and other available tools with candidates for intermediate patterning goals starting to appear.

• Resolution continues to show improvement on the Intel MET. - specifically sub-30 nm iso lines; 35nm L/S and 40nm holes.

• LWR is challenging and a predictor of transistor performance. Intermediate patterning targets may be achievable with conventional materials, but new concepts may be required to meet long term needs.

• Several university / material supplier and internal programs are extending our knowledge and providing interesting materials designed to help us meet our goals.

• New prototype materials controlling molecular behavior, interfacial chemistry and film organization show new performance opportunities.
Acknowledgements

Resist / Material suppliers

University Collaborators

Sematech / IMEC / NIST / National Labs*

Intel Components Research EUV Litho Team

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