Characterization of advanced EUV resists using the Berkeley MET tool

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Special Thanks
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AMD
Outline

• Capabilities of the Berkeley MET tool
• Demonstration of resist-limited performance
• Constraints on resist development
• Metrics for intrinsic resolution
• Champion resist results from the Berkeley MET tool
• Summary
• Based on MET optic
• Magnification = 5x, NA = 0.3
• Rayleigh resolution = 27 nm
• Field size = 200x600 µm
• Programmable coherence illuminator for low $k_1$
• Reticle and wafer load-lock systems
• nm-resolution wafer-height sensor and focus actuation
• Pupil-fill monitor
Berkeley MET modeled to have good DOF down to 25 nm with annular illumination

Predicted aerial-image DOF:
- +/-10% CD control
- 10% Total EL contrast > 45%
- ILS > 20

Bossungs based on 10% dose increments
Programmable coherence capabilities enable ultra-high resolution printing

- **Prolith** modeling results including EUV-measured wavefront.
Even with best EUV resists, resolution limit determined by resist not aerial image.

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Predicted aerial-image contrast

KRS resist provided by Carl Larson and Greg Wallraff, IBM.

LBNL-MET, annular

Even with best EUV resists, resolution limit determined by resist not aerial image.
Status in late 2005 showed a resolution limit in EUV CAR of ~32 nm.
Dose limitations places severe restrictions on levers available for improved resolution.

- **32nm hp, 22.7mJ/cm²**
- **32nm hp, 46.3mJ/cm²**
- **32nm hp, 71.6mJ/cm²**
- **32nm hp, 79.1mJ/cm²**
- **28nm hp, 22.7mJ/cm²**
- **28nm hp, 46.3mJ/cm²**
- **28nm hp, 71.6mJ/cm²**
- **28nm hp, 79.1mJ/cm²**
- **24nm hp, 79.1mJ/cm²**

Materials and data courtesy of Roger Nassar, RHEM

**LBNL-MET**

**Y-Monopole**

Patrick Naulleau

Opening Workshop of SANKEN US Branch, 12/15/06
Ultrathin film effects limit the effectiveness of thickness reduction for improved resolution

- Top-loss and LER become worse with decreasing thickness
- Film dominated by interface effects
- Is it possible to mitigate these effects with BARC and/or topcoat?

Data courtesy of Tom Wallow, AMD

XP6305-G resist, LBNL-MET, Y-Monopole
PEB reduction improves exposure latitude, but at the cost of reduced sensitivity

XP6305-A resist, LBNL-MET, Y-Monopole

Data courtesy of Tom Wallow, AMD
PEB reduction gains quickly saturate

Data courtesy of Tom Wallow, AMD
What is the best metric for characterizing intrinsic resolution?

KRS | MET 1K | Supplier C
---|---|---
35-nm | | 
30-nm | | Severe collapse

LBNL-MET, Y-Monopole
Resist based MTF measurements provide insight into resist and system properties.

- MTF = pitch-dependent contrast
- Contrast determined from:
  - $D_{\text{max}}$, the dose at which resist lines first begin to clear
  - $D_{\text{min}}$, the dose at which resist lines disappear

\[
\text{Contrast} = \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}} = \frac{D_{\text{max}} - D_{\text{min}}}{D_{\text{max}} + D_{\text{min}}}
\]
Resist performance has strong impact on measured contrast
Modeling Resist Using Simple Point-Spread-Function (PSF) Method

- PSF resist modeling* is fast and convenient
- Model easily generated
- Provides intuitive link to resist resolution limit
- Few parameters makes model less susceptible to extrapolation errors
- Resist process well approximated by deprotection function**

Extracting the deprotection blur from MTF data

**Graph 1:**
- Aerial Image
- Blurred

**Graph 2:**
- Aerial Image
- MET 1K
- Blurred

### Table: Res. Blur (nm)
<table>
<thead>
<tr>
<th>Resist</th>
<th>Res. (nm)</th>
<th>Blur (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUV 2D</td>
<td>50</td>
<td>45</td>
</tr>
<tr>
<td>Supplier A</td>
<td>35</td>
<td>24</td>
</tr>
<tr>
<td>KRS</td>
<td>32.5</td>
<td>14</td>
</tr>
<tr>
<td>MET 1K</td>
<td>35</td>
<td>21</td>
</tr>
<tr>
<td>Supplier C</td>
<td>35</td>
<td>22</td>
</tr>
</tbody>
</table>
LER roll-off as a resolution metric

