EUV high NA anamorphic imaging

It’s all about the angles

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Eelco van Setten, Gerardo Bottiglieri, Thorsten Last, Alberto Colina, Jan Lubkoll, Gijsbert Rispens, Jan van Schoot

2016 International Symposium on Extreme Ultraviolet Lithography, Hiroshima, Japan

EUV: it's all about the angles

High-NA comes with large angles

ASML

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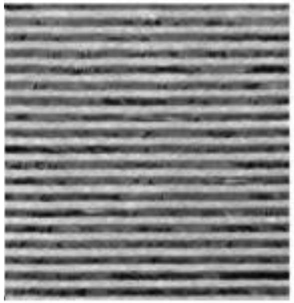
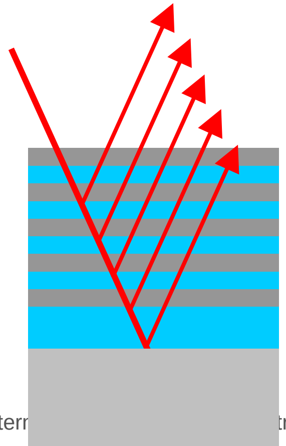
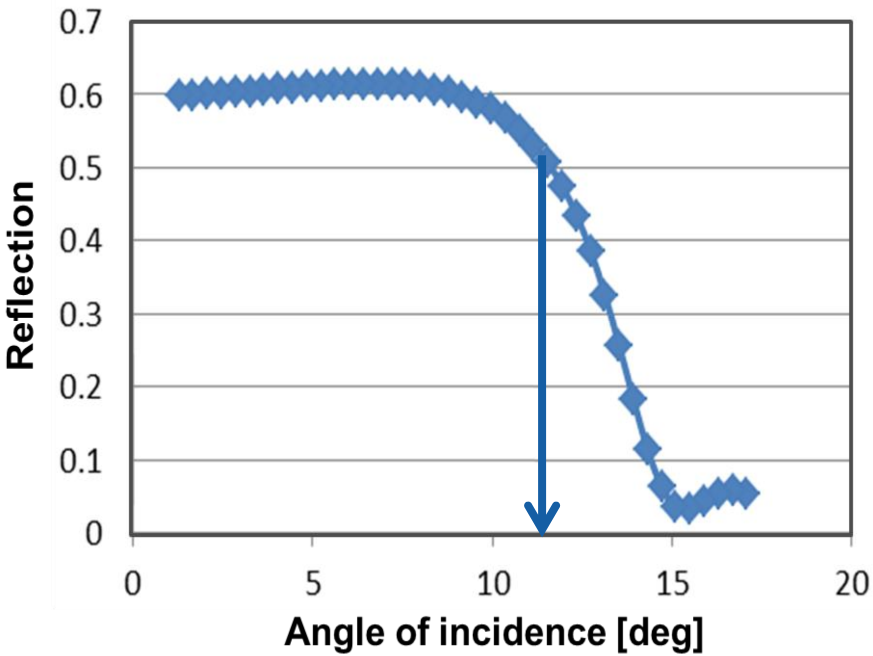
MoSi Multilayer

