Feasibility study of grapho-epitaxy DSA for complementing EUV lithography beyond N10

ASML Brion: Chenxi Lin, Yi Zou
ASML Research: Davide Ambesi, Tamara Druzhinina, Sander Wuister
IMEC: Ioannis Karageorgos, Julien Ryckaert, Praveen Raghavan, Roel Gronheid

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## DSA: Complementary to EUV Lithography

**Pitch Multiplication**

<table>
<thead>
<tr>
<th>Litho + DSA simulation(^1)</th>
<th>Placement error DSA</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUV</td>
<td>1 nm</td>
<td>44x89nm</td>
</tr>
<tr>
<td>193i</td>
<td>2 nm</td>
<td>62x110nm</td>
</tr>
</tbody>
</table>

**Note:** 193i with full SMO for only this feature, EUV only mask optimization.

Using EUV compared to 193i saves factor 2 in DSA added overlay and factor 1.7 in area.

Specs:
- CD = 20 nm
- Pitch = 45nm

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High fidelity pre-pattern shapes enabled by EUVL helps **minimize DSA placement error**, and **use small area footprint** (relax design restriction).

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Sander Wuister *et al.*, *Proc. SPIE* 9049, 904910
Experimental data shows DSA helps EUVL reduce LCDU.
Summary of ASML findings to date

• DSA is a potential hole shrinking technique complementary to EUV lithography for contact/via applications
  • We performed a DSA feasibility study for contact/via use case with relevant design rule beyond N10.
    • For N7 use case, DSA may help reduce LCDU and relax dose requirement for EUV.
    • For N5 use case, DSA enables pitch multiplication.
• 193i lithography in combination with DSA viewed as an alternative technology to SAQP for line/space patterning (e.g. fin application)
Simulation Flow and Assumptions
Simulation flow: Overview

1. EUV DSA pre-pattern optimization
2. Optimize block copolymer for given d, CD and R
3. Optimization of CDU and LCDU in Tachyon NXE SMO
4. Rigorous stochastic simulations
5. Rigorous DSA simulations

To optimize Litho+DSA for a design is a high-dimensional optimization problem.

- Polymer length and composition.
- Pre-pattern shape and size, sidewall chemistry.
- EUV pupil and mask for printing the pre-pattern.
- Target bias and dose.
Simulation flow: **Pre-pattern** and BCP co-op.

1. EUV DSA pre-pattern optimization

2. Optimize block copolymer for given d, CD and R

3. Optimization of CDU and LCDU in Tachyon SMO

4. Rigorous stochastic simulations

5. Rigorous DSA simulations

- Pre-pattern size determines the **complexity of DSA templates**, as well as the **placement error**.
- Pre-pattern size depends upon litho. option and DSA process.

Large Pre-pattern CD

Small Pre-pattern CD

Sander Wuister et al., *Proc. SPIE* 9049, 90491O
Simulation flow: Pre-pattern and BCP co-op.

1. EUV DSA pre-pattern optimization
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PS-wetting sidewall and 28nm pre-pattern CD is selected for the 7nm/5nm feasibility study.

<table>
<thead>
<tr>
<th>BCP formula</th>
<th>CD = 36nm</th>
<th>CD = 32nm</th>
<th>CD = 30nm</th>
<th>CD = 28nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A31B17</td>
<td></td>
<td></td>
<td></td>
<td>P.E. = 1.8nm</td>
</tr>
<tr>
<td>A19B13</td>
<td></td>
<td></td>
<td></td>
<td>P.E. = 0.4nm</td>
</tr>
<tr>
<td>A14B12</td>
<td></td>
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</tr>
</tbody>
</table>

PS-wetting sidewall

Sidewall: strong affinity for PMMA

Sidewall: strong affinity for PS

Natural Pitch Increase
Simulation flow: Print bias/Dose, and SMO co-op.

- Print bias, dose, mask shape and illuminator need to be co-optimized to achieve **balanced LCDU and CDU**.
- Tachyon NXE SMO supports stochastic-aware optimization flow based on an empirical image-based SEPE (stochastic EPE) model.

**Empirical SEPE formula**

$$SEPE = \frac{a}{IL_{blur}^b} \times (\text{dose} \times \text{blurred image intensity})^c$$

**Optimization Flow**

1. EUV DSA pre-pattern optimization
2. Optimize block copolymer for given d, CD and R
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5. Rigorous DSA simulations

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S. Hsu et al. Proc. of SPIE Vol. 9422 94221I-14
Simulation flow: Print bias/Dose, and SMO co-op.

1. EUV DSA pre-pattern optimization
2. Optimize block copolymer for given $d$, CD and $R$
3. Optimization of CDU and LCDU in Tachyon SMO
4. Rigorous stochastic simulations
5. Rigorous DSA simulations

**Optimization Step #1: ILS optimization by increasing dose sensitivity**

**Optimization Step #2: Target bias and dose optimization**

NXE:3350B

Current Assumption

Further LCDU reduction

NXE:3400B (projected)

S. Hsu et al. Proc. of SPIE Vol. 9422 94221I-14
Simulation flow: Rigorous stochastic simulation

1. EUV DSA pre-pattern optimization
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Simulation Flow: DSA simulation

1. EUV DSA pre-pattern optimization
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Example SCFT* DSA Simulation Results

PS phase density shown

final PMMA holes in an example std. cell

3D top-view
3D side-view

SCFT*: Self-Consistent Field Theory
Process Assumptions
Process assumption: choice of EUV photoresist

26NM HP CONTACTS
QUASAR ILLUMINATION, 60NM FT

A calibrated empirical resist model is used in Tachyon SMO for LCDU prediction and optimization.

