OPC flare and optical modeling requirements for EUV

Lena Zavyalova, Kevin Lucas, Brian Ward*, Peter Brooker

Synopsys, Inc., Austin, TX, USA 78746
*Synopsys assignee to IMEC, Leuven, Belgium B3001
Abstract

It is now widely considered a requirement that EUV production mask flows will need to employ optical and process proximity correction (OPC). OPC will be required in order to compensate for: very long range and substantial percentage layout dependent flare effects; imaging effects due to non-telecentric imaging optics; mask 3D effects caused by the large mask absorber topography relative to the illumination wavelength; complex resist behavior effects; and across-field changes in wafer pattern due to the azimuthal angle of the optical axis changing across the field. In this study we investigate OPC requirements for the 22nm logic node assuming an EUV patterning strategy. We present accuracy vs. runtime analysis results for OPC modeling requirements of EUV optical systems where we show the comparison of OPC model fit to rigorous EUV traditional lithography simulation results.

Keywords: EUV modeling, EUV OPC, 22nm logic
Motivation

• Determine impact of realistic EUV optics & masks on 22nm and 16nm node patterns
• Understand requirements for mask compensation of EUV optical effects on 22nm and 16nm node patterns
  – Mask write
  – Modeling
  – Correction software
Through-pitch optical proximity effect

**Line width CD thru pitch**

**SentaurusLitho (EUV)**

- Kirchhoff (multi-layer) mask approximation
- Aerial image CD

### Convergence between ProGen and S-Litho EUV

<table>
<thead>
<tr>
<th>Threshold-to-Size:</th>
<th>Anchor</th>
<th>S-Litho</th>
<th>ProGen</th>
<th>% diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>25nm 1:1</td>
<td>0.261229</td>
<td>0.260155</td>
<td>-0.41%</td>
<td></td>
</tr>
<tr>
<td>35nm 1:1</td>
<td>0.250489</td>
<td>0.249077</td>
<td>-0.56%</td>
<td></td>
</tr>
<tr>
<td>45nm 1:1</td>
<td>0.225474</td>
<td>0.225093</td>
<td>-0.17%</td>
<td></td>
</tr>
</tbody>
</table>
# Model-based correction

## EUV OPC calibration testpattern
- Different 1d & 2d type structures
- Pitch, line width and gap are varied
- min cd=25nm, max cd=200nm
- min space / gap=25nm

<table>
<thead>
<tr>
<th>Pattern Group</th>
<th>Correction amount (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N Mean</td>
</tr>
<tr>
<td>Corner Splitting</td>
<td>93.0</td>
</tr>
<tr>
<td>H Shape</td>
<td>184.0</td>
</tr>
<tr>
<td>Post Array</td>
<td>108.0</td>
</tr>
<tr>
<td>Line End</td>
<td>52.0</td>
</tr>
<tr>
<td>L-E Asym</td>
<td>164.0</td>
</tr>
<tr>
<td>L-E In Bars</td>
<td>52.0</td>
</tr>
<tr>
<td>Line Block</td>
<td>399.0</td>
</tr>
<tr>
<td>Line Space</td>
<td>223.0</td>
</tr>
<tr>
<td>Space Line</td>
<td>223.0</td>
</tr>
<tr>
<td>Total</td>
<td>1498.0</td>
</tr>
</tbody>
</table>

- Build OPC model
- Apply OPC
- Verify CD, check proximity effects (iso-dense bias, line-end pullback)
OPC model description

- **Model ambit** – region of influence of proximity effect (aka optical radius or sample area extent)
- **Optical kernels** in model – number of terms in the TCC for system description
- Success criteria
  - 0.2nm RMSE → 22nm node (35nm hp)
  - 0.15nm RMSE → 16nm node (25nm hp)
- RMSE vs. #kernels by node
  - little change in fit RMSE with larger ambit
- Min requirement
  - 5 retained kernels
  - 0.3um ambit
Mask topography effect

\[ NA = 0.25, \ \sigma = 0.5, \ \varphi = 6^\circ, \ \lambda = 13.4 \text{ nm} \]

Reflected field amplitude
Rigorous 3D mask simulation (S-Litho EUV)

Stack simulation conditions
\( Ta_6N_4 \) absorber 70nm (~ 5\( \lambda \))
ML stack: 40 Mo/Si pairs, \( \Gamma = 0.725 \)
Quartz substrate

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Shadowing effect

- Shadowing for "horizontal" x-parallel lines
  - H-V bias
  - Pattern shift (~5nm @bf)
- Effect varies across lens slit
  \( \theta \approx 66^\circ - 90^\circ - 114^\circ \)

Shadowing effect across lens slit

CD change as a function of azimuthal illumination angle $\theta$

<table>
<thead>
<tr>
<th>Feature type</th>
<th>Orientation</th>
<th>Nominal CD, nm</th>
<th>Incident angle $\theta$</th>
<th>Meas CD, nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>dense</td>
<td>vertical</td>
<td>35</td>
<td>90°</td>
<td>35.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>66°, 114°</td>
<td>35.58</td>
</tr>
<tr>
<td></td>
<td>horizontal</td>
<td>35</td>
<td>90°</td>
<td>36.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>66°, 114°</td>
<td>36.62</td>
</tr>
<tr>
<td>iso</td>
<td>vertical</td>
<td>35</td>
<td>90°</td>
<td>40.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>66°, 114°</td>
<td>40.26</td>
</tr>
<tr>
<td></td>
<td>horizontal</td>
<td>35</td>
<td>90°</td>
<td>42.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>66°, 114°</td>
<td>41.76</td>
</tr>
</tbody>
</table>

- H-V bias @90° (center of slit) is:
  - 1.9 nm for dense line/space
  - 2.1 nm for isolated lines

- H-V bias @90±24° (edge of slit) is:
  - 1 nm for dense line/space
  - 1.5 nm for isolated lines
Full 3D vs. Kirchhoff mask: comparison through pitch

- 35nm line/space
  - 0.7 nm mean difference
  - 1.0 nm mean difference

- 25nm line/space
  - 0.1 nm mean difference
  - 0.7 nm max difference
CD sensitivity to flare

- 0 – 16% (absolute) flare
- 35nm and 25nm CD, 1:1 dense and iso
- \( \frac{dCD}{dF} \approx 0.5 – 0.7 \text{ nm/\%} \)


\[ I_F(x, y) = I_0(x, y) \times (1 - F) + F \times \left\langle T \right\rangle \]
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I_F(x, y) = I_0(x, y) \times (1 - F) + F \times \langle T \rangle
\]

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Summary

• EUV “optical” proximity effects considerable at 22 & 16nm nodes
• OPC simulators provide very high optics accuracy with few numerical terms
• 3D effects across-field are moderate and can be accurately compensated for with rules
• Flare has only minor dependence upon pitch and feature CD
  • models needed to calculate and correct
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