2H’08 IEUVI Resist TWG
Optimizing RLS

Todd R. Younkin
Components Research
Technology Manufacturing Group
Intel Corporation
Presentation Overview

• Intel Lithography Requirements
• EUV Patterning Mechanism
• RLS + Quantification of Improvement
• 2008 EUV Photoresist Progress / Status
  • EUV Sensitization = Higher AGE
  • Guest/Host → Polymer-bound PAGs = Homogeneity + Reduced DL

• Ways to Improve / “Cheat” RLS
  • Underlayers / Multilayer Film Stacks = Improved Resolution + DOF
  • Ancillary Chemicals + Post-processing = Reduced LWR
  • Photoresists with Increased Absorption = Higher \( H^+ \) yields
  • Higher Quantum Efficiency PAGs = Higher AGE
  • Molecular Glass Resists = Homogeneity + Reduced pixel size

• “RLS + OR” – Can’t Forget Resist Outgassing
  • Negative-tone photoresists = Good patterning w/ lower OR?

• Recommendations / Next Step
## Intel Critical Litho Roadmap

<table>
<thead>
<tr>
<th>MPU Node</th>
<th>Potential Approaches</th>
<th>HVM Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>32 nm</td>
<td>193nm ≥ 1.2NA</td>
<td>2009</td>
</tr>
<tr>
<td>22 nm</td>
<td>193nm ≥ 1.30NA DP or “SE” w/ Low k1</td>
<td>2011</td>
</tr>
<tr>
<td>16 nm</td>
<td><strong>EUV ≥ 0.25NA</strong> or 193nm ≥ 1.30NA DP</td>
<td><strong>2013</strong></td>
</tr>
<tr>
<td>11 nm</td>
<td>EUV &gt; 0.25NA or TBD</td>
<td>2015</td>
</tr>
</tbody>
</table>

- Half Pitch Scales ~0.7x per Generation from 45 nm Node @80nm HP
- Intel will Continue to Monitor all Emerging Lithography Technologies

**EUV Readiness Requires 32 nm HP and Below**

- LWR < 10% of FCCD; $E_{size} < 10\text{mJ/cm}^2$
Mechanism for EUV Chemically Amplified

Currently :: 1 photon $\rightarrow$ $\sim$4-8 2nd e-s $\rightarrow$ $\Phi$$\sim$2-4

**Anisotropic**
- [1] Photon Absorption

**Isotropic**
- [3] PAG Activation by Thermal Electrons
- [4] Acid Diffusion / Deprotection / Quenching
- [5] Develop

Tagawa, Kozawa, Gallatin, Brainard, Fedynyshyn, etc
• RLS limitation is intrinsic to CARs \(\rightarrow\) must reduce material constant through improved design

\[\Rightarrow\] Z-factor is easy way to quantify material constant......
**Z-Factor**

\[ Z-FACTOR \, (mJ*nm^3) = (RES)^3 \times (LER)^2 \times (SEN) \]

\[ nZ_{32} = \frac{\text{Material Z-Factor}}{32 \, \text{HP Target Z-Factor}} \]

<table>
<thead>
<tr>
<th></th>
<th>CD (nm)</th>
<th>Min LWR 3s (nm)</th>
<th>ESIZE (mJ/cm^2)</th>
<th>Z-FACTOR (mJ*nm^3)</th>
<th>nZ_{32}</th>
</tr>
</thead>
<tbody>
<tr>
<td>32 HP Target</td>
<td>32</td>
<td>2.00</td>
<td>10.00</td>
<td>6.6E-09</td>
<td>1.0</td>
</tr>
<tr>
<td>Intel Q4'08 Goal</td>
<td>30</td>
<td>4.00</td>
<td>7.50</td>
<td>1.6E-08</td>
<td>2.5</td>
</tr>
</tbody>
</table>

**PRO**

- Simplified approach where limiting resolution becomes proxy for experimentally measured resist blur
- Easy to remember, quick calculation, quantifies improvement
- Plugs into existing infrastructure

