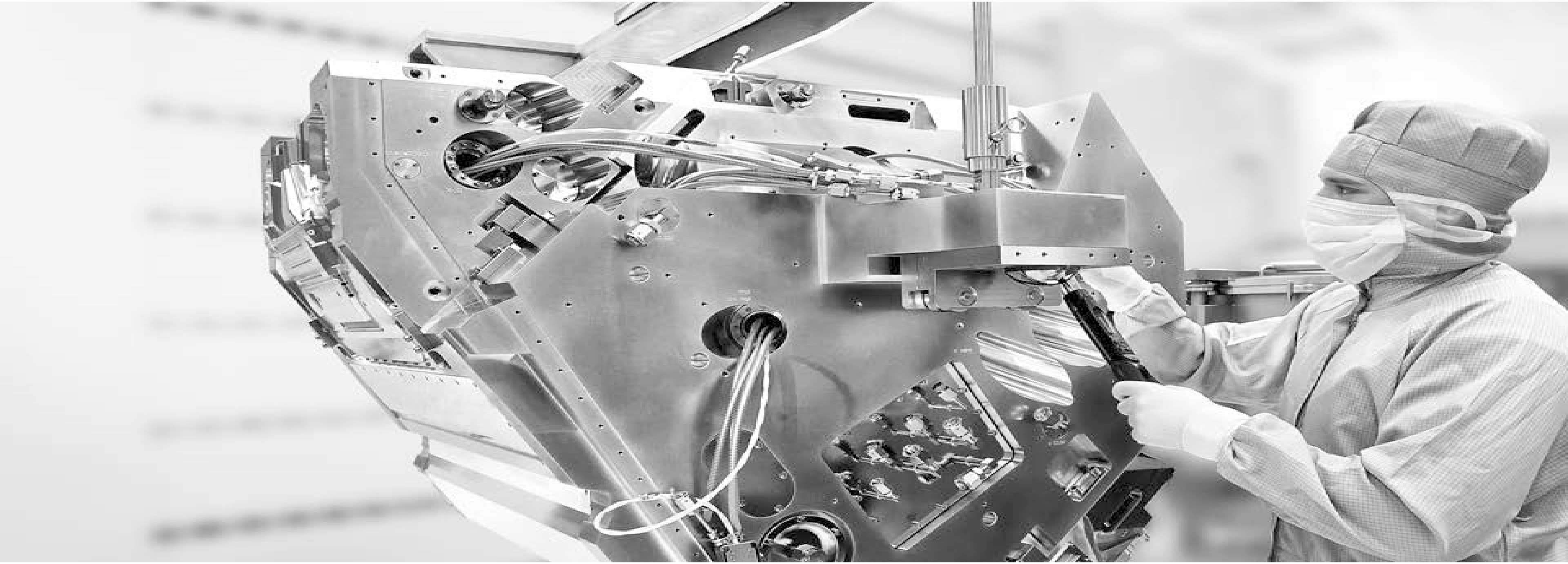
Anamorphic High NA Optics enabling EUV Lithography with sub 8nm Resolution



Tilmann Heil, Bernhard Kneer, Sascha Migura, Johannes Ruoff, Matthias Rösch, Jens Timo Neumann, Winfried Kaiser (ZEISS); Jan van Schoot (ASML).

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This talk is about resolution

$$\text{Resolution} = k_1 \cdot \frac{\lambda}{\text{NA}}$$

EUV 13.5nm

High-NA

NA > 0.5 enables (sub) 8nm

NA	**0.33**	**…**	**0.4**	**…**	**0.5**	**…**	**0.6**
Resolution @ k1=0.3 single exposure / nm	**12.3**	**…**	**10.1**	**…**	**8.1**	**…**	**6.8**