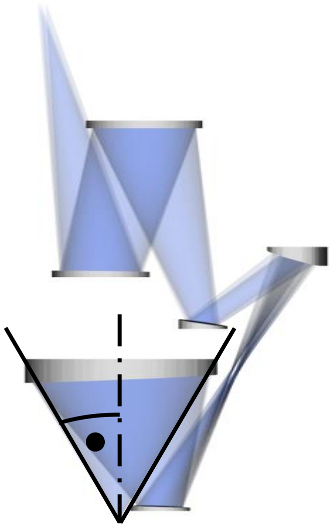




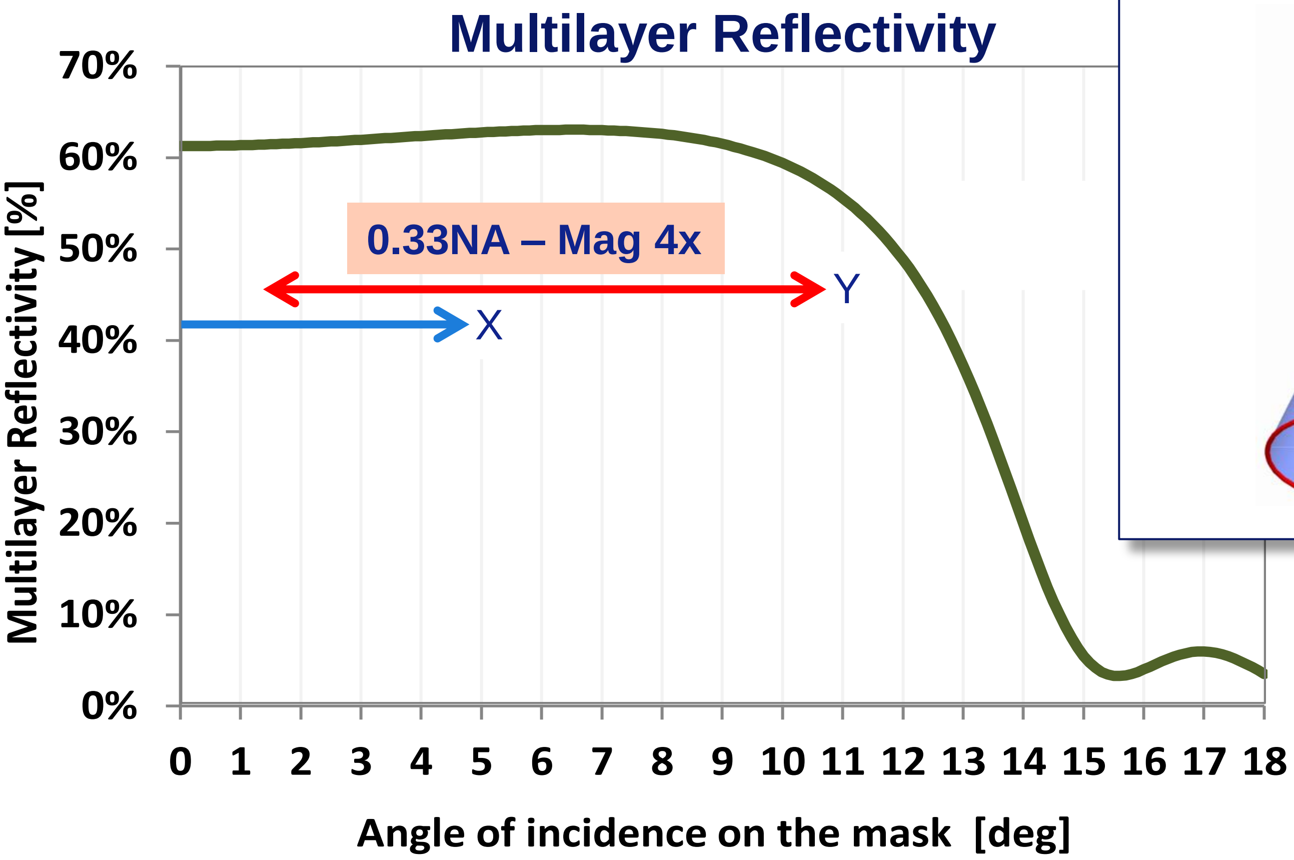
ML reflection

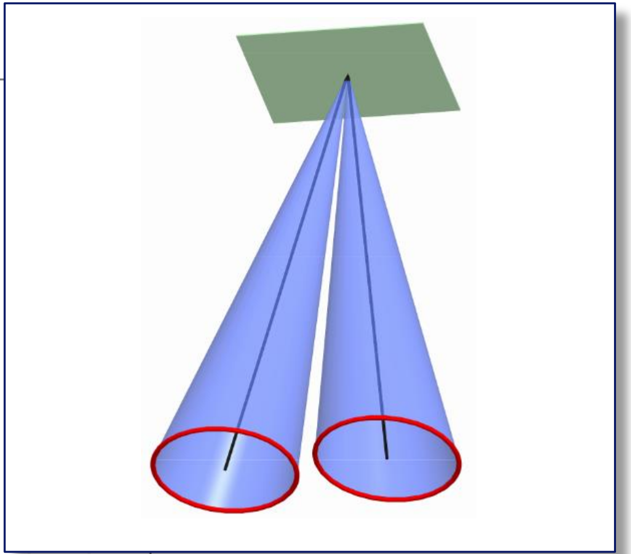


NA=0.55