**CON**

- Simplification results in exposure-tool / illumination-dependent Z-factor since NILS term is not accounted for.....

\[ Z = 3 \times 10^{-8} \]

\[ Z = 1 \times 10^{-8} \]

**Intel Benchmarking All EUV resists using Z-factor (or nZ_{32}) Moving Forward**

Intel MET :: Experimental Conditions

- $\lambda = 13.5$ nm
- 0.3 NA with 10% Area Central Obscuration
- Annular Illumination (0.36/0.55)
- Low Flare $\sim 3$ (DF) -6% (BF)
- Field Size = 200 um x 600 um
- Developer = NMD-3
- TOK 1123 E0 $\sim 5.90$ mJ/cm$^2$
  (New LBNL/NIST Dose Calibration)

2008 Performance Metrics

- > 85% Uptime
- Delivering $\sim$90 J/cm$^2$/week
  ($\sim$50 J/cm$^2$/week in 2007)

> 120 Resists Screened in ’08

- No Evidence of Measurable Reflectivity Loss in PO
  (Contamination Seen in Illuminator Optics)
## EUVL Allows Diverse Material Options

<table>
<thead>
<tr>
<th>Novolac</th>
<th>Negative Tone</th>
<th>PHS</th>
<th>Hybrid (PHS-co-Acrylate)</th>
<th>Acrylate</th>
<th>Fluorinated</th>
<th>Polymer - Bound PAG</th>
<th>Molecular Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>365+</td>
<td>248+</td>
<td>248</td>
<td>248</td>
<td>193, 193i</td>
<td>157, 193i</td>
<td>193+</td>
<td>193+</td>
</tr>
</tbody>
</table>

### Examples From Literature

- Hybrid Resin
- Acrylic Resin
- Fluoropolymer
- Polymer Bound PAG

**Focus on Improved Sensitivity and Controlling Blur**

**Academics / Vendors can Reuse Existing Core Competencies (w/ Eye on Continued Innovation)**
Resist Sensitivity Improved 30-50% via Addition of EUV Sensitizing Agents

No Loss In Resolution or Degradation in LWR

Multiple Suppliers Achieved Similar Results in 1H’08

Resist A  $nZ_{32} \sim 17.7$
S=13.8 mJ; L<5.5 nm

Resist B  $nZ_{32} \sim 6.3$
S=7.0 mJ; L<5.0 nm

Resist C = 1H’08 RLS Fast Champion

Defocus (μm) | -0.30 | -0.27 | -0.24 | -0.21 | -0.18 | -0.15 | -0.12
---|---|---|---|---|---|---|---
LWR (nm) | NA | 7.92 | 4.68 | 4.85 | 4.73 | 5.24 | 6.24

30 nm HP, 4.7 nm LWR, 10.3 mJ/cm²

nZ₃₂~3.7

Usable DOF > 0.1 μm

Fast Polymer-Bound PAG Platform with Reasonable DOF, EL, and LWR @ 30 nm HP
Leading EUV Resists = Great Progress 1H’08

Resist B
- $E_{\text{size}}(34)=7 \text{ mJ/cm}^2$
- Min LWR = 5.5 nm
- (Calc LER ~ 3.9 nm)
- $ZF=4.2E-08 \text{ mJ*nm}^3$
- $nZ_{32}=6.3$

Resist C
- $E_{\text{size}}(30)=10.8 \text{ mJ/cm}^2$
- Min LWR = 4.7 nm
- (Calc LER ~ 3.4 nm)
- $ZF=2.4E-08 \text{ mJ*nm}^3$
- $nZ_{32}=3.7$

Resist D
- $E_{\text{size}}(28)=14.3 \text{ mJ/cm}^2$
- Min LWR = 4.2 nm
- (Calc LER ~ 3.0 nm)
- $ZF=2.2E-08 \text{ mJ*nm}^3$
- $nZ_{32}=3.4$

Challenges Remain, but 32 HP Patterning is Looking Viable w/ EUVL + CAR Platforms. Focus on EUV throughput + CAR Extension to 22 HP.