LER roll-off (correlation length) is NOT a good indicator of resolution

<table>
<thead>
<tr>
<th>Resist</th>
<th>Res. (nm)</th>
<th>$L_c$ (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUV 2D</td>
<td>50</td>
<td>24</td>
</tr>
<tr>
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<td>35</td>
<td>20</td>
</tr>
<tr>
<td>KRS</td>
<td>32.5</td>
<td>18</td>
</tr>
<tr>
<td>MET 1K</td>
<td>35</td>
<td>22</td>
</tr>
<tr>
<td>Supplier C</td>
<td>35</td>
<td>28</td>
</tr>
<tr>
<td>Supplier E</td>
<td>35</td>
<td>26</td>
</tr>
<tr>
<td>Supplier F</td>
<td>30</td>
<td>25</td>
</tr>
</tbody>
</table>
Comparing MTF and Correlation Length Metrics for Process Studies

Raw data courtesy of Tom Wallow, AMD

<table>
<thead>
<tr>
<th>PEB</th>
<th>Blur (nm)</th>
<th>$L_c$ (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90° C</td>
<td>22</td>
<td>20.7</td>
</tr>
<tr>
<td>100° C</td>
<td>29</td>
<td>23.8</td>
</tr>
<tr>
<td>110° C</td>
<td>32</td>
<td>22.6</td>
</tr>
</tbody>
</table>
Corner Rounding as a Resolution Metric

- Use fine-corner detail in large feature to determine resolution limit

Modeling data provided by Ryoung-han Kim, AMD
## Performance of the Corner Rounding Metric

<table>
<thead>
<tr>
<th>Resist</th>
<th>Res.(nm)</th>
<th>Corner Radius (nm)</th>
<th>Blur* (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUV 2D</td>
<td>50</td>
<td>87</td>
<td></td>
</tr>
<tr>
<td>MET 1K</td>
<td>35</td>
<td>56</td>
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</tr>
<tr>
<td>Supplier E</td>
<td>35</td>
<td>60</td>
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</tr>
<tr>
<td>Supplier F</td>
<td>30</td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>

Corner-rounding appears to be a good predictor of resolution.
Corner-Rounding Analysis Showed Supplier F to be Best Sample: Printing Results

Coded 45-nm:90-nm
Actual  38-nm:90-nm
LER 3.0 nm: L = 403 nm

Dose to size (50-nm 1:1) = 19 mJ/cm²

Coded 40-nm:80-nm
Actual  33-nm:80-nm
LER 3.1 nm: L = 403 nm

Coded 35-nm:70-nm
Actual  27-nm:70-nm
LER 3.0 nm: L = 366 nm

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More Supplier F Printing Results

Coded 32.5-nm:65-nm
Actual 28-nm:70-nm
LER 4.4 nm: L = 407 nm

Coded 30-nm:60-nm
Actual 24-nm:60-nm
LER 4.0 nm: L = 350 nm

Coded 30-nm:60-nm
Actual 21-nm:60-nm
LER 4.0 nm: L = 350 nm

Coded 22.5-nm:67.5-nm
Actual 22.7-nm:67.5-nm
LER 4.0 nm: L = 512 nm

LBNL-MET
Y-Monopole
EUV Resist LER & Sensitivity

LER versus Sensitivity for selection of known EUV resists

Status: Line Edge Roughness (HVM Spec): < 1.6 nm
Line Edge Roughness (Best Current): 2.5 nm
Summary

• The SEMATECH MET facility at Lawrence Berkeley National Lab provides ultrahigh resolution capabilities from a conventional projection EUV system

• EUV resolution is currently resist limited

• High sensitivity requirements places stringent constraints on resist resolution improvements

• Interface effects may require the use of more complex film stacks

• MTF and corner-rounding provide good metrics for intrinsic resolution

• A new resist outperforming KRS has been identified
  • 30-nm dense, 22.5-nm semi-isolated
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Tom Wallow

AMD

Kim Dean

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