SEMATECH EUV Resist Benchmarking Results

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SEMATECH
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Accelerating the next technology revolution.

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Outline

- Introduction
- Objective
- Methodology
- Benchmarking Data
- Effects of illumination conditions on <25nm imaging
- Summary
Introduction

- Extreme Ultraviolet Lithography (EUVL) is one of the leading candidates for next generation lithography technology for the 32 nm HP and beyond.
- The availability of EUV resists is one of the most significant challenges facing its commercialization.
- To accelerate EUV resist development, SEMATECH provides access to two exposure tools:
  - The EUV Resist Test Center (RTC) at SEMATECH at the University at Albany, SUNY, NY.
  - The SEMATECH microexposure tool (ALS-MET) at Lawrence Berkeley National Laboratory (LBNL).
- The results in this report were collected on the SEMATECH Berkeley MET.
**Objective**

- Evaluate resist samples from commercial suppliers with well-defined protocols and specification targets.
  - Provide benchmarking data package using consistent protocol to supplier for feedback and improvement.
  - Focus on Resolution, LWR and Photo speed.

<table>
<thead>
<tr>
<th>Specifications</th>
<th>2007 Goals</th>
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<tbody>
<tr>
<td>Resolution lines 1:1 (nm)</td>
<td>32</td>
</tr>
<tr>
<td>Resolution lines 1:5 (nm)</td>
<td>25</td>
</tr>
<tr>
<td>Resolution contact holes 1:1 (nm)</td>
<td>45</td>
</tr>
<tr>
<td>Resolution contact holes 1:5 (nm)</td>
<td>45</td>
</tr>
<tr>
<td>Low frequency LWR (nm, 3 σ)</td>
<td>&lt;2.5</td>
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<tr>
<td>Photospeed, EUV (mJ/cm²)</td>
<td>10</td>
</tr>
<tr>
<td>Outgassing (molecules/cm²)</td>
<td>6.5E+14</td>
</tr>
</tbody>
</table>

Assumptions: Resolution results confirmed with cross-sectional SEM. Resolution targets can be met with Y-monopole illumination. Photospeed target is for 1:1 lines. Outgassing spec is for 35-200 AMU excluding 44 AMU.
Resist Benchmarking protocol Procedure

Sample

Resist Outgassing

FD Matrix Exposure (Top down)
- EL, DOF at $E_{\text{size}}$ for 1:1 (40 & 30 nm L/S)
- LWR on 40 nm & 30 nm
- LWR vs dose (top down)

Contact (top down) - No data available at this time
- EL, DOF at E-size for 1:1 (45 nm contact CD)
- EL, DOF at E-size for 1:5 (45 nm contact CD)
- Proximity Bias

SEM cross-section Confirm profile
- Resist top loss
- EL, DOF at E size for 1:1 (40 nm L/S)
- EL, DOF at E size for 1:1 (30 nm L/S)
- Ultimate Resolution (1:1)

Data Base
Toolset used for Benchmarking at LBNL (4" wafer)

Resist outgas screening (SUNY)

Resist coat

Resist Expose

Resist Develop

SEM- Hitachi-S4800 (4")

CD/ LWR measurement (SEMCD- SuMMit)
SEMATECH-RTC

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SEMATECH MET printing station at Berkeley supports advanced resist testing with unique low-$k_1$ capabilities

Examples of lossless programmable pupil fills

From synchrotron

Scanner modules

Reticle stage

MET

Wafer stage and height sensor

Pupil-fill monitor

Patrick Naulleau
Benchmarking Data From Five Resists

- Top down SEMs of resist images
- Dose/ Focus process latitude on 40 nm HP
- CD & LWR vs Dose matrix @ 40 nm HP
- Ultimate resolution images
- SEM cross-section images

NOT SURE YOU NEED THIS SLIDE
Printing down to 24-nm achieved

- Resist D demonstrated lowest LWR.
- Resist E demonstrated best resolution
Up to 18% exposure latitude @ 40nm HP