UL Enhances Resist B Patterning to 30 HP

<table>
<thead>
<tr>
<th>Resist B + Underlayer A</th>
<th>Resist B + Underlayer B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Max Res = 34 HP</strong></td>
<td><strong>Max Res = 30 HP</strong></td>
</tr>
<tr>
<td>( nZ_{32} \approx 6.3 )</td>
<td>( nZ_{32} \approx 5.0 )</td>
</tr>
</tbody>
</table>

Multi-layer stacks may play a vital role in delivering RLS patterning package that can be integrated.
Rinse Agent Improves EUVL Manufacturability

<table>
<thead>
<tr>
<th>30 nm HP</th>
<th>1H’08 “Smooth” RLS Champs</th>
<th>“Fast” RLS Champion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resist D</td>
<td>Resist C</td>
<td>Resist B + Rinse Agent</td>
</tr>
<tr>
<td>Resist B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN LWR (nm)</td>
<td>3.8</td>
<td>4.3</td>
</tr>
<tr>
<td>DOSE (mJ/ cm²)</td>
<td>14.0</td>
<td>11.0</td>
</tr>
<tr>
<td>nZ₃₂</td>
<td>3.4</td>
<td>3.7</td>
</tr>
</tbody>
</table>

- Pre- and/or post-processing techniques can significantly improve roughness of high resolution / fast EUV resist.

- We are evaluating ancillary chemicals that can increase EUV throughput and provide improved patterning.

193 Lithography

- Resolution (R)
- Resist Sensitivity (S)
- LER/ LWR Roughness (L)

- 193 nm Chemically Amplified Photoresist
- High Power 193nm Lasers + Low Loss Optics

EUV Lithography

- Resolution (R)
- Resist Sensitivity (S)
- LER/ LWR Roughness (L)

- EUV Chemically Amplified Photoresist
- Pre- or Post-Processing Smoothing Techniques
• Albany ROX data scaled to HVM outgassing rate shows good progress towards meeting HVM target (7E+12).

• Underlayers + negative tone CARs tend to demonstrate lower outgassing rates than positive tone materials.

▷ Significant improvement required to simultaneously meet RLS and OR targets for 32 HP and below.
**High Performance Negative Tone (Resist F)**

<table>
<thead>
<tr>
<th>32 nm HP</th>
<th>Bright Field Patterning</th>
<th>Dark Field Patterning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Positive Tone (Resist E)</td>
<td>Negative Tone (Resist F)</td>
</tr>
<tr>
<td></td>
<td>nZ\textsubscript{32}~11.6</td>
<td>nZ\textsubscript{32}~20.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MIN LWR (nm)</th>
<th>6.5</th>
<th>8.0</th>
<th>5.0</th>
<th>6.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOSE (mJ/ cm\textsuperscript{2})</td>
<td>11.0</td>
<td>13.0</td>
<td>14.0</td>
<td>19.0</td>
</tr>
</tbody>
</table>

- **Developer = NMD-3**
- **Gap Narrowing Between Positive-\((E)\) + Negative-\((F)\) Tone**  
  (Expect better performance under BF / high flare patterning condition)
- **Resist F has Best in Class Outgassing Performance**  
  (Albany ROX = 2.5E13 mol/cm\textsuperscript{2}/sec @ 8.5 mW/cm\textsuperscript{2} for 45-200 amu – 2/4/08)

**Negative Tone Platforms Warrant Further Investigation**
Peering Around the Corner...

- Significant RLS Gains Needed for 22 nm HP+ w/ EUVL.
- 16/22 nm HP Aerial Image Capability Needed Soon to Provide Ample Time for Material Readiness

➡️ While Looking to Improve Resolution of CARs, Industry Should Also Continue to Investigate non-CARs w/ Improved Sensitivity.

4Solak, et al EUVL, Tahoe 2008
Summary

- Intel-MET and Strong Vendor/ Academic Engagements Allow for World Class EUV Resist Work from First Principles to Patterning / Integration.