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

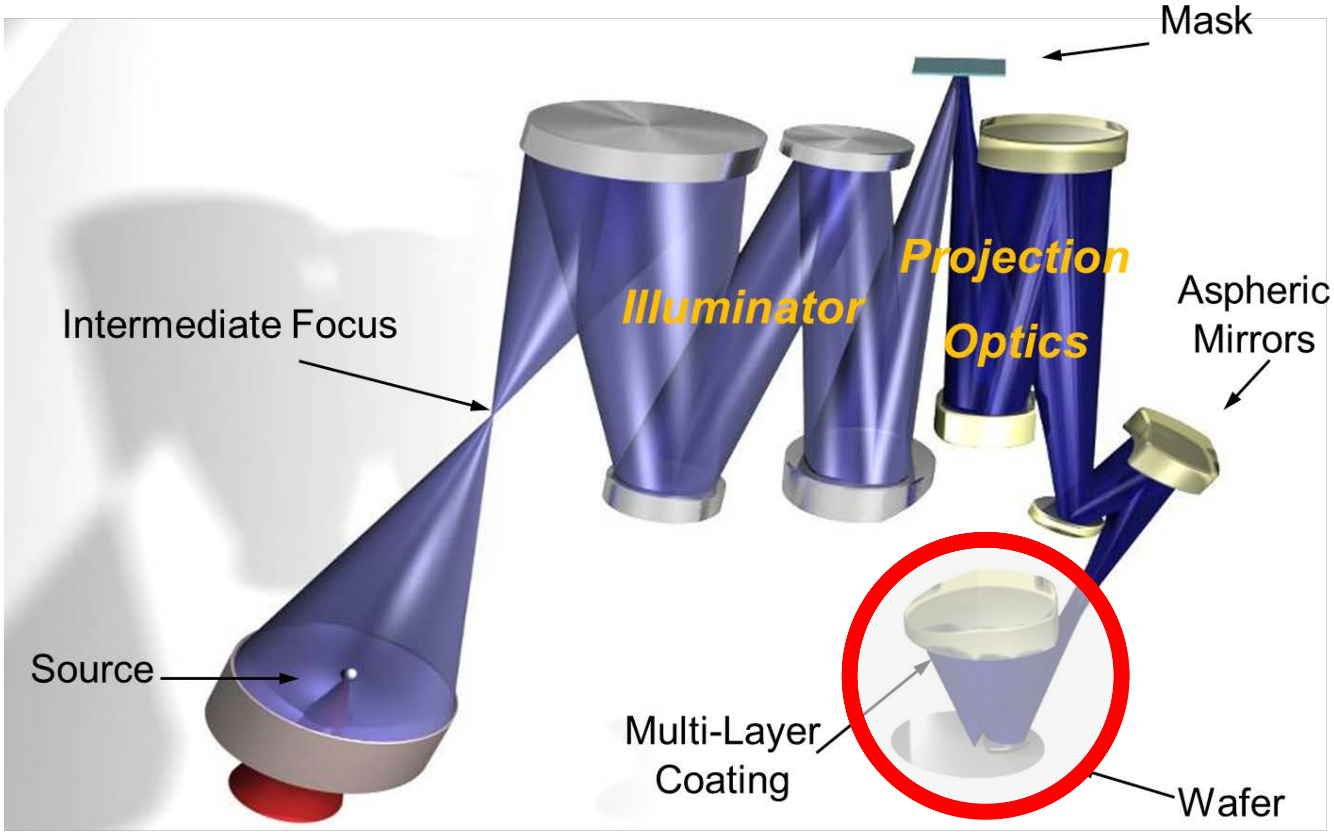
Structure of presentation

1 Optical Solutions for High NA EUV Lithography

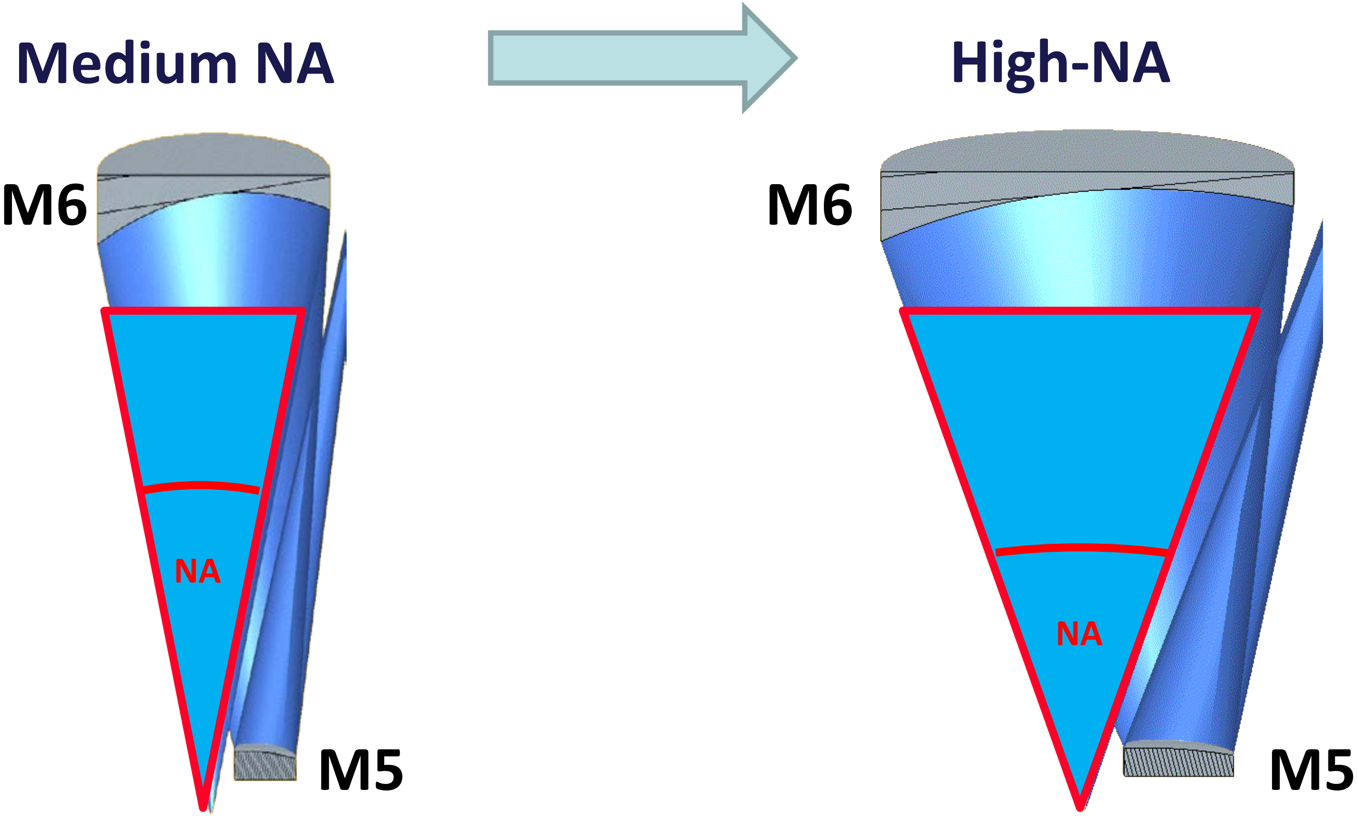
2 Anamorphic Imaging

3 Lens Magnification Options

The EUV Optical System:
The finer the resolution, the larger the angles!