- Use a “fast” resist with high LCDU, as shown in red star.

Source: updated imec resist screening chart from Oct. 2014 ALP meeting.
Process assumption: etch and DSA process

IMEC grapho-epitaxy DSA contact hole flow used as DSA processing assumption

- BCP self-assembled inside SoC confinement.
- A litho print bias can be used to minimize pre-pattern LCDU.
- A simple constant sizing operation is used to create final 28nm pre-pattern shape.

Example stochastic ADI and AEI contour

Red: “ADI” contour
Blue: “AEI” contour
Simulation Results
N7 Use Case: IMEC V₀ Random Logic Std. Cell
Pitch Assumption (42nmx32nm)

\[ P_x = 42\text{nm}, \ P_y = 32\text{nm} \]

Design restriction: no neighboring vias in the vertical direction, min. pitch Y=64nm

- 193i requires at least four masks.
- DSA+193i MPT can only reduce the mask count by one.

- EUV enables good printability with single exposure.
- DSA + EUV enables LCDU and dose reduction.
Only “single contact hole shrink” use case is required for this design scenario.

**DSA offers a significant LCDU reduction:**
- 35% improvement is due to the large pre-pattern size.
- The local healing property of DSA enables further reduction (21%).

<table>
<thead>
<tr>
<th>Dose [mJ/cm²]</th>
<th>EUV</th>
<th>EUV+DSA</th>
<th>LCDU [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td><img src="image1" alt="Design" /></td>
<td><img src="image2" alt="Design" /></td>
<td>2.16</td>
</tr>
</tbody>
</table>
N5 Use Case: Ground Rules for $V_x$ layer

- Use current IMEC N5 $V_x$ design assumption ($M_x$ and $M_{x+1}$ pitch = 24 nm, no side-by-side VIAs allowed).
- The five most challenging constructs are listed below.

![Diagrams showing the most challenging constructs and those with good EUV printability.](Image)
N5 Use Case: Example $V_x$ clip

Scale N7 P&R’ed $V_x$ designs according to N5 design rules.

What are the patterning options?

- **193i MPT**
- **EUV SE**
- **EUV DPT**
- **EUV SE + DSA**

Critical construct:
- 34nm pitch diagonal Vias
- Relaxed min. pitch ~ 54nm

At least 4 masks are required.

Pitch multiplication by using DSA, merge the critical construct.
Stochastics-aware SMO simulation Flow

Step #1: Regular SMO for the entire clip.

Step #2: ILS optimization for SEPE reduction

Step #3: Target bias and dose optimization for further SEPE reduction

Critical construct A (Diagonal VIA pair array min. pitch = 34nm)
Rigorous + DSA Simulation

EUV Litho. and DSA simulation results for an array of the most critical construct.

DSA bridging defect due to local process variability
## Summary

<table>
<thead>
<tr>
<th></th>
<th>EUV SE</th>
<th>EUV DPT</th>
<th>EUV SE+DSA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Illuminator</strong> (optimized for 2D design)</td>
<td><img src="image1.png" alt="EUV SE illuminator" /></td>
<td><img src="image2.png" alt="EUV DPT illuminator" /></td>
<td><img src="image3.png" alt="EUV SE+DSA illuminator" /></td>
</tr>
<tr>
<td><strong>Design/Final Si CD</strong></td>
<td>N5 V_x with symmetric M_x and M_{x+1} (Pitch = 24nm) /16nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Resist</strong></td>
<td></td>
<td>EUV J1915</td>
<td></td>
</tr>
<tr>
<td><strong>Litho. Target CD/LE Bias (per edge)</strong></td>
<td>20nm/2nm</td>
<td>34nm/9nm</td>
<td>38nm/4nm</td>
</tr>
<tr>
<td><strong>Worst 3sigma LCDU</strong></td>
<td>4.9nm</td>
<td>1.92nm*</td>
<td>1.40nm*</td>
</tr>
</tbody>
</table>

The LCDU for EUV SE can be further reduced by using advanced EUV illuminator and more aggressive OPC.

* EUV SE+DSA reduced EUV SE LCDU and lowered dose requirements.
EUV Advanced Illuminator and EUV SRAF

NXE:3350B
No Assisting Features

FlexPupil Illuminator

Litho. Target

Black: Target
Green: PV band
Blue: Stochastic band

Avg. PV band width: 1.8nm
Avg. SEPE: 3.5nm

NXE:3400B (Projected)
w/ EUV SRAF

Avg. PV band width: 1.0nm
Avg. SEPE: 2.7nm

44% reduction in PV band width and 23% reduction in mean. SEPE
Conclusions

- DSA grapho-epitaxy is a potential shrinking technique complementary to EUV lithography for contact/via applications.
- DSA has the potential to lower EUV’s dose requirements and also extend EUV (NA=0.33) single patterning roadmap.
- EUV lithography can relax the strong design restriction required to enable DSA for contact/via applications.
- EUV lithography (hardware) and Tachyon NXE SMO (software) help print high-fidelity DSA pre-pattern, minimizing DSA added placement error and DSA defectivity.