A Comparison of Positive- and Negative-tone Contact Hole Process Flows Using the IMEC NXE:3100

Todd R. Younkin, Gustaf Winroth, & Roel Gronheid

Oct. 4, 2012
Outline

- **Introduction & Motivation**
  - Why NTD Resists for EUVL?
  - Graphoepitaxial Directed Self Assembly (DSA) for C/H Shrink Using a Blended Material
  - Process Flows We Are Comparing
    - 193i NTD + DSA Shrink Results at IMEC

- **NTD Resist Performance on the IMEC NXE3100**: Recent Progress to 30P60.

- **DSA Blended Shrink for NTD**: ~10-35% Improvement vs. NTD Alone.

- **Best Results To Date**: PTD Still the Champion, but Alternatives Quickly Maturing.

- **Conclusions & Next Steps**
  - Acknowledgements
  - Personal Recommendation for Best Belgian Chocolate
Outline

- Introduction & Motivation
  - NTD Resist Performance on the IMEC NXE3100
  - DSA Blended Shrink for NTD
  - Best Results To Date
  - Conclusions & Next Steps
Over-exposing dots improves NILS in ArF, resulting in improved LCDU.

Can we over-expose dots in EUV to increase NILS? YES.

- Potential benefit: Use more photons/hole; Improves shot noise.
- Absolute flare will be higher; But flare variation should decrease.
- Optimization yields material sets which are complementary to latest 193i NTD layers and are beneficial to several DSA flows.

R. Gronheid et al. SPIE 2012, 83220M
EUVL graphoepitaxy flow requires solvent-compatible pre-pattern. Primary path is an NTD EUVL resist with the appropriate thermal and chemical performance.
In parallel to the EUV work presented here, we are using a 193i NTD process to fabricate an IMEC electrical test vehicle for the direct comparison of standard patterning processes to variants which employ DSA.

Results from our 193i NTD + DSA blended shrink flow (55% integrated shrink) are illustrated above.

- Can we extend similar integration schemes to NXE-patterned wafers?
- If so, can we improve EUVL resolution, CDU, and / or wafer throughput?

<table>
<thead>
<tr>
<th>Image (Top-Down @ 200k)</th>
<th>Litho</th>
<th>+DSA Blend</th>
<th>Hardmask Etch</th>
<th>Dielectric Etch</th>
<th>XSEM Following Dielectric Etch</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD (nm)</td>
<td>~ 55</td>
<td>~ 35 (~36% ↓)</td>
<td>~ 35</td>
<td>~ 35</td>
<td>~ 25 (~55% ↓)</td>
</tr>
</tbody>
</table>

Lithography = ASML 1950i, NTD Resist + Develop
DSA = Blended Shrink, Anneal + Develop
Outline

• Introduction & Motivation
  ➢ NTD Resist Performance on the IMEC NXE3100
• DSA Blended Shrink for NTD
• Best Results To Date
• Conclusions & Next Steps
As material performance improves, we want to be cognizant of how the new material sets compare to positive-tone EUVL champion materials.

- In Feb’12, we expected further improvements via a combination of new material design as well as process improvements.

- NILS is meeting initial expectations. Further mask / modeling studies are required to refine our understanding.
**IMEC NXE Latest NTD Optimization**

<table>
<thead>
<tr>
<th>Resist</th>
<th>Gen-3</th>
<th>Gen-4</th>
<th>Gen-4</th>
<th>Gen-3</th>
<th>Gen-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAB/PEB</td>
<td>130/100</td>
<td>130/100</td>
<td>130/120</td>
<td>130/100</td>
<td>130/100</td>
</tr>
<tr>
<td>NTD Developer</td>
<td>Developer-1</td>
<td>Developer-2</td>
<td>Developer-2</td>
<td>Developer-1</td>
<td>Developer-2</td>
</tr>
<tr>
<td>NXE Illumination</td>
<td>Conventional</td>
<td>Conventional</td>
<td>Conventional</td>
<td>Quasar</td>
<td>Quasar</td>
</tr>
</tbody>
</table>

- **Image** *(Top-Down @ 230k)*

| Esize (mJ/cm²) | 17.0 | 20.8 | 10.8 | 15.8 | 20.8 |
| CD (nm) | 27.6 | 30.3 | 29.4 | 30.7 | 27.2 |
| 3 Sigma (nm) | 4.9* | 6.1 | 7.6* | 5.3* | 3.2 |

- **Gen-4 platform showing reduced occurrence of missing contact holes.**
- **Best NTD Performance To Date Comes From Gen-4 Resist, Developer-2, & Quasar Illumination.**

*Missing holes observed*
Noteworthy Improvement Across Supplier Base

• Seeing good improvement in a relatively short period of time.