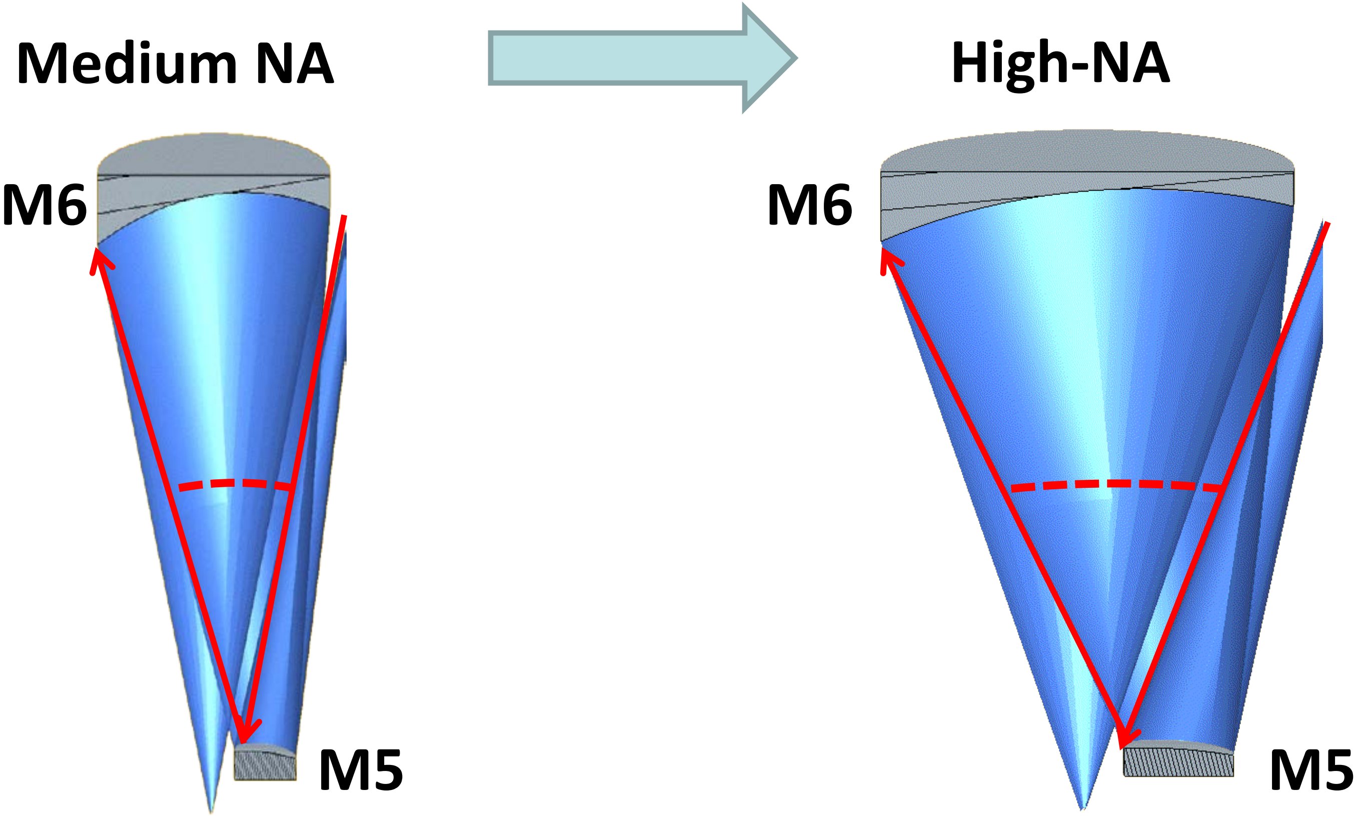


Higher NA increases the light cone above the wafer, and…

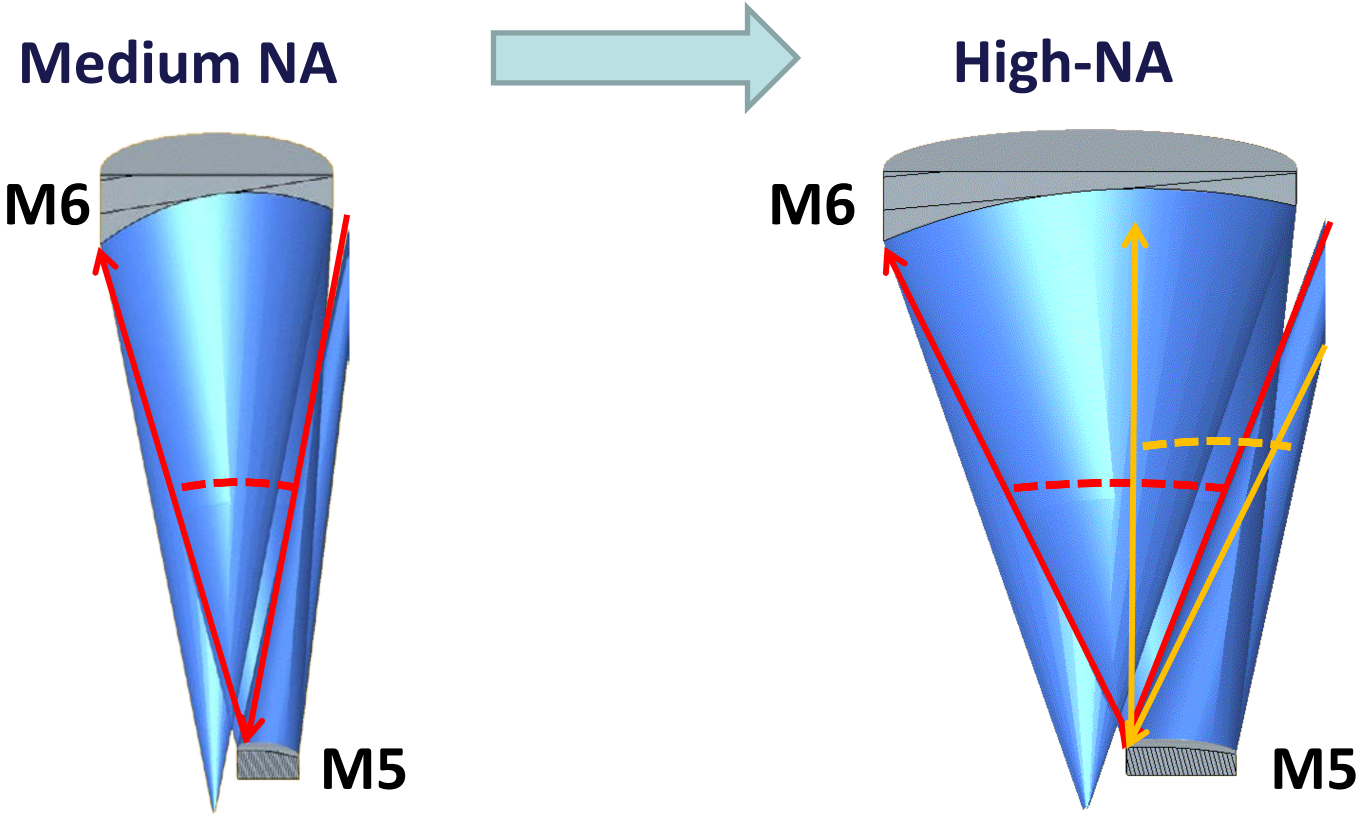


…increases the angles on M5, and…

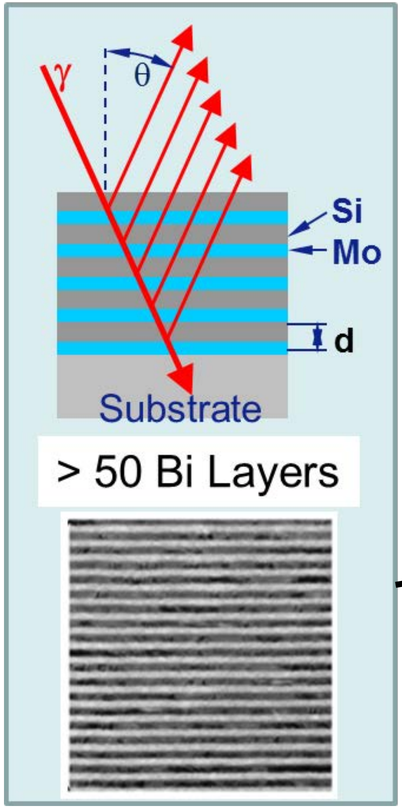
Medium NA **High-NA**

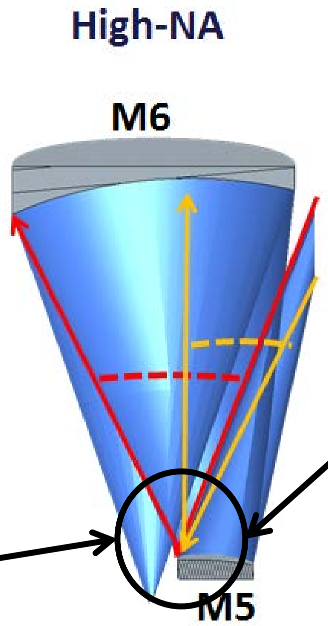


…increases the angular spread on M5.



Multi-layer coatings set limits for angles & angular spread on EUV mirrors.

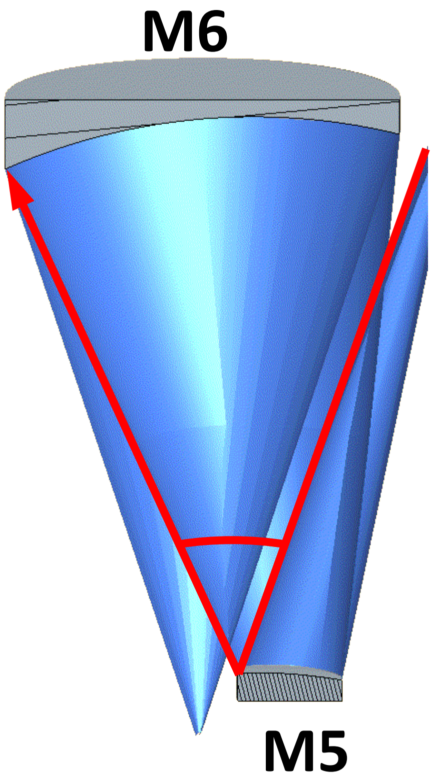




Standard EUV coatings are not able to reflect the combination of large angles and large angular spreads on M5 needed for high-NA.

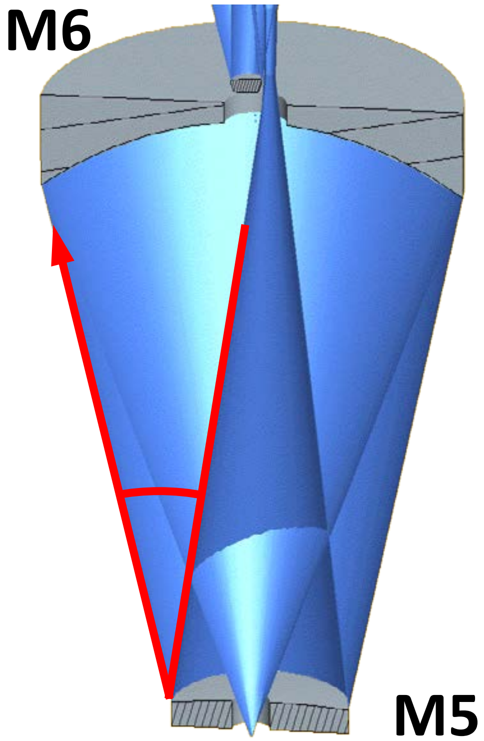
→ Angles must be reduced for high-NA EUV optics.

There is a solution: Obscuration – We drill a hole into the mirror.

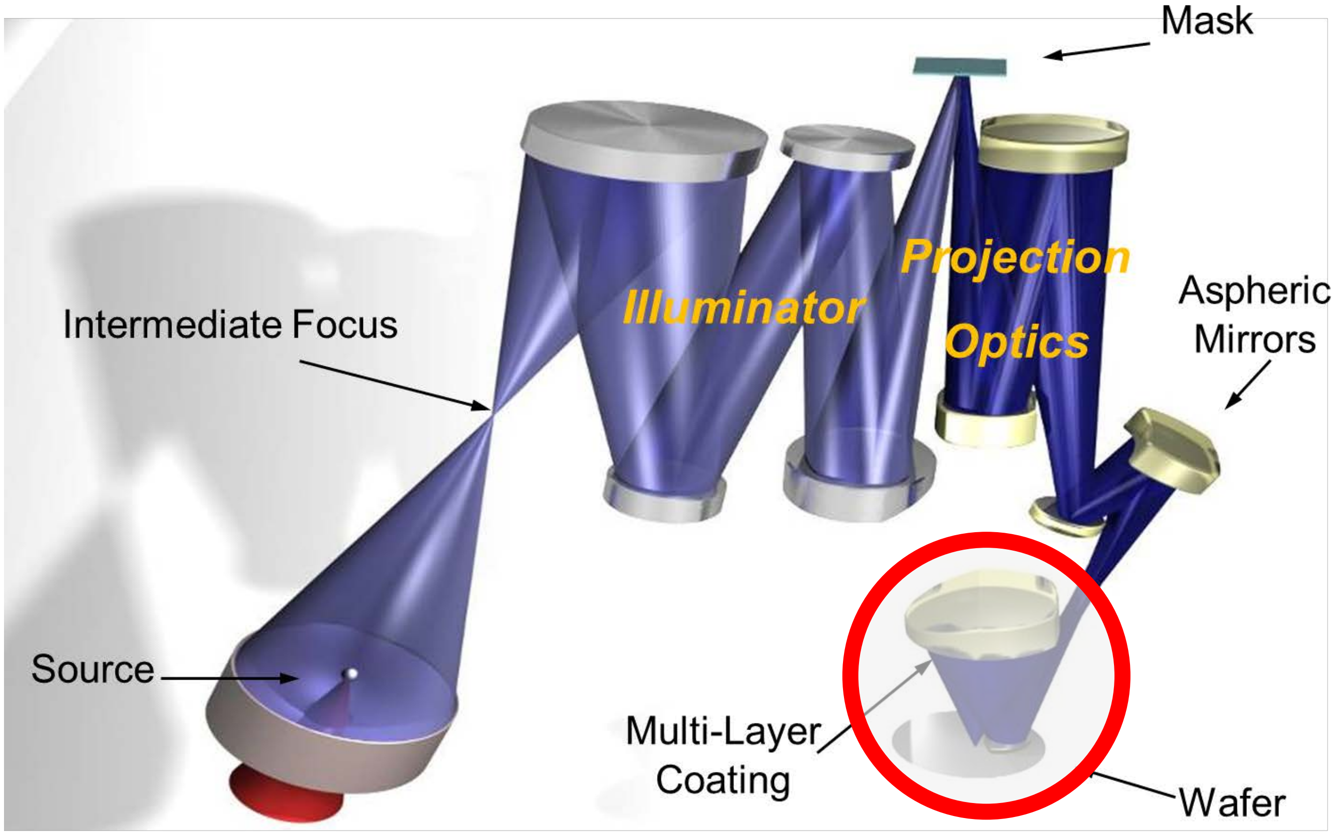


The obscuration massively reduces angles & angular spread on the mirrors…

…which significantly increases the transmission of the optical system vs. 3300!