<table>
<thead>
<tr>
<th>Resist A</th>
<th>Resist B</th>
<th>Resist C</th>
<th>Resist D</th>
<th>Resist E</th>
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<tbody>
<tr>
<td>Y-Mono</td>
<td>Y-Mono</td>
<td>Rot-Dipole</td>
<td>Rot-Dipole</td>
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<td>Best Focus</td>
<td>Best Focus</td>
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<td>Dose</td>
<td>CD/LWR</td>
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<td>46.8/9.2</td>
<td>43.4/8.7</td>
<td>42.0/7.6</td>
<td>39.3/6.9</td>
<td>36.5/7.2</td>
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<tr>
<td>44.2/6.2</td>
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<td>44.8/5.6</td>
<td>41.4/5.2</td>
<td>37.3/5.0</td>
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<td>16mj</td>
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<td>40.5/4.9</td>
<td>36.2/3.7</td>
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<td>40.1/5.6</td>
<td>39.2/5.0</td>
<td>35.7/4.9</td>
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Up to 250-nm focus latitude at 40nm HP

<table>
<thead>
<tr>
<th>Resist A</th>
<th>BF - 100 nm</th>
<th>BF - 50 nm</th>
<th>Best Focus</th>
<th>BF + 50 nm</th>
<th>BF + 100 nm</th>
<th>BF + 150 nm</th>
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<tbody>
<tr>
<td>Y-Mono</td>
<td>38.4/9.2</td>
<td>38.2/8.3</td>
<td>39.3/6.9</td>
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<td>38.2/5.3</td>
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<th>Resist B</th>
<th>BF - 100 nm</th>
<th>BF - 50 nm</th>
<th>Best Focus</th>
<th>BF + 50 nm</th>
<th>BF + 100 nm</th>
<th>BF + 150 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-Mono</td>
<td>37.7/9.2</td>
<td>37.9/8.1</td>
<td>42.0/5.3</td>
<td>40.3/4.3</td>
<td>40.1/4.0</td>
<td>42.6/11.0</td>
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</table>

<table>
<thead>
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<th>Resist C</th>
<th>BF - 100 nm</th>
<th>BF - 50 nm</th>
<th>Best Focus</th>
<th>BF + 50 nm</th>
<th>BF + 100 nm</th>
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<tbody>
<tr>
<td>Rot-Dipole</td>
<td>41.2/5.0</td>
<td>40.5/4.9</td>
<td>40.5/4.9</td>
<td>41.3/5.5</td>
<td>44.9/10.6</td>
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<table>
<thead>
<tr>
<th>Resist D</th>
<th>BF - 100 nm</th>
<th>BF - 50 nm</th>
<th>Best Focus</th>
<th>BF + 50 nm</th>
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<table>
<thead>
<tr>
<th>Resist E</th>
<th>BF - 100 nm</th>
<th>BF - 50 nm</th>
<th>Best Focus</th>
<th>BF + 50 nm</th>
<th>BF + 100 nm</th>
<th>BF + 150 nm</th>
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</thead>
<tbody>
<tr>
<td>Rot-Dipole</td>
<td>43.4/6.8</td>
<td>41.5/6.6</td>
<td>40.9/7.1</td>
<td>41.3/7.3</td>
<td>43.1/8.4</td>
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</tbody>
</table>

- Resist A and B demonstrated 250nm of DOF on 40 nm HP
CD & LWR vs Dose matrix @ 40nm HP

- Resist A demonstrated 18% of EL and 250nm of DOF @ 40nm HP

MAYBE DROP THIS SLIDE
Ultimate Resolution Images

Resist A
Y-Monopole
30nm HP
30.4 nm

Resist B
Y-monopole
30nm HP
30.2 nm

Resist C
Rot-Dipole
28nm HP
28.6nm

Resist D
Rot-Dipole
30nm HP
30.8 nm

Resist E
Rot-Dipole
24nm HP
21.7 nm

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### Summary of Dose/Focus process latitude at 40nm HP