> While NTD is not yet on par with PTD, it is starting to become competitive.
Outline

• Introduction & Motivation
• NTD Resist Performance on the IMEC NXE3100
  ➢ DSA Blended Shrink for NTD
• Best Results To Date
• Conclusions & Next Steps
Use DSA Shrink As E-size Enhancement?

- Rev0 proof of concept demonstrated.
  - Possible throughput gain (~35% vs. NTD scheme).

Gen-3 NTD
CD = 39.9 nm
CDU = 2.2 nm

Gen-3 NTD + Shrink-A
CD = 35.6 nm
CDU = 2.2 nm

Rev0 proof of concept demonstrated.

- Possible throughput gain (~35% vs. NTD scheme).

48P80 → 40hp
## DSA Shrink Behavior Through Dose / CD

<table>
<thead>
<tr>
<th>Dose</th>
<th>11.5</th>
<th>15.0</th>
<th>17.5</th>
<th>20.0</th>
<th>23.0</th>
<th>24.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD</td>
<td>66.6</td>
<td>56.6</td>
<td>50.9</td>
<td>44.1</td>
<td>39.9</td>
<td>37.3</td>
</tr>
<tr>
<td>3Sig</td>
<td>3.98</td>
<td>3.53</td>
<td>2.94</td>
<td>2.52</td>
<td>2.21</td>
<td>2.04</td>
</tr>
<tr>
<td>+ DSA Blend and Dev</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD</td>
<td>42.6</td>
<td>35.6</td>
<td>30.9</td>
<td>27.5</td>
<td>25.0</td>
<td>ND</td>
</tr>
<tr>
<td>3Sig</td>
<td>ND</td>
<td>2.23</td>
<td>1.70</td>
<td>1.26</td>
<td>0.94</td>
<td>ND</td>
</tr>
<tr>
<td>CD δ (nm)</td>
<td>24.0</td>
<td>21.0</td>
<td>20.0</td>
<td>16.6</td>
<td>14.9</td>
<td>ND</td>
</tr>
<tr>
<td>CD δ (%)</td>
<td>36%</td>
<td>37%</td>
<td>39%</td>
<td>38%</td>
<td>37%</td>
<td>ND</td>
</tr>
<tr>
<td>3s δ (nm)</td>
<td>ND</td>
<td>1.3</td>
<td>1.2</td>
<td>1.3</td>
<td>1.3</td>
<td>ND</td>
</tr>
<tr>
<td>3s δ (%)</td>
<td>ND</td>
<td>37%</td>
<td>42%</td>
<td>50%</td>
<td>57%</td>
<td>ND</td>
</tr>
</tbody>
</table>

- DSA blended agent requires closed pre-pattern and saturates ~ 25-30 nm.

- May be used (instead) as CDU enhancement? Metrology / understanding = I/P

48P80 → 40hp Gen-3 Resist Shrink A
Performance of DSA Shrink vs. Mask Bias

27 hp Conv. = Not Yet Resolved

- Today, target features are 34P60 – 38P60 by conventional or quasar illumination.
- Continued optimization will likely yield 27 hp resolution with Esize < 20 mJ/cm²
  ➢ Ideal bias for NTD and NTD+DSA process is ~13 - 30 %
Key Parameter = DSA Shrink Agent FT

<table>
<thead>
<tr>
<th>NTD Resist</th>
<th>Gen-3</th>
<th>Gen-3</th>
<th>Gen-3</th>
<th>Gen-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrink</td>
<td>None</td>
<td>Shrink A, Std FT</td>
<td>Shrink A, FT+</td>
<td>Shrink A, FT++</td>
</tr>
<tr>
<td>Image</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>Esize (mJ/cm²)</td>
<td>23.5</td>
<td>20.8 (11 %)</td>
<td>20.4 (13 %)</td>
<td>17.0 (27 %)</td>
</tr>
<tr>
<td>CD (nm)</td>
<td>32.5</td>
<td>30.2</td>
<td>29.2</td>
<td>27.3</td>
</tr>
<tr>
<td>CDU (nm)</td>
<td>1.4*</td>
<td>1.3*</td>
<td>1.3</td>
<td>1.0</td>
</tr>
</tbody>
</table>

* Missing holes observed; Believed to arise from NTD pre-pattern

- Optimization = Shrink FT > Resist FT >> Resist Anneal > Shrink Anneal
  - Process optimization yielded ~10-25% Esize Gain at 30 hp vs. NTD
Outline