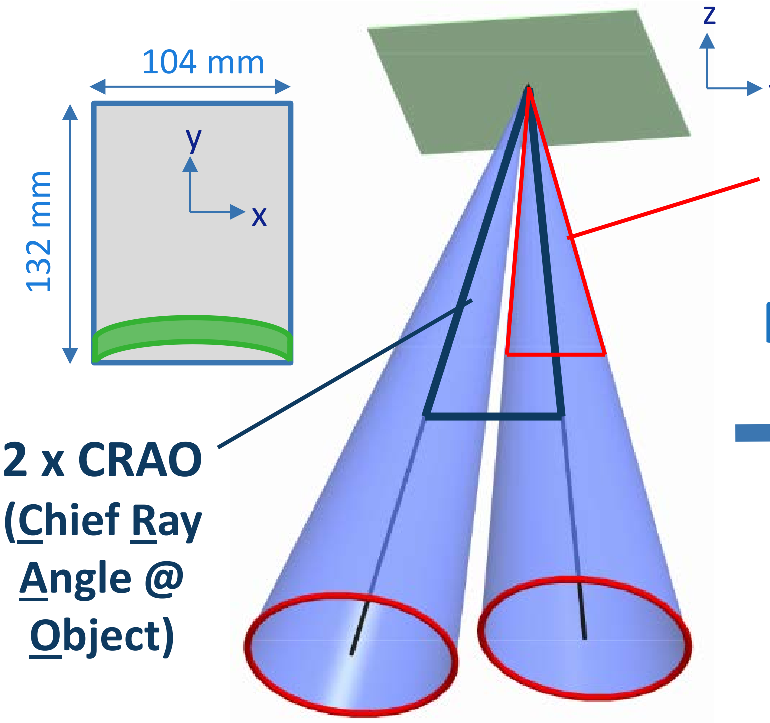


The EUV Optical System



Fields and light cones at reticle and wafer are connected via MAG.

@ reticle



2 x CRAO (Chief Ray Angle @ Object)

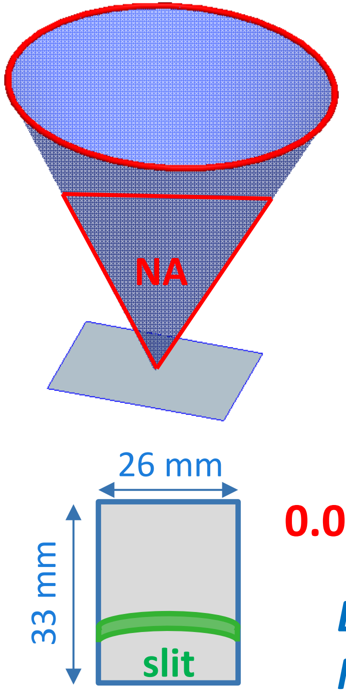
NA @ reticle $= \dfrac{\text{NA}}{\text{MAG}}$

Projection with MAG 4x

CRAO 6°

NA 0.33

@ wafer

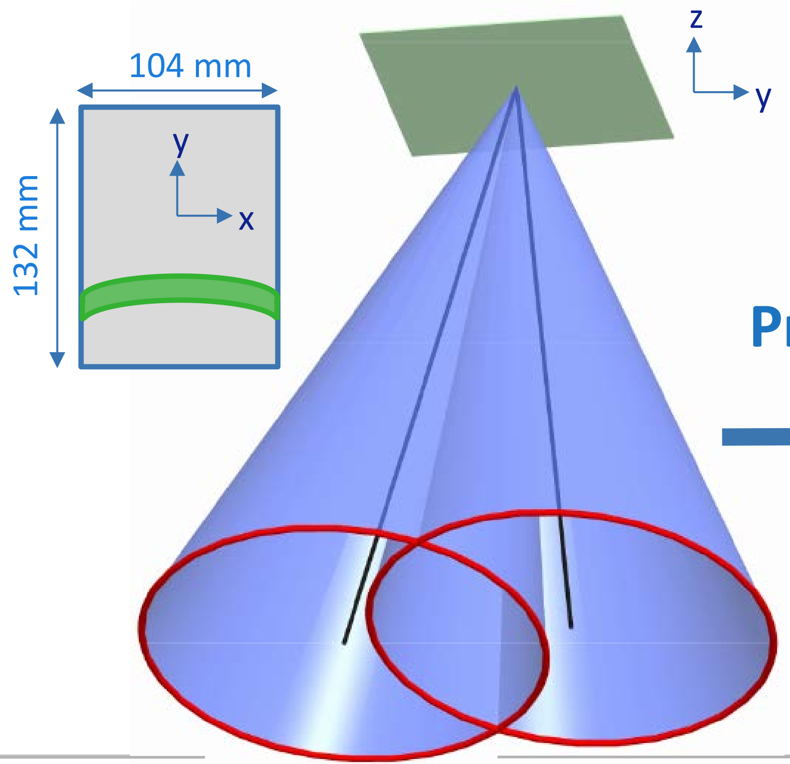


$0.0825 = \dfrac{0.33}{4x}$

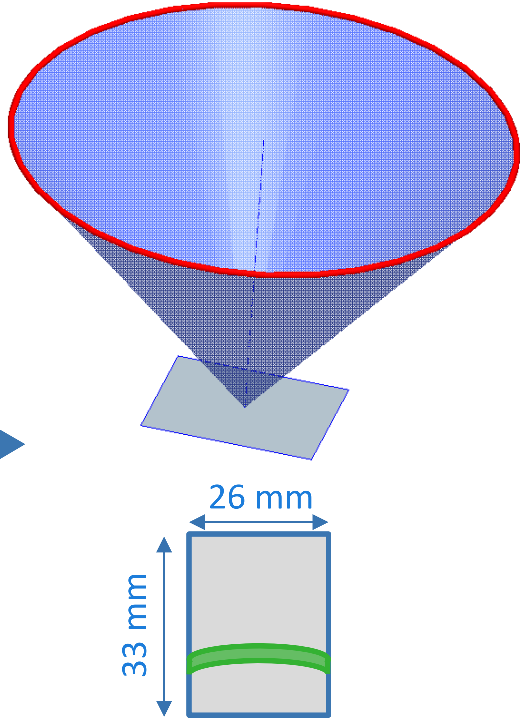
Example NXE:3300

Increasing NA, light cones @ reticle start to overlap.

@ reticle



@ wafer



Projection with MAG 4x

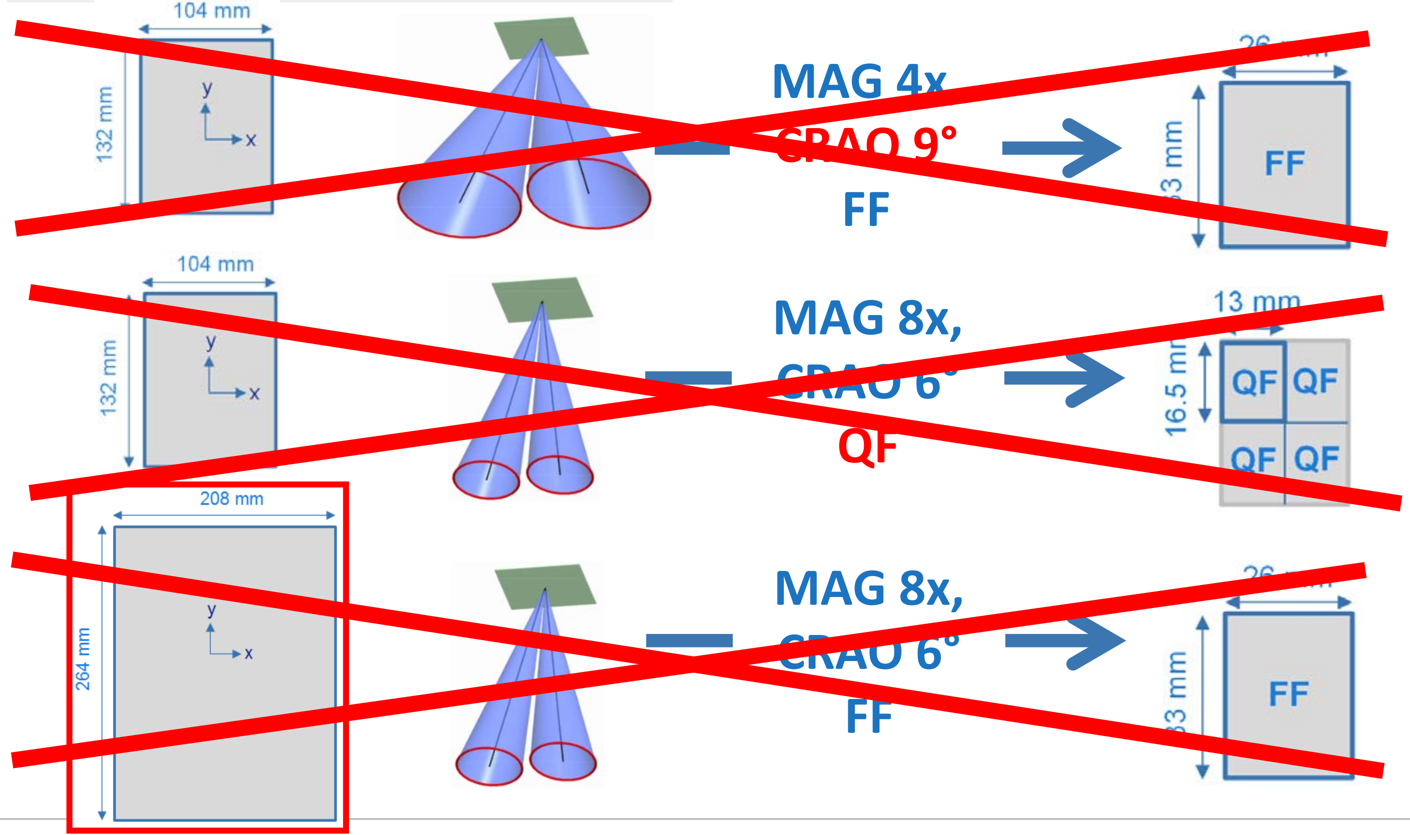
CRAO 6°

NA 0.5

High-NA EUV – Conventional approaches fail

@ reticle

@ wafer



~~MAG 4x~~
~~CRAO 9°~~
~~FF~~

Shadowing
➔ Bad imaging

~~MAG 8x,~~
~~CRAO 6°~~
~~QF~~

small field
➔ Bad Tput

~~MAG 8x,~~
~~CRAO 6°~~
~~FF~~

No large mask

Maybe looking at movies helps…

Reality

Film

Cinema Widescreen

Image by Bernd Geh

Record with a conventional lens

Project with a conventional lens

Same aspect ratio, same angles.

