EUV Lithography Optics for sub 9 nm Resolution

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EUV program at ZEISS.

2003 MET (Micro Exposure Tools)
2006 ADT (α-Demo Tool)
2009 Starlith 3100™
2012 Starlith 3300™

prototypes small series HVM series production

High-NA

Starlith 3100™
Starlith 3300™

This talk is about resolution.

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

- What happens when increasing the NA of an EUV tool?
- What are the optical solutions?

<table>
<thead>
<tr>
<th>NA</th>
<th>0.33</th>
<th>...</th>
<th>0.4</th>
<th>...</th>
<th>0.5</th>
<th>...</th>
<th>0.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution @ ( k_1 = 0.3 ) single exposure / nm</td>
<td>12.3</td>
<td>...</td>
<td>10.1</td>
<td>...</td>
<td>8.1</td>
<td>...</td>
<td>6.8</td>
</tr>
</tbody>
</table>

EUV 13.5nm High-NA
Agenda.

1. The Dilemma of High-NA EUVL.
2. The Solution: Anamorphic Lithography.
3. The Optical Systems.
Overall optical column.

- Reticle (mask)
- Field facet mirror
- Intermediate focus
- Plasma
- Source
- Illuminator
- Projection optics
- Pupil facet mirror
- Collector
- Wafer

Mask = grating

Diffraction orders: 
- \(-1^{st}\)
- \(0^{th}\)
- \(1^{st}\)

Finer resolution leads to larger diffraction angles.
Overall optical column.

Projection optics catches and combines these diffraction orders on to the wafer.

- Reticle (mask)
- Illuminator
- Projection optics
- Source
- Plasma
- Collector
- Wafer
- Field facet mirror
- Intermediate focus
- Pupil facet mirror
Fields and light cones at reticle and wafer are connected via MAG.

Projection with MAG 4x

CRAO 6°

NA @ reticle = \( \frac{NA}{MAG} \)

NA @ reticle = 0.33

26 mm

33 mm

slit
Increasing NA, light cones @ reticle start to overlap.

Projection with MAG 4x
CRAO 6°
NA 0.45
To separate light cones again, CRAO must be increased.
Absorber shadowing @reticle is angular dependent.

Absorber thickness 55nm.
Absorber shadowing for a CRAO of 9° leads to imbalanced pupils, and hence to telecentricity errors and loss of image contrast.

0th order imbalance: telecentricity error

0th/1st order imbalance: contrast loss
Due to shadowing, a system with MAG 4x and 9° CRAO does not resolve even 11 nm hp using a standard multilayer @ reticle.

NA 0.33, CRAO 6°
15nm Horizontal L&S

NA 0.45, CRAO 9°
11nm Horizontal L&S

NA 0.33, CRAO 6°
15nm Vertical L&S

NA 0.45, CRAO 9°
11nm Vertical L&S

imaging simulations

inacceptable contrast loss

diffraction orders not in folding direction

Contrast [%]

NXE:3300

High-NA
The only way to decrease angular spread @reticle is to increase MAG.

**Projection with MAG 4x**

**CRAO 6°**
Changing MAG is changing field sizes: Same mask leads to 13 mm slit...
…or keeping 26 mm slit requires a large mask.
The Dilemma of High-NA EUVL.

1. MAG 4x, CRAO 9°, FF
2. MAG 8x, CRAO 6°, QF
3. MAG 8x, CRAO 6°, FF

@ reticle

@ wafer

imaging
small field
large mask
Agenda.

1. The Dilemma of High-NA EUVL: High-NA EUVL requires a new optical solution.
2. The Solution: Anamorphic Lithography.
3. The Optical Systems.
Reduce angles by increasing MAG only in the direction that matters...

@ reticle

@ wafer

CRAO 6°
...which enables a High-NA EUVL optical system with 26mm slit.

Projection with MAG 4x in x
MAG 8x in y

CRAO 6°
NA >0.5
For anamorphic Half Field, the illumination optics must provide entrance pupils with anamorphic settings.

*Example: c-quad illumination setting*

**isomorphic**

MAG 4x, FF

**anamorphic**

MAG 4x/8x, HF
An anamorphic lens transforms entrance pupils with anamorphic settings into circular settings @ wafer.

**Example: c-quad illumination setting**

![Diagram showing anamorphic lens transformation](image-url)
The anamorphic High-NA design enables **sub 9 nm resolution** imaging using a standard multilayer @ reticle.
Agenda.

1. The Dilemma of High-NA EUVL:
   High-NA EUVL requires a new optical solution.

2. The Solution: Anamorphic Lithography.
   Anamorphic Half Field is enabling High-NA EUVL.

3. The Optical Systems.
We have designs for such anamorphic High-NA optics available.

- Really big optical system with very large mirrors and extreme aspheres at increased accuracy requirements

→ Challenge to optics technology and manufacturing
By narrowing the angles in the optical system, we see potential to improve the optical column transmission by a factor ~2 wrt NXE:3300.

**Example: Central obscuration reduces angles on M5.**

<table>
<thead>
<tr>
<th>Obscuration [%]</th>
<th>Illumination</th>
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</thead>
<tbody>
<tr>
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<tr>
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<td>45</td>
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<tr>
<td>50</td>
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No noticeable imaging impact
Limited contrast loss for a few pitches
Forbidden pitches due to obscuration
The Dilemma of High-NA EUVL:
High-NA EUVL requires a new optical solution.

The Solution: Anamorphic Lithography.
Anamorphic Half Field is enabling High-NA EUVL.

The Optical Systems:
Technical solutions for optical systems look feasible.
Conclusions.

- Anamorphic Lithography with Half Field is making High-NA EUVL economically feasible with NA >0.5 and utilizing existing 6“ mask infrastructure.

- The considered optical concept has potential to increase the transmission of the optical column by a factor of ~2 wrt NXE:3300.
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