• Introduction & Motivation
• NTD Resist Performance on the IMEC NXE3100
• DSA Blended Shrink for NTD
  ➢ Best Results To Date
  ➢ Conclusions & Next Steps
Comparison of Champion Results

<table>
<thead>
<tr>
<th>Resist</th>
<th>PTD</th>
<th>Gen-3 NTD</th>
<th>Gen-3 NTD</th>
<th>Gen-4 NTD</th>
<th>Gen-4 NTD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrink</td>
<td>NO</td>
<td>NO</td>
<td>YES, Shrink A, Std FT</td>
<td>NO</td>
<td>YES, Shrink B, Std FT</td>
</tr>
<tr>
<td>NXE Illumination</td>
<td>Conventional</td>
<td>Quasar</td>
<td>Quasar</td>
<td>Quasar</td>
<td>Quasar</td>
</tr>
<tr>
<td>Image</td>
<td>(Top-Down @ 230k; 2nd Image @ 300k)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Esize (mJ/cm²)</td>
<td>17.0</td>
<td>15.8</td>
<td>14.4 (9 % ↓)</td>
<td>20.8</td>
<td>18.3 (12% ↓)</td>
</tr>
<tr>
<td>CD (nm)</td>
<td>30.4</td>
<td>30.7</td>
<td>24.7</td>
<td>27.2</td>
<td>27.6</td>
</tr>
<tr>
<td>Normalized Exposure Time</td>
<td>1.00</td>
<td>1.65</td>
<td>1.55 (6 % ↓)</td>
<td>1.90</td>
<td>1.75 (8 % ↓)</td>
</tr>
</tbody>
</table>

- Move from Gen-3 to Gen-4 resist platform decreased missing C/H rate (but increased Esize).
- DSA Blend agent does not increase missing hole rate when target CD > 20-25 nm.

> Champion EUVL Process Remains Positive Tone Resist.
Summary

• NTD resists have recently realized good progress to 30P60.
• Ideal bias for NTD (as well as NTD+DSA process) is ~13 - 30 %
  ➢ Best NTD performance to date comes from Gen-4 resist, developer-2, and NXE3100 Quasar illumination.

• Novel DSA blended shrink agents can provide ~10-35% improvement vs. NTD alone.
• DSA optimization = Shrink FT > Resist FT >> Resist Anneal > Shrink Anneal.
• Using 193i, we have illustrated a 55% integrated shrink following dielectric etch using a similar blended DSA shrink agent.

➢ While our best results to date show that PTD is still the primary EUVL solution, alternative options are quickly maturing.
Next Steps

- **NTD Resist**
  - Understand NTD outgassing & WP contamination rate. (& Improve...)
  - Correlate mask measurements to design and wafer level observations.
  - Use stochastic resist model to understand potential areas for material and / or process improvement.
  - Once resolution of NTD resist(s) warrants it, use OAI to push patterning limits.

- **DSA Shrink Agent**
  - Validate pattern transfer for EUVL-patterned + DSA blended shrink wafers.
  - Understand how material or process optimization can push to CDs < 20-25 nm or 2-5 beard seconds#.

- **IMEC DSA Electrical Test Vehicle**
  - SPIE’13 :: Use IMEC e-test vehicle to evaluate process flows having blended DSA agent to those using a block copolymer (BCP).
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Philippe Foubert

IMEC Material Support
AZ Electronic Materials
Brewer Science, Inc.
Fujifilm Holdings Corporation
JSR Corporation
Nissan Chemical
TOK (Tokyo Ohka Kogyo Col, LTD)
Best Belgian Chocolate

- **Mary’s Furtive!**
  - Fresh vanilla cream dusted with speculoos

- Mary’s ([www.mary.be](http://www.mary.be)) is located in the Galerie de la Reine (Glass Gallery near the Grand Place) ::
  - 36 Galerie de la Reine, 1000 Brussels
Representative performance of DSA shrink agent for 55P110 on IMEC 1950i.
### 193i + DSA Shrink :: IMEC Integrated Efforts

<table>
<thead>
<tr>
<th>Feature</th>
<th>Dense</th>
<th>Isolated</th>
<th>Staggered</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>After Litho</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Pre-DSA Shrink)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD (nm)</td>
<td>50.4</td>
<td>41.9</td>
<td>51.5</td>
</tr>
<tr>
<td><strong>After Dielectric Etch</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDU (nm)</td>
<td>29.1</td>
<td>20.2</td>
<td>26.9</td>
</tr>
<tr>
<td>Shrink (%)</td>
<td>42%</td>
<td>52%</td>
<td>48%</td>
</tr>
</tbody>
</table>

- Characterizing a variety of features to understand iso-nested performance for DSA blended shrink process.