Comparative Stochastic Process Variation Bands for N7 (N5, N3) at EUV

KLA-Tencor: Alessandro Vaglio Pret, Trey Graves, David Blankenship, Kunlun Bai, Stewart Robertson, John J. Biafore
IMEC: Peter De Bisschop

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Outline

• Simulations: 2D SRAM-like structures
  • N7
    • N5 & Multiple-resist platforms
    • N3 & Multiple-patterning approaches

• Conclusions
Material performance comparison: DOE setup

- Analysis performed on 550k simulated SRAM-like cells
  N7: simulations performed with NA=0.33, Organic CAR
  - Fixed (best) dose&focus
  - “Real case”
Structure and metrology definition

• SRAM-like N7 cell:
  • X pitch: 42nm - CD X = Target CD = 21nm
  • Gap CD Y = 25nm
• N5 cell: @ SPIE
• N3 cell: @ SPIE

Metrology planes: 26 CDs
  ▪ 10 Lines (averaging length = Target CD)
  ▪ 8 Spaces (averaging length = Target CD)
  ▪ 8 Gaps (averaging length = 3 nm)

Optical (non-stochastic) source optimization performed for each node, across ± 60nm DoF

No OPC applied
N7, organic CAR, fixed dose/focus

<table>
<thead>
<tr>
<th>Develop tone</th>
<th>PTD</th>
</tr>
</thead>
<tbody>
<tr>
<td># features (L, S, Gaps)</td>
<td>14.3M (26 x 550K)</td>
</tr>
<tr>
<td>Dose, mJ/cm²</td>
<td>45</td>
</tr>
<tr>
<td>Pitch, nm</td>
<td>42</td>
</tr>
<tr>
<td>Target L CD, nm</td>
<td>21</td>
</tr>
<tr>
<td>Illumination type</td>
<td>Dipole</td>
</tr>
<tr>
<td>AI &lt;NILS&gt;</td>
<td>2.54</td>
</tr>
<tr>
<td>Gap &lt;CD&gt;, nm</td>
<td>29.4</td>
</tr>
<tr>
<td>&lt;1σ LCDU&gt;, nm</td>
<td>1.00</td>
</tr>
<tr>
<td>fails, PPM</td>
<td>3-4</td>
</tr>
<tr>
<td>&lt;1σ P. E.&gt;, nm</td>
<td>0.40</td>
</tr>
<tr>
<td>&lt;n_ph&gt;/nm³</td>
<td>0.058</td>
</tr>
<tr>
<td>&lt;n_ph&gt;/Gap ± &lt;1σ&gt;</td>
<td>1696 ± 148</td>
</tr>
</tbody>
</table>
As more contours from randomized trials are added, the stochastic bandwidth grows, representing the spatial range of the edge placement.

Probability Plot explanation

Yellow = 0 means that we have always found photoresist.

All the others represent stochastic variation of the contour placement.

Example:
This light-blue~4
We should expect to find resist (not necessarily \( \mu \)-bridging!) 1 occurrence every 10,000.

Blue < -5.74036 means that we have never found photoresist.

Only at 4\( \sigma \) a “systematic” pinch between line tips appears.
N7 stochastic PW comparison
Each focus/dose condition is averaged on ~2000 trials (~550K total simulations). No perturbations applied

PW limited by CD only

PW limited by CD & failures

DoF = 190 nm @ 5% EL
Max EL = 12.2%
Max DoF = 190 nm

DoF = 120 nm @ 5% EL
Max EL = 11.7%
Max DoF = 120 nm
N7, organic CAR, “real case”

• “Real cases” are performed with uniformly-distributed perturbations to key parameters
  • Chief Ray Azimuthal Angle: -88.6/-91.4 → corresponding to 1/13\textsuperscript{th} of the slit length
  • Exposure Dose: 45 mJ/cm\textsuperscript{2} ± 0.25%
  • Focus Range: 0 nm ± 15 nm
  • Resist Thickness: ± 0.3 nm
  • PEB Temperature: ± 0.02° (Temperature-dependent stochastic resist model)
  • Mask CD Bias X & Y : ± 0.3 nm (wafer scale)
N7, organic CAR, “real case”

PROLITH captures divergence from normal behavior in both over and underexposure. Gap CD distribution exhibits a strong non-normal behavior; nevertheless no failures are reported.
Main difference is noticeable only in the $4\sigma$ range (light blue). The devil resides in the “black swan” details.
Conclusions

• We performed 550,000 stochastic 3D PROLITH™ simulations of 2D SRAM-like cells for each node-material combination

• ~5 million unique simulations completed in this experiment, collecting over 100 million CDs

• PROLITH can be used to study:
  • Complex effects in EUV lithography
  • Printing fidelity
  • Feature variability
  • Failure rates
  • Location of stochastic defects and repair strategies

• LCDU and failure rates are only loosely related for non-Gaussian distributions: any fail rate extrapolation from limited samples is hazardous at the best.
SPIE extra slides
N5, fixed dose/focus

### Organic CAR

- Develop tone: PTD
  - Dose, mJ/cm²: 35
  - $<1\sigma$ LCDU, nm: 1.08
  - fails, PPM: > 100
  - $<1\sigma$ P.E., nm: 0.43
  - $<n_{ph}>$/nm³: 0.049
  - $<n_{ph}>$/Gap $+ <1\sigma>$: 1301 ± 111

### Fast Organic CAR

- Develop tone: PTD
  - Dose, mJ/cm²: 17
  - $<1\sigma$ LCDU, nm: 1.52
  - fails, PPM: > 3000
  - $<1\sigma$ P.E., nm: 0.56
  - $<n_{ph}>$/nm³: 0.024
  - $<n_{ph}>$/Gap $+ <1\sigma>$: 624 ± 54

### Metal Oxide

- Develop tone: NTD
  - Dose, mJ/cm²: 53
  - $<1\sigma$ LCDU, nm: 0.897
  - fails, PPM: ~ 1
  - $<1\sigma$ P.E., nm: 0.36
  - $<n_{ph}>$/nm³: 0.11
  - $<n_{ph}>$/Gap $+ <1\sigma>$: 2938 ± 218
**N3, organic CAR, fixed dose/focus**

**NA = 0.33**

- Dose, mJ/cm²: 39
- Illumination type: Dipole
- AI <NILS>: 1.97
- Gap <CD>, nm: 20.8
- <1σ LCDU>, nm: 1.44
- fails, PPM: ~ 126K
- <1σ P. E.>, nm: 0.54
- <n_ph>/nm³: 0.044
- <n_ph>/Gap ± 1σ: 1032 ± 135

**NA = 0.33 Double Patterning**

- Dose, mJ/cm²: 34 per pass
- Illumination type: Large Dipole
- AI <NILS>: 2.19
- Gap <CD>, nm: 20.9
- <1σ LCDU>, nm: 2.14
- fails, PPM: ~ 700
- <1σ P. E.>, nm: 0.71
- <n_ph>/nm³: 0.063
- <n_ph>/Gap ± 1σ: 1468 ± 443

**NA = 0.55 Anamorphic**

- Dose, mJ/cm²: 41
- Illumination type: C-quad
- AI <NILS>: 2.67
- Gap <CD>, nm: 25.4
- <1σ LCDU>, nm: 0.89
- fails, PPM: 1-2
- <1σ P. E.>, nm: 0.33
- <n_ph>/nm³: 0.061
- <n_ph>/Gap ± 1σ: 1422 ± 72

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West Australian black swan