Anamorphic magnification solves the angular spread at the mask





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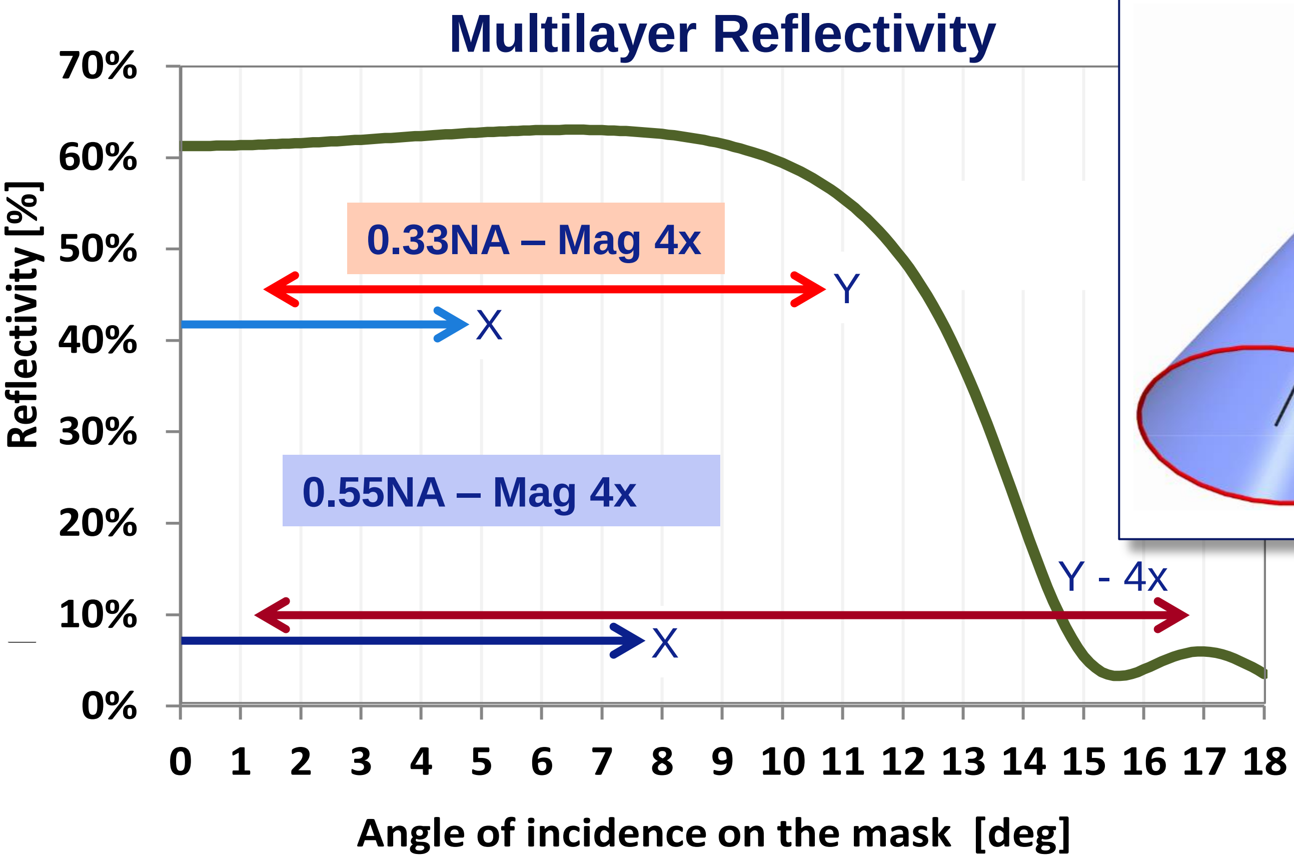