<table>
<thead>
<tr>
<th>Resist Name</th>
<th>Resist THK (nm)</th>
<th>Illumination</th>
<th>Mask</th>
<th>Esize (mJ/cm²)</th>
<th>Exposure Latitude (%)</th>
<th>DoF (nm)</th>
<th>Ultimate Imaging (CD/LWR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resist A</td>
<td>80</td>
<td>Offset Y-monopole</td>
<td>A Vertical Cleave</td>
<td>23.2</td>
<td>18</td>
<td>250</td>
<td>30.4/8.3</td>
</tr>
<tr>
<td>Resist B</td>
<td>50</td>
<td>Offset Y-monopole</td>
<td>A Vertical Cleave</td>
<td>23.9</td>
<td>10</td>
<td>250</td>
<td>30.2/8.5</td>
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<tr>
<td>Resist C</td>
<td>70</td>
<td>Rot-Dipole</td>
<td>B Horizontal Cleave</td>
<td>19.0</td>
<td>10</td>
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<td>28.6/8.0</td>
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<tr>
<td>Resist D</td>
<td>80</td>
<td>Rot-Dipole</td>
<td>B Horizontal Cleave</td>
<td>25.7</td>
<td>10</td>
<td>150</td>
<td>30.8/4.7</td>
</tr>
<tr>
<td>Resist E</td>
<td>50</td>
<td>Rot-Dipole</td>
<td>B Horizontal Cleave</td>
<td>17.0</td>
<td>15</td>
<td>150</td>
<td>21.7/14.3</td>
</tr>
</tbody>
</table>

- Resist A had largest process latitude EL (18%) and DOF (250nm)
- Resist E has best photospeed (17.0 mJ/cm²)
- Resist C has the lowest LWR at 40nm HP (4.8 nm)
- Resist E demonstrated best resolution
Exposure Latitude at 30nm HP

- Resist E demonstrated 10% EL @ 30nm HP.
- Resist A, B, and C have 2.5% EL @ 30nm HP.
Focus Latitude at 30nm HP (1:1)

- Resist E demonstrated 150nm of DOF.
- Resist C had 50nm of DOF.
SEM Cross-section Images

- All resists demonstrated 35 nm resolution and printing capabilities below 30nm
Different Illumination Conditions vs images

- Rot-Dipole illumination has better image modulation than Annular and Y-monopole illumination.
Rotated dipole on the Berkeley MET predicted to provide enhanced performance for CDs below 26 nm

At 22 nm, rotated dipole improves contrast from 51% to 75%

Note: Prolith Aerial image modeling includes full measured wavefront data and assumes ideal thin mask
Conclusion

- Total of 21 resist have been benchmarked since May 2007, the benchmarking results are being furnished to suppliers.
  - Demonstrate printing capability down to ~22 nm.
  - Demonstrate 10.0% of EL & 150 nm of DOF at 30 nm HP.
  - Thinner resist (50nm) and rotated dipole illumination are important factors to increase imaging capability.
- LWR and photospeed are still the most critical challenges for 32 nm node.
- The current benchmarked resist process window is not sufficiently to support 32nm pilot line. (please review backup slides)
- The best performing resist:
  - Resist A has the largest process latitude with 18% of EL and 250nm of DOF @ 40nm HP.
  - Resist D has lowest LWR of 4.7 nm at 30 nm HP
  - Resist E has fast photospeed of 17mJ/cm² with 10% of EL and 150nm of DOF @ 30 nm HP.
  - Resist E demonstrate ~22nm of printing images capability with rot-dipole illumination.
Acknowledgement:

SEMATECH: Matt Malloy, Khurshid Anwar, Cecilia Montgomery for processing support.

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