Expectation and challenges of higher NA EUV lithography

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Lithography Challenges for advanced LSI
LSI scaling

Ref. ITRS 2013

Sub-10nm after 2020
Lithography for sub-10nm

- Extension of immersion lithography
  - 1D layout by **SAxP + cut mask**
    - L&S by SADP (19 nm) ➔ SAQP (10 nm) ➔ SAOP (sub-10 nm)
    - Cut mask by LE^8~ or NGL

  **Issues**
  - Restrict design
  - Complex process control
  - Long process steps

  **High cost**

- **NGL**
  - 2D layout by single exposure
    - **High NA EUVL**
  - Bottom-up patterning
    - DSAL + EUVL

- **We need NGL for sub 10nm with low cost!**
EUV lithography for sub-10nm
The potential of EUVL is attractive.

Resolution = \( k_1 \frac{\lambda}{\text{NA}} \)

- \( \lambda \) : exposure wavelength
- NA : Numerical Aperture
- \( k_1 \) : process constant \([>0.25]\)

<table>
<thead>
<tr>
<th>NA</th>
<th>0.40</th>
<th>0.35</th>
<th>0.30</th>
<th>0.25</th>
<th>( k_1 )</th>
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<tbody>
<tr>
<td>0.25</td>
<td>21.6</td>
<td>18.9</td>
<td>16.2</td>
<td>13.5</td>
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<tr>
<td>0.30</td>
<td>18.0</td>
<td>15.8</td>
<td>13.5</td>
<td>11.3</td>
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<tr>
<td>0.33</td>
<td>16.4</td>
<td>14.3</td>
<td>12.3</td>
<td>10.2</td>
<td></td>
</tr>
<tr>
<td>0.35</td>
<td>15.4</td>
<td>13.5</td>
<td>11.6</td>
<td>9.6</td>
<td></td>
</tr>
<tr>
<td>0.40</td>
<td>13.5</td>
<td>11.8</td>
<td>10.1</td>
<td>8.4</td>
<td></td>
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<tr>
<td>0.45</td>
<td>12.0</td>
<td>10.5</td>
<td>9.0</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>0.50</td>
<td>10.8</td>
<td>9.5</td>
<td>8.1</td>
<td>6.8</td>
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<tr>
<td>0.55</td>
<td>9.8</td>
<td>8.6</td>
<td>7.4</td>
<td>6.1</td>
<td></td>
</tr>
<tr>
<td>0.60</td>
<td>9.0</td>
<td>7.9</td>
<td>6.8</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td>0.70</td>
<td>7.7</td>
<td>6.8</td>
<td>5.8</td>
<td>4.8</td>
<td></td>
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</table>

NA \( \geq 0.55 \) will be desirable.
Concerns for high NA EUVL

- **High NA EUV tradeoff**
  - Resolution (high NA) / full field (throughput)/ 6 inch mask

- **High power source**
  - Power loss by increasing in mirror number and pellicle
  - Low sensitivity resist

- **Optics for high NA and high power**
  - Increase in NA (> 0.5) → Tighter mirror roughness and aberration specification for larger mirror
  - Damage due to high power EUV light
    - ML mirror, mask and Pellicle durability

- **Resist for high NA**
  - RLS tradeoff: Resolution / LER / Sensitivity ~ shot noise issue
High NA EUV trade-off: EUV optics

**Countermeasure**

1) **Increasing CRA:** Difficult
   - Because of pattern shift in defocus due to mask 3D effect

2) **Reduction ratio change from 1/4 to 1/6 ~ 1/8** with keeping CRA=6 deg.
   - 2-1) **Increasing mask size to 9 inch:** Difficult
     - Because of the renewal of mask infrastructure
   - 2-2) **Decreasing of exposure field size to ½ or ¼**
     - Challenge for TPT (concern about CoO)
Etched ML pattern for high NA EUVL

In order to overcome the tradeoff of high NA EUVL, mask structure is optimized.

Etched multilayer L/S pattern of 40 nm hp on mask (10 nm hp on wafer using 4X optics) is achieved.