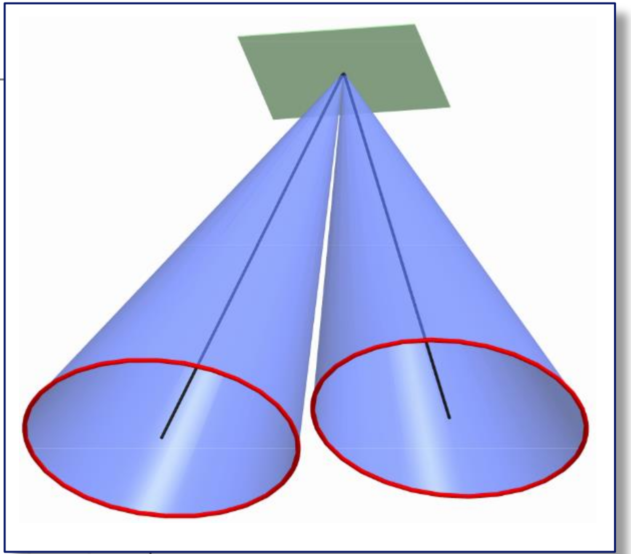

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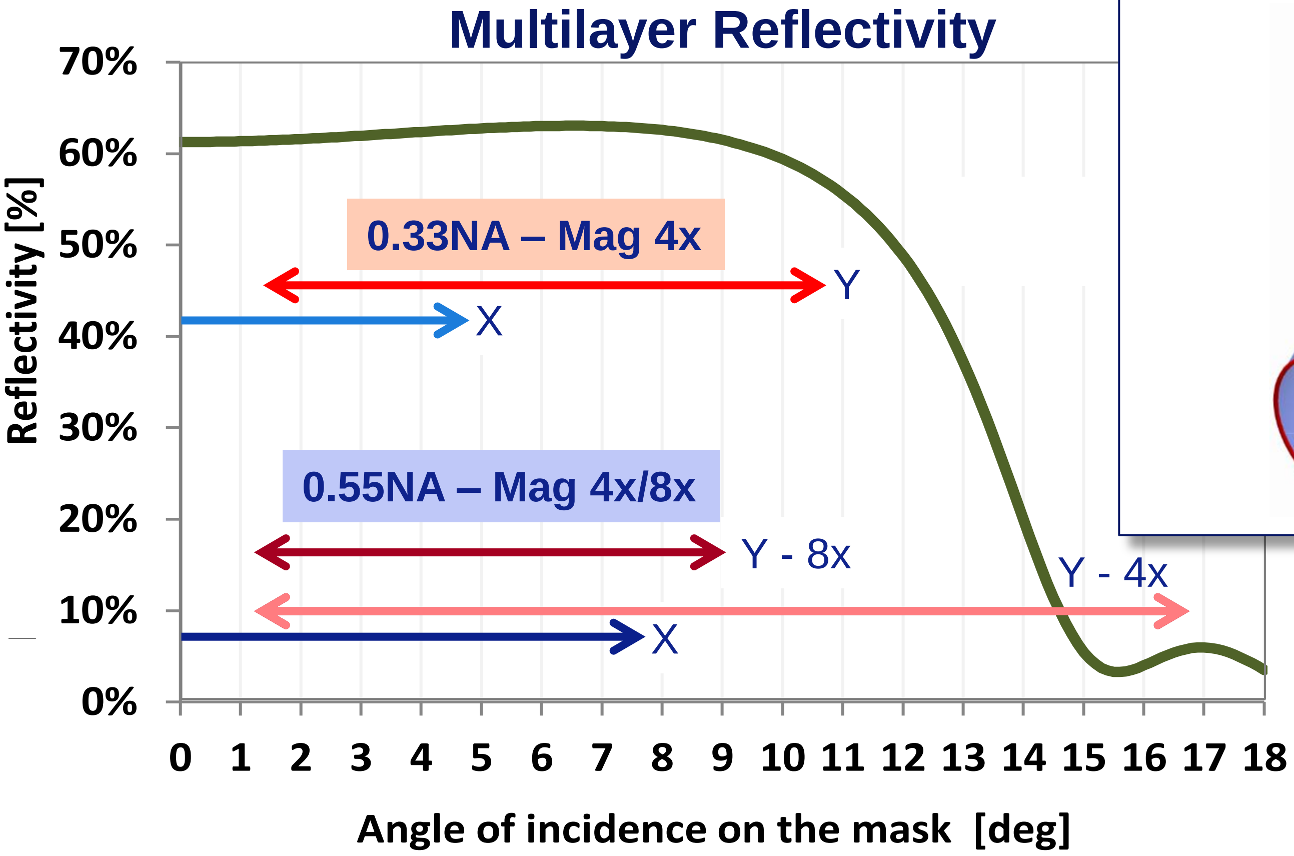