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**

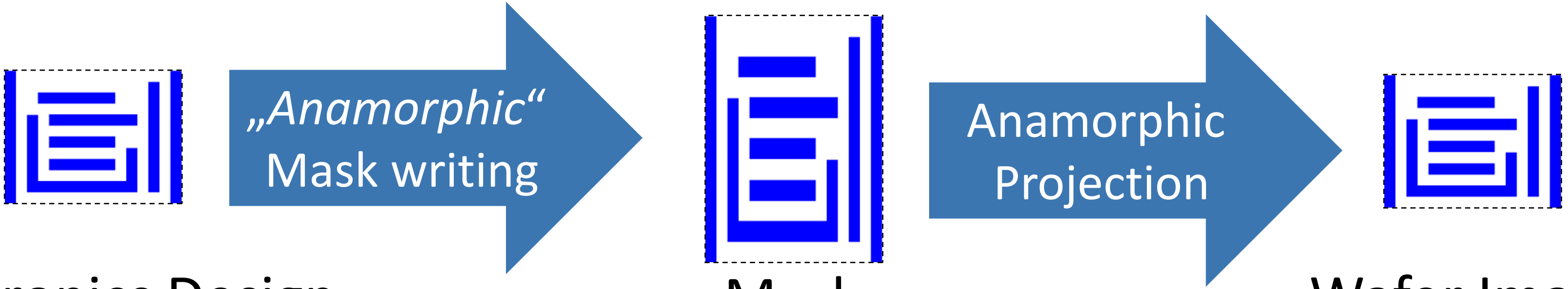
**e.g. a ZEISS Master Anamorphic Lens*

…to reduce angles at the mask and increase resolution in lithography.

Reality

Film

Cinema Widescreen



„Anamorphic“ Mask writing

Anamorphic Projection

Electronics Design

Mask

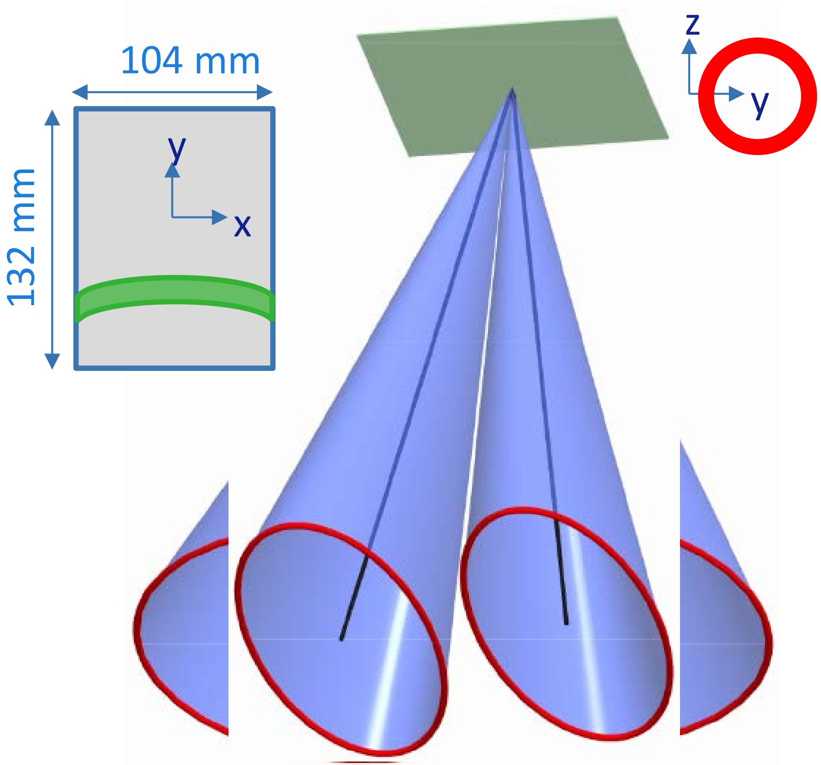
Wafer Image

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...

@ reticle

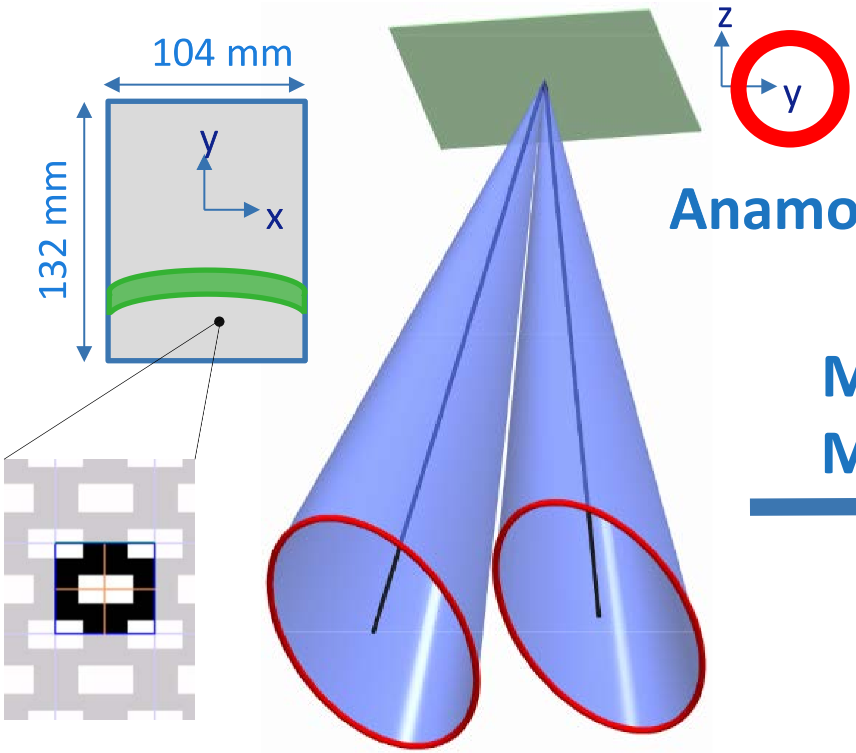
@ wafer



…enables a High-NA EUVL optical system with a 26mm slit and Half-Field.