- New Intel Champion = Resist B + New UL + Ancillary Rinse = 30 nm HP w/ 3.9 nm LWR, 0.20 um DOF, and \( E_{\text{size}} = 8.7 \text{ mJ/cm}^2 \). Continued characterization / optimization in progress.

- 32 nm HP+ Patterning is Looking Viable w/ EUVL + CAR Platforms ::
  1) Positive-Tone : Polymer-Bound PAGs + Ancillaries are Leading the Way...
  2) Multi-layer Stacks : Likely Required for Integrated RLS Solution....

- 22 nm HP+ Patterning Requires Improvement for RLS Solution ::
  1) High Absorption Photoresists : Models + Early Data is Very Compelling, but Material Challenges are Present...
  2) Negative-Tone : Great Start with Best in Class Outgassing...
  3) Molecular Glasses : Compelling and Maturing Rapidly for 16/ 22 HP...

- Resist Outgassing Must Remain High Priority to Meet HVM Targets.
- 16/22 nm HP Aerial Image Capability Needed Soon to Provide Ample Time for Material Readiness.
- Thin Film Effects are a Growing Concern Below 30 nm HP.
Intel EUVL Team

Terrance Bacuita
James Blackwell (LBNL MAP)
Robert Bristol
Roman Caudillo
Manish Chandhok
Kwang-woo Choi (NIST)
James Clarke
Armando Cobarrubia
Kent Frasure
Jacque Georger (ISMT)
Long He
Edward Johnson
Ted Liang
Michael Leeson (imec)
Andy Ma

Alan Myers (imec)
Kevin Orvek (ISMT)
Seh-jin Park
Bryan Rice (ISMT)
Jeanette Roberts
James Ryan
Steve Putna
Gil Vandentop
Pei-Yang Yan
Todd Younkin
Wang Yueh
Guojing Zhang
Thank You
Backup
**Film Thickness Effects (Resist G)**

50 nm HP

<table>
<thead>
<tr>
<th>FT</th>
<th>80 nm</th>
<th>60 nm</th>
<th>40 nm</th>
<th>20 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD (nm)</td>
<td>51.0</td>
<td>48.9</td>
<td>49.1</td>
<td>53.0</td>
</tr>
<tr>
<td>LWR (nm)</td>
<td>4.5</td>
<td>4.9</td>
<td>6.2</td>
<td>10.3</td>
</tr>
<tr>
<td>Dose (mJ/cm²)</td>
<td>15.5</td>
<td>13.5</td>
<td>13.5</td>
<td>12.5</td>
</tr>
<tr>
<td>NODE PC (AR=2)</td>
<td>40 HP</td>
<td>30 HP</td>
<td>20 HP</td>
<td>10 HP</td>
</tr>
</tbody>
</table>

**EUV Patterning Highly Dependent on Film Thickness**

- Resist patterning modulates as a function of film thickness
- Acceptable levels of dark loss can become a problem in thin films
- Need to understand film homogeneity / diffusion vs. thickness

ежду Growing Issue as Patterning Moves Below 30 nm HP
Molecular Glass Platform (Resist H)

- MG Achieved 28 nm HP Resolution w/ Min LWR ~ 5.8 nm

**MG Resolution Finally Compelling when Compared to Polymeric Resins**
- Need continued improvement in S/L
- Adhesion and thermal metrics need continued improvement

**Maturation of Novel Platforms May Play Key Role in Meeting 2013+ Patterning Needs**

<table>
<thead>
<tr>
<th></th>
<th>34 nm 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>CD (nm)</td>
<td>35.9</td>
<td>33.8</td>
<td>30.9</td>
<td>27.9</td>
<td></td>
</tr>
<tr>
<td>LWR (nm)</td>
<td>5.1</td>
<td>5.2</td>
<td>6.2</td>
<td>5.8</td>
<td>Pattern</td>
</tr>
<tr>
<td>S (mJ/cm²)</td>
<td>13.8</td>
<td>13.8</td>
<td>14.3</td>
<td>14.8</td>
<td>Collapse</td>
</tr>
<tr>
<td>Pattern Collapse</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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