⇒ Enabler of high NA, 4X full-field and 6 inch mask
High power EUV source

• LPP (Laser Produced Plasma)
  – **Current level:** 40~60W
  – Challenges
    • Heat treatment
    • Debris
    • Lifetime of collector mirror
    • Running cost

• Target of source power: 250 W in 2015
• Big gap between target and current level
• High NA EUVL will need higher power
• Scalability of LPP source to >> 250 W?
An FEL has the potential of high power source, for example over 10kW to multiple scanners.
But FEL for EUV source is still in the conceptual stage.
Concerns for FEL

- Proof of concept; FEL of $\lambda=13.5$ nm with high power of $>10$ kW
- Availability for 365D/24H
- Impact for wafer cost
- Electrical power consumption
- Facilities size
- Timely readiness; long lead items
Comparison of wafer cost

The sum of adding all of patterning cost for 1 layer

Reference (> 10 nm)

Wafer cost of FEL is expected to be lower than LPP.
ERL will reduce the electric power consumption of FEL.
Concerns for FEL

- Proof of concept; $\lambda=13.5$ nm / > 10 kW
  - **Need research and development**
- Availability for 365D/24H
  - **Redundancy system**
- Impact for wafer cost
  - FEL will be better than LPP.

There are many challenges for high power EUV-FEL. But nothing will be a show stopper, technically. Careful and sufficient optimization will be required.

- Facility size
  - **Very large underground facilities (~100 m)**
- Timely readiness; long lead time items
  - **Long term project management**
Optics for high NA and high power

- Increase in NA ($\geq 0.6$) leads the specification of mirror roughness and aberration tighter.
- Damage due to high power EUV light for all optics (e.g. beam splitter and transport system, ML mirror, mask and pellicle)

$\Rightarrow$ Concern for durability

Beam splitter & transport system

XFEL

Actual size $\sim 100$ m
EUV resist tradeoff

Difficult to overcome RLS tradeoff. We need high resolution 1st for sub-10 nm. Not only CAR but also alternative platform resist such as inorganic resist should be considered more.
### Trend of EUV Lithography

<table>
<thead>
<tr>
<th>Year</th>
<th>EUV Source</th>
<th>EUV Mask</th>
<th>EUV Resist</th>
<th>Challenges</th>
<th>ITRS</th>
<th>Technology Node/HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>40W LPP</td>
<td>16nm</td>
<td>16~13nm</td>
<td>Source power, CoO</td>
<td>Logic (node/hp)</td>
<td>5/18nm</td>
</tr>
<tr>
<td>2013</td>
<td>80-125W LPP</td>
<td>11nm</td>
<td>11nm</td>
<td>Mask size/Mag</td>
<td>NAND Flash mem</td>
<td>12nm</td>
</tr>
<tr>
<td>2014</td>
<td>250W LPP</td>
<td>11nm</td>
<td>11nm</td>
<td>Pellicle, Higher sensitivity for scaling, CoO</td>
<td></td>
<td>13nm</td>
</tr>
<tr>
<td>2015</td>
<td>500W LPP</td>
<td>&lt;11nm</td>
<td>&lt;6nm</td>
<td>RLS trade-off, Pattern collapse, Resist for high NA EUV</td>
<td></td>
<td>8nm</td>
</tr>
<tr>
<td>2016</td>
<td>500W LPP</td>
<td>&lt;11nm</td>
<td>&lt;6nm</td>
<td>Defectivity, Pattern placement error, Process stability, Metrology &amp; inspection, Optimization of guide pattern design</td>
<td></td>
<td>5nm</td>
</tr>
</tbody>
</table>

**1st Target:**
- NA = 0.33
- Source Power: 250W LPP
- EUV Resist: 11nm

**High NA EUV:**
- Source Power: 500W LPP
- EUV Resist: <6nm

**Mask size/Mag:**
- EUVL + DSA

**Hard work to realize the cost effective EUVL!**
Summary
Summary

- **High NA EUVL** is the most promising candidate for sub-10 nm lithography, because of its patterning potential.

- We should take our best effort to establish **cost effective** high NA EUVL.

- There are many **concerns** for high NA EUVL.
  - Etched ML mask will enable **4X full-field 6 inch mask**.
  - **Higher power source** will be required for sub-10 nm. An FEL is one of the candidates for future high power EUV source.
  - **Damage** due to high power EUV light for all optics is concern for durability.
  - Alternative platform **resist** should be considered more for sub-10 nm.