@ reticle

@ wafer

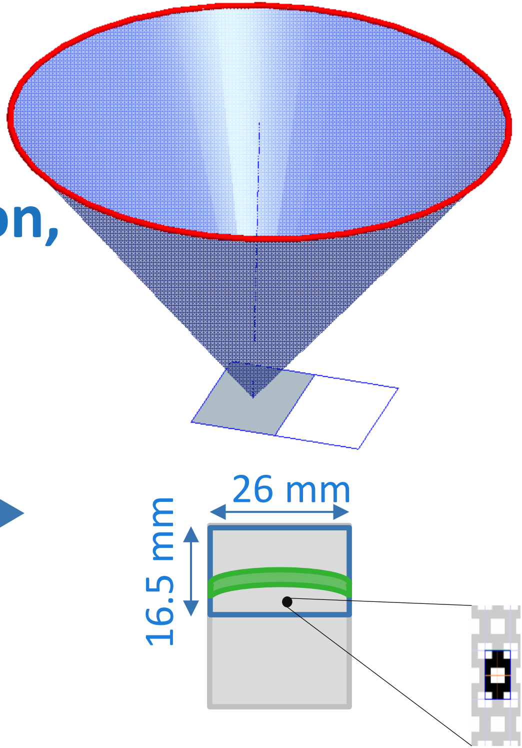


Anamorphic Projection,
e.g. with

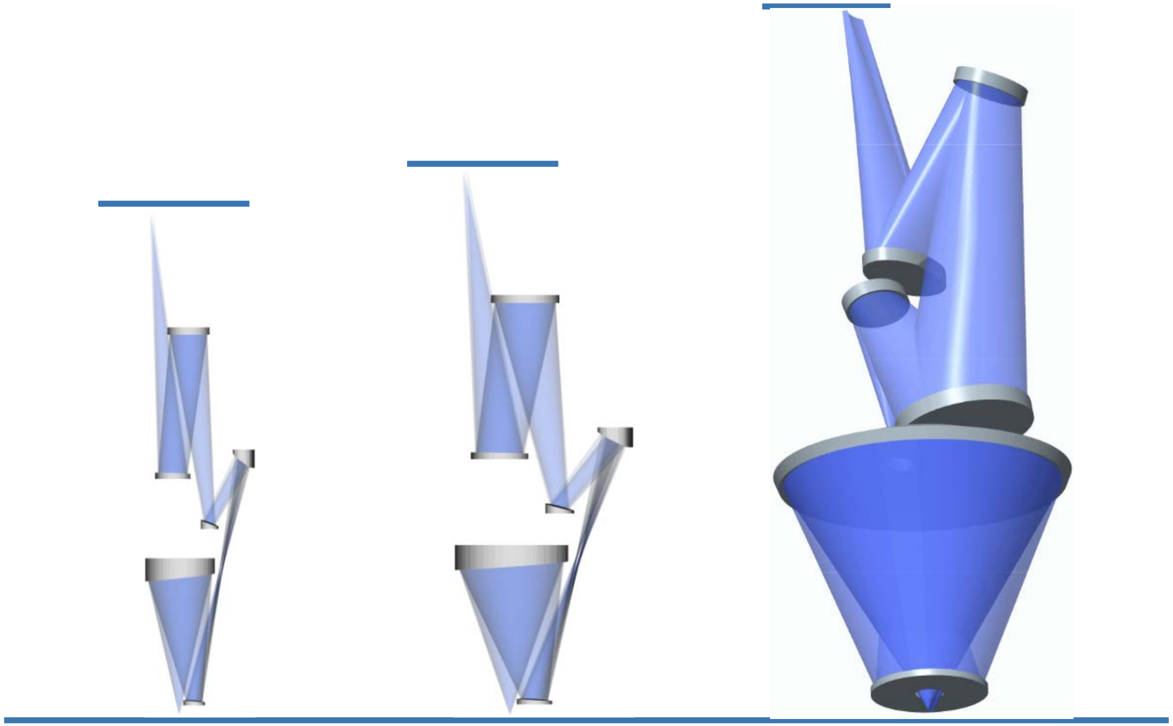
MAG 4x in x
MAG 8x in y

CRAO 6°

NA >0.5



The Anamorphic High-NA EUV Projection Optics with obscuration…



Reticle level

Wafer level

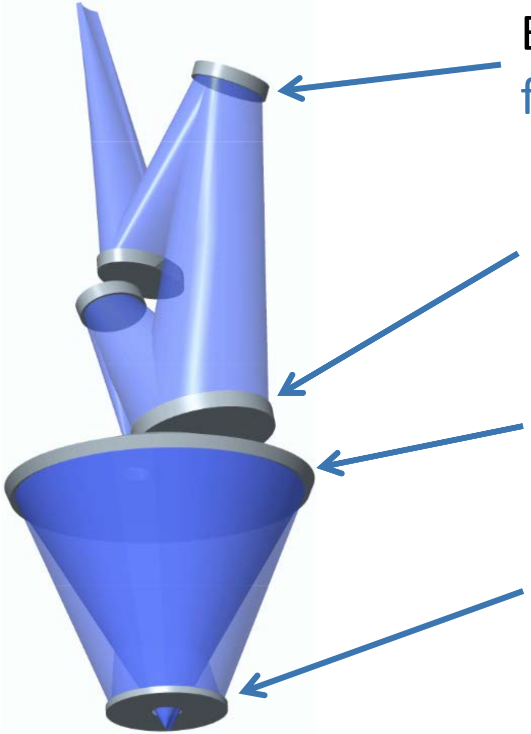
NA 0.25

NA 0.33

NA > 0.5

Design examples

…is a big optical system using large mirrors with extreme aspheres and accuracy requirements.



Large
overall
size of
optical
system

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

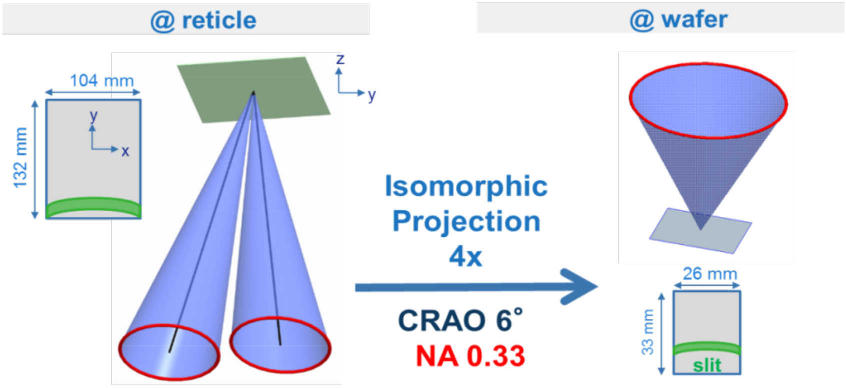
Structure of presentation

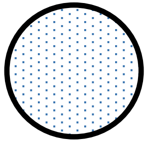
1 Anamorphic High-NA EUV Optics enables sub 8nm resolution EUVL with 26mm slit @wafer and 6’’ mask

2 Anamorphic Imaging

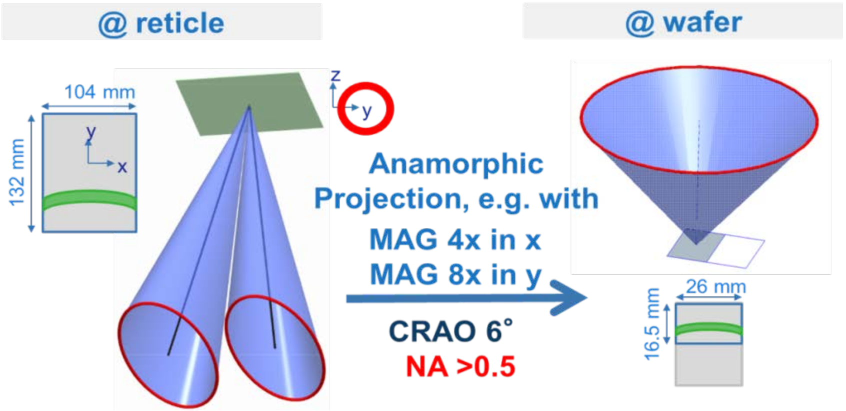
3 Lens Magnification Options

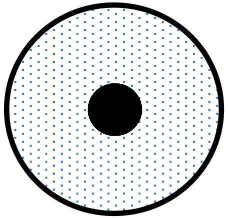
Compare given NA=0.33 Isomorphic imaging vs. Anamorphic High-NA with obscuration





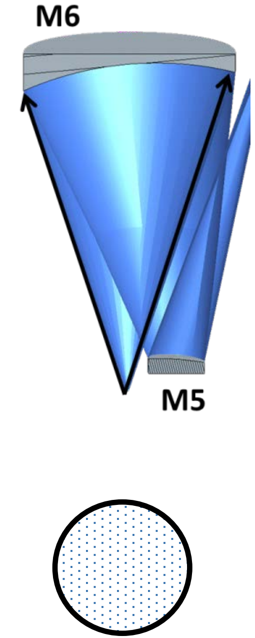
Isomorphic,
Unobscured,
NA=0.33



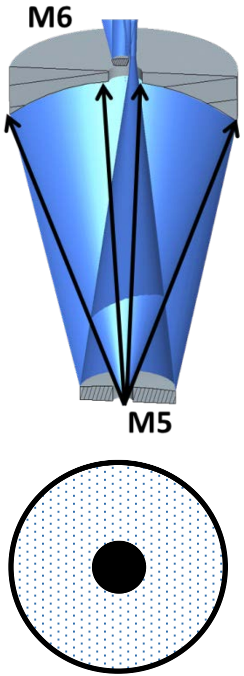


Anamorphic,
Obscured,
NA > 0.5

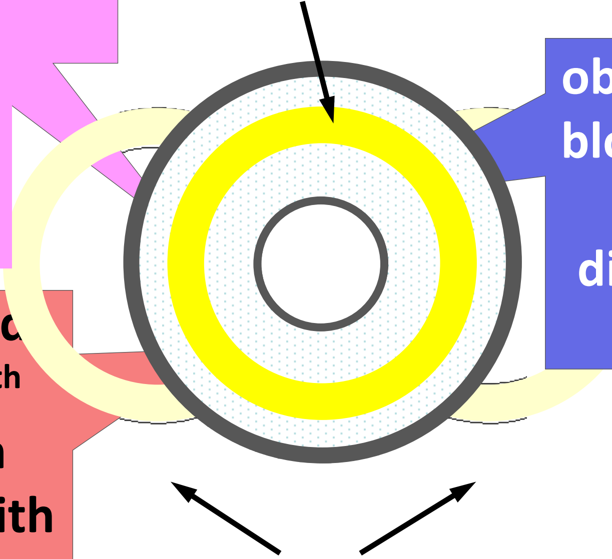
Obscuration may lead to an application dependent contrast loss…



unobscured pupil



obscured pupil



this part lacks its corresponding 1st order

contrast loss

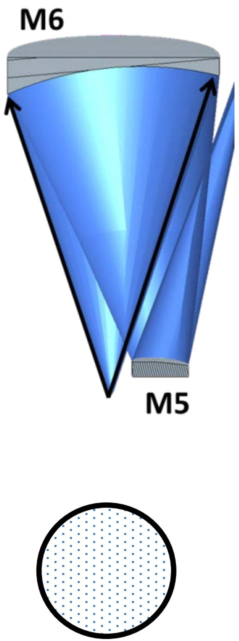
red colored parts of 0th order can interfere with corresponding 1st order

0th diffraction order

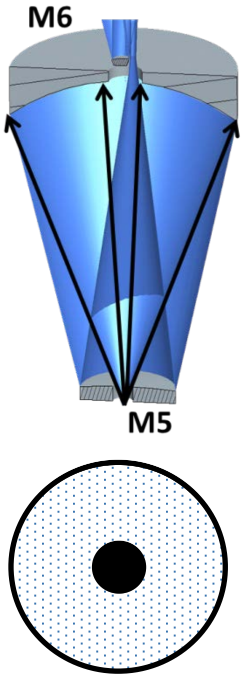
obscuration blocks parts of 1st diffraction orders

±1st diffraction orders

...which can be tolerated if kept below ~20% radius.



