Anamorphic High NA Optics enabling EUV Lithography with sub 8nm Resolution

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This talk is about resolution

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

- How does a High-NA EUV Optics look like?
- How does it image?
- Can we further optimize system performance?

<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 @ k1=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

NA > 0.5 enables (sub) 8nm
Structure of presentation

1. Optical Solutions for High NA EUV Lithography
2. Anamorphic Imaging
3. Lens Magnification Options
The EUV Optical System:
The finer the resolution, the larger the angles!
Higher NA increases the light cone above the wafer, and...
...increases the angles on M5, and...
...increases the angular spread on M5.
Multi-layer coatings set limits for angles & angular spread on EUV mirrors.

Standard EUV coatings are not able to reflect the combination of large angles and large angular spreads on M5 needed for high-NA.

Angles must be reduced for high-NA EUV optics.
There is a solution: Obscuration – We drill a hole into the mirror.

The obscuration massively reduces angles & angular spread on the mirrors...

...which significantly increases the transmission of the optical system vs. 3300!
The EUV Optical System

- Source
- Intermediate Focus
- Illuminator
- Projection Optics
- Mask
- Aspheric Mirrors
- Multi-Layer Coating
- Wafer
Fields and light cones at reticle and wafer are connected via MAG.

\[ NA \text{ @ reticle} = \frac{NA}{MAG} \]

Projection with MAG 4x

CRAO 6°

NA 0.33

Example

NXE:3300

2 x CRAO

(Chief Ray Angle @ Object)

104 mm

132 mm

26 mm

33 mm

0.0825 = 0.33

4x
Increasing NA, light cones @ reticle start to overlap.

Projection with MAG 4x

CRAO 6°

NA 0.5
High-NA EUV – Conventional approaches fail

@ reticle

MAG 4x, CRAO 9°
FF

104 mm
132 mm

104 mm
132 mm

208 mm
284 mm

MAG 8x, CRAO 6°
QF

3 mm
13 mm
16.5 mm

MAG 8x, CRAO 6°
QF

@ wafer

Shadowing ➔ Bad imaging

small field ➔ Bad Tput

No large mask
Maybe looking at movies helps...

Reality

Record with a conventional lens

Film

Same aspect ratio, same angles.

Cinema Widescreen

Project with a conventional lens

BUT: Bad usage of space, Lower resolution
where anamorphic cinematographic lenses are used...

Reality  

Film  

Cinema Widescreen

Record with an Anamorphic lens*  

Project with an Anamorphic lens  

Anamorphic MAG vertically „stretches“ image for good usage of space, lower angles, better resolution

*e.g. a ZEISS Master Anamorphic Lens
...to reduce angles at the mask and increase resolution in lithography.

Same image on wafer, but much lower angles in stretching direction!
The solution: Reducing the angles by increasing MAG only in the direction that matters...
...enables a High-NA EUVL optical system with a 26mm slit and Half-Field.

Anamorphic Projection, e.g. with MAG 4x in x
MAG 8x in y
CRAO 6°
NA >0.5
The Anamorphic High-NA EUV Projection Optics with obscuration...

Reticle level

Wafer level

NA 0.25
NA 0.33
NA > 0.5
...is a big optical system using large mirrors with extreme aspheres and accuracy requirements.

- Extreme aspheres enabling further improved wavefront /imaging performance
- Tight surface specifications enabling low straylight / high contrast imaging
- Big last mirror driven by High NA
- Obscuration enables significantly higher optics transmission vs. 3300 ➔ Optimized Productivity

→ Challenge to optics technology and manufacturing, but no fundamental limits
Structure of presentation

1. Anamorphic High-NA EUV Optics enables sub 8nm resolution EUVL with 26mm slit @wafer and 6” mask

2. Anamorphic Imaging

3. Lens Magnification Options
Compare given $NA=0.33$ Isomorphic imaging vs. Anamorphic High-NA with obscuration.

Isomorphic, Unobscured, $NA=0.33$

Anamorphic, Obscured, $NA > 0.5$
Obscuration may lead to an application dependent contrast loss...

- Unobscured pupil
- Obscured pupil

This part lacks its corresponding 1\textsuperscript{st} order

Contrast loss

Red colored parts of 0\textsuperscript{th} order can interfere with corresponding 1\textsuperscript{st} order

0\textsuperscript{th} diffraction order

Obscuration blocks parts of 1\textsuperscript{st} diffraction orders

\( \pm 1\textsuperscript{st} \text{ diffraction orders} \)
...which can be tolerated if kept below ~20% radius.

Generic Lines & Spaces through pitch simulation

<table>
<thead>
<tr>
<th>Illumination</th>
<th>Obscuration [%], radius</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Annular</td>
<td></td>
</tr>
</tbody>
</table>

- **unobscured pupil**
- **obscured pupil**

- No noticeable imaging impact
- Limited contrast loss for a few pitches
- Forbidden pitches due to obscuration
Excellent Imaging Scaling with NA – Obscuration and Anamorphicity have no visible impact on process window

- Focus axis scales according to familiar $1/NA^2$ behaviour.
- Good Imaging scaling with NA
- No obscuration effects, no orientation dependence (H-V) due to Anamorphicity
Anamorphic High-NA Optics enables sub 8nm resolution EUVL with 26mm slit @wafer and 6” mask

The considered High-NA concept shows excellent imaging in line with the expected NA scaling

Lens Magnification Options
The Optics can be designed in various ways to fit the (26 x 16.5)mm wafer field on the (132 x 132)mm reticle field.

- **(132 x 132) mm reticle field**
  - Quality area with 14mm process radius
  - **Mag:** 4x/8x

- **(104 x 132) mm reticle field**
  - **Mag:** 5.1x/6.3x

- **(132 x 104) mm reticle field**
  - **Mag:** 4.8x/7.5x

- **(123.8 x 123.8) mm reticle field**
  - **Mag:** 4.8x/7.5x

NXE:33xy reticle field
The Optics can be designed in various ways to fit the (26 x 16.5)mm wafer field on the (132 x 132)mm reticle field.
First evaluation of Anamorphicity Options via MEF*

\[ MEF^* = \frac{\Delta CD_{\text{Wafer} \ WL}}{\Delta CD_{\text{Reticle} \ RL}} \]

MEF* measures directly the impact of mask errors on wafer errors.

No normalization with MAG. Hence, MEF* is different for H- and V-structures in Anamorphic Lithography.
A MAG of 4.8x/7.5x improves the critical Mask Error Sensitivity MEF* by ~20% for vertical structures...

12nm spaces through pitch, small annular setting
...while imaging and process windows using 4x/8x and 4.8x/7.5x optical systems are very similar.

Both MAG options are comparable in terms of optical design complexity, optics technology and manufacturing.
Structure of presentation

1. Anamorphic High-NA Optics enables sub 8nm resolution EUVL with 26mm slit @wafer and 6” mask

2. The considered High-NA concept shows excellent imaging in line with the expected NA scaling

3. Further optimization of MAG Ratio is being studied – 4.8x/7.5x seems favorable from mask point of view.
In conclusion...

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

- Simulations based on the considered High-NA concept show excellent imaging performance in line with the expected NA scaling.

- An optimization of the optics MAG ratio is under investigation and may lead to a further improved overall system performance.
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We make it visible.