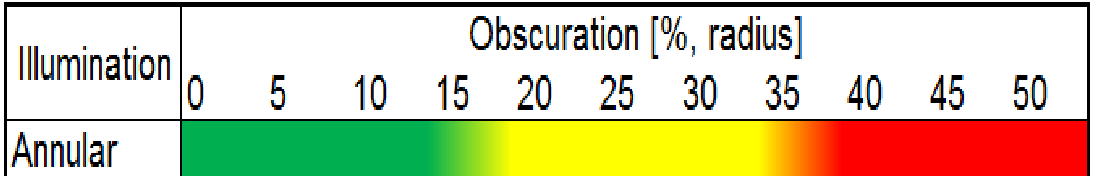
unobscured pupil



obscured pupil

Generic Lines & Spaces through pitch

simulation

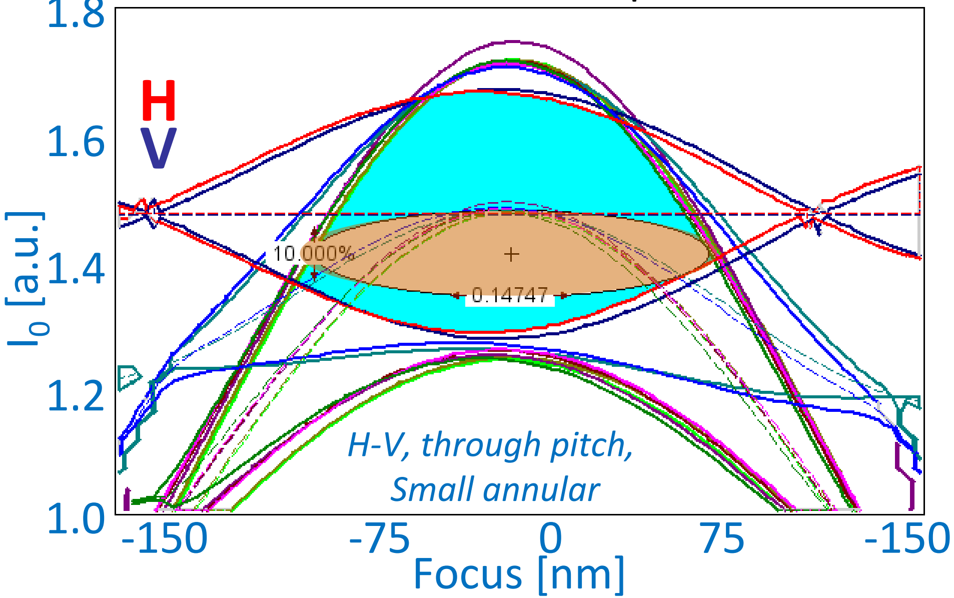


Illumination	Obscuration [%, radius]										
	0	5	10	15	20	25	30	35	40	45	50
Annular	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟧	🟥	🟥	🟥

- 🟩 No noticeable imaging impact
- 🟨 Limited contrast loss for a few pitches
- 🟥 Forbidden pitches due to obscuration

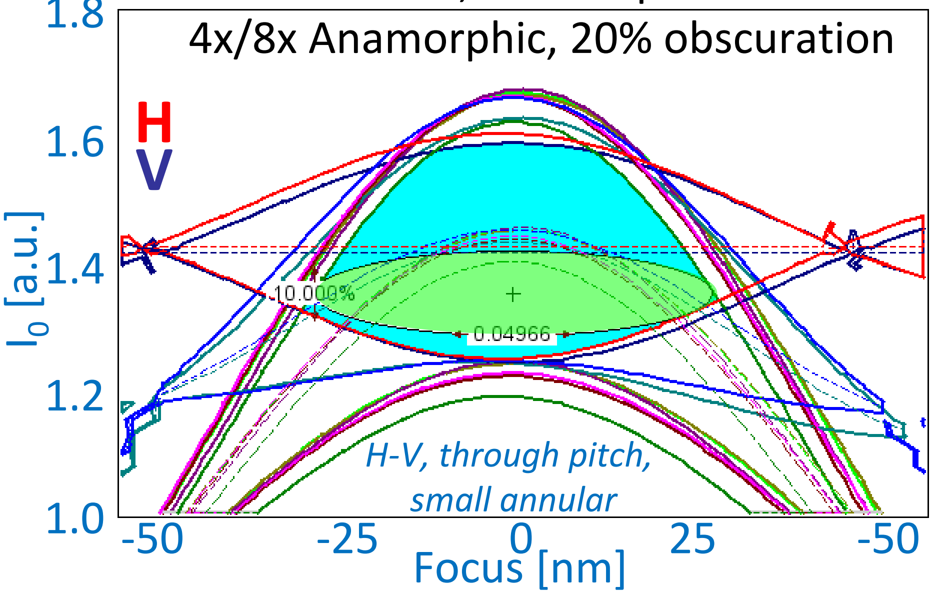
Excellent Imaging Scaling with NA – Obscuration and Anamorphicity have no visible impact on process window

NA=0.33, **20 nm** spaces



NA=0.55, **12 nm** spaces

4x/8x Anamorphic, 20% obscuration

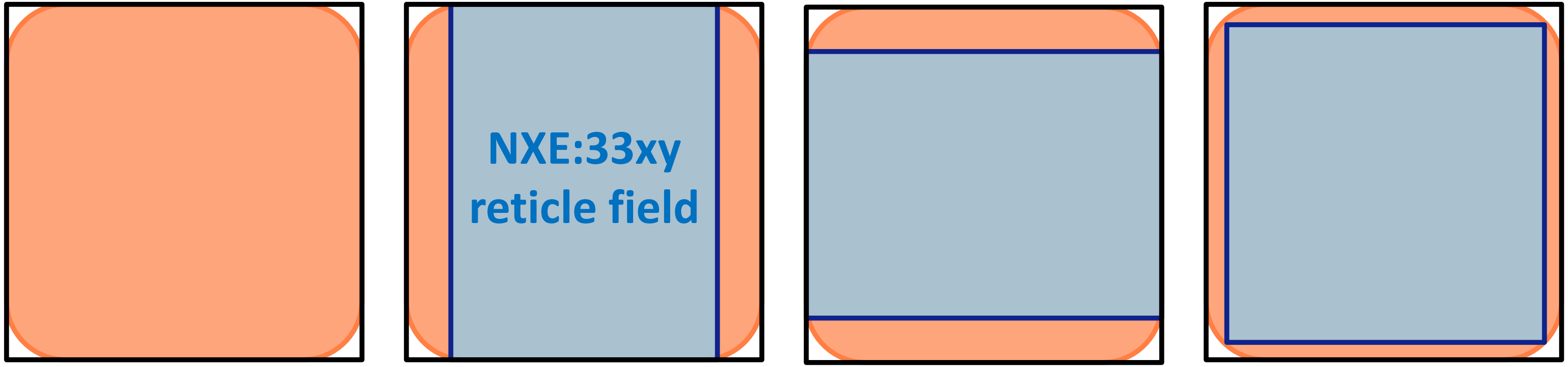


- **Focus axis scales according to familiar 1/NA^2 behaviour.**
- **Good Imaging scaling with NA**
- **No obscuration effects, no orientation dependence (H-V) due to Anamorphicity**

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. 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



(132 x 132) mm
reticle field

Quality area with
14mm process radius

(104 x 132) mm
reticle field

(26x16.5) mm
wafer field

Mag:
4x/8x

(132 x 104) mm
reticle field

(26x16.5) mm
wafer field

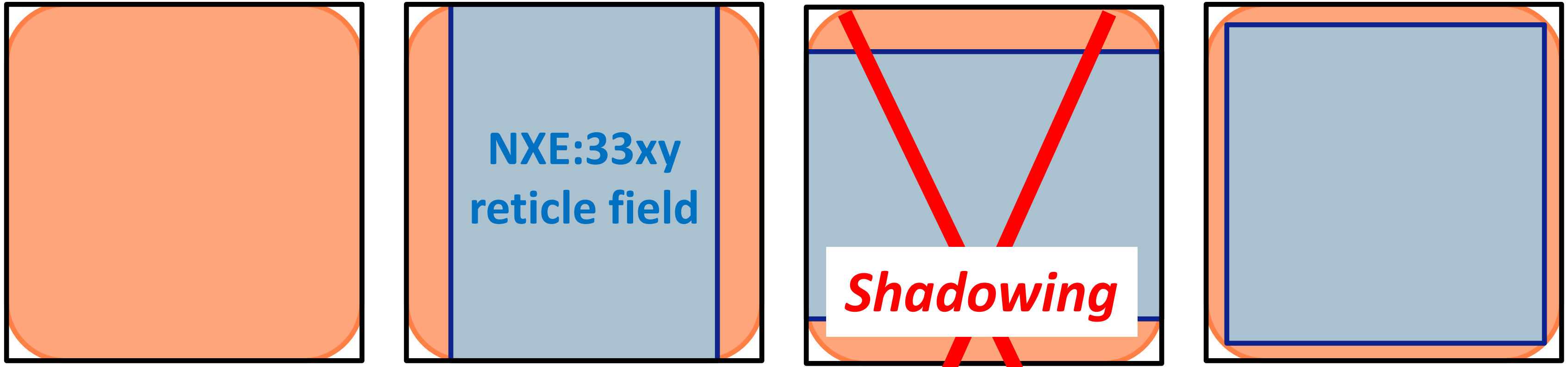
Mag:
5.1x/6.3x

(123.8 x 123.8) mm
reticle field

(26x16.5) mm
wafer field

Mag:
4.8x/7.5x

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



(132 x 132) mm
reticle field

Quality area with
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wafer field

Mag:
5.1x/6.3x

(123.8 x 123.8) mm
reticle field

(26x16.5) mm
wafer field

Mag:
4.8x/7.5x

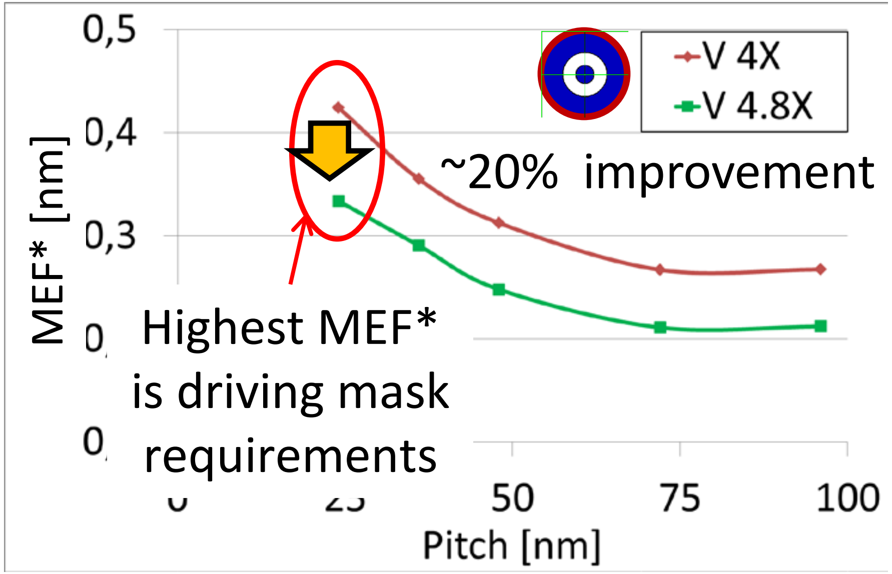
First evaluation of Anamorphicity Options via MEF*

$$MEF^{*} = \frac{\Delta CD_{Wafer\ WL}}{\Delta CD_{Reticle\ RL}}$$

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

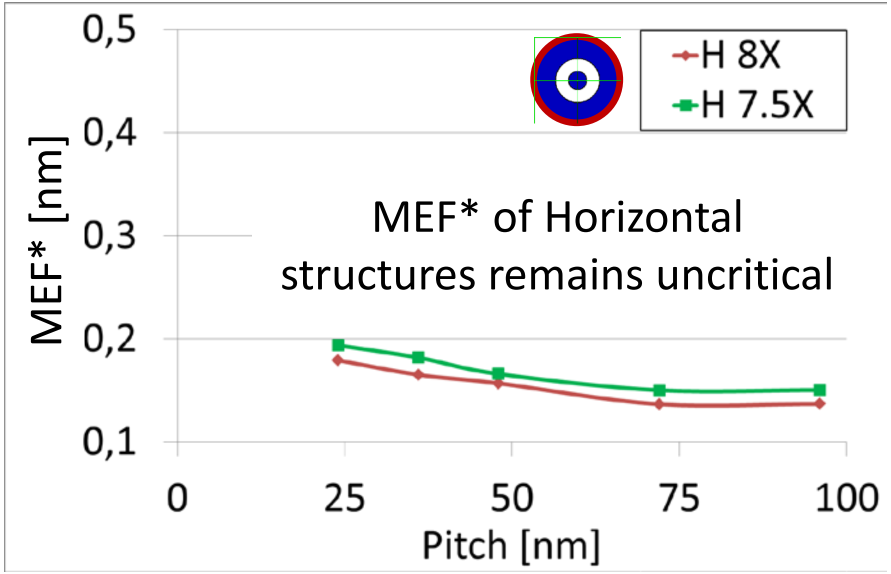
No normalization with MAG. Hence, MEF* is different for H- and V-structures in Anamorphic Lithography

A MAG of 4.8x/7.5x improves the critical Mask Error Sensitivity MEF* by ~20% for vertical structures…



~20% improvement

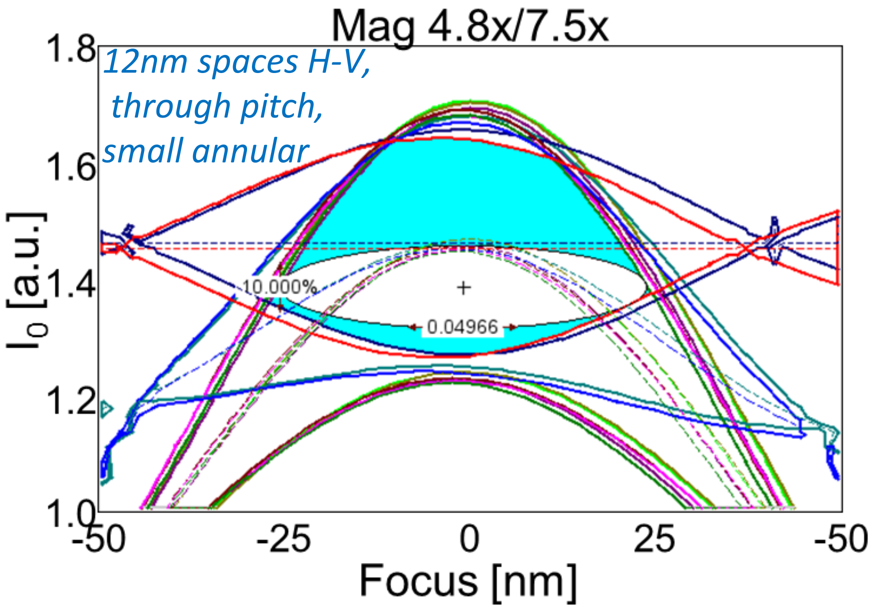
Highest MEF* is driving mask requirements

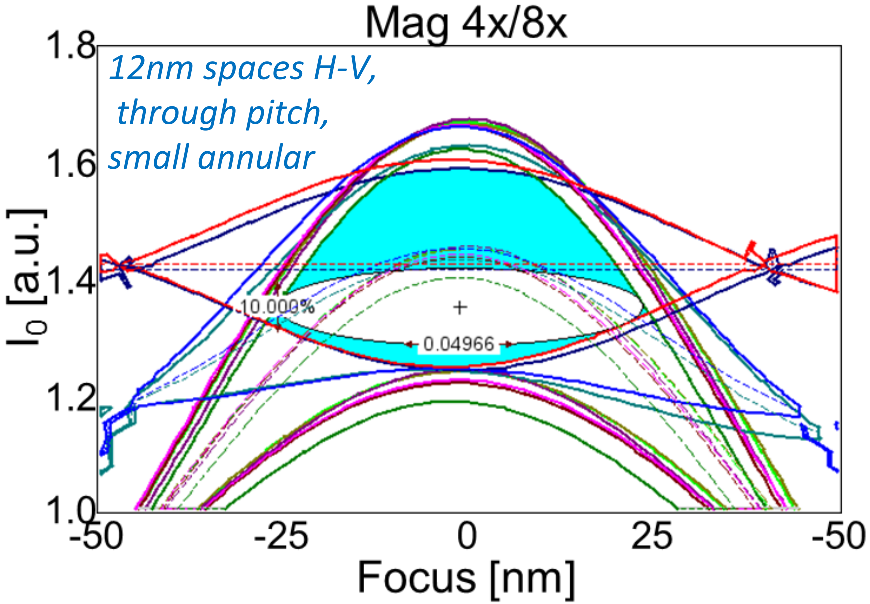


MEF* of Horizontal structures remains uncritical

***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.

Acknowledgements

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- **EUV Teams at ZEISS & ASML and our partners**

We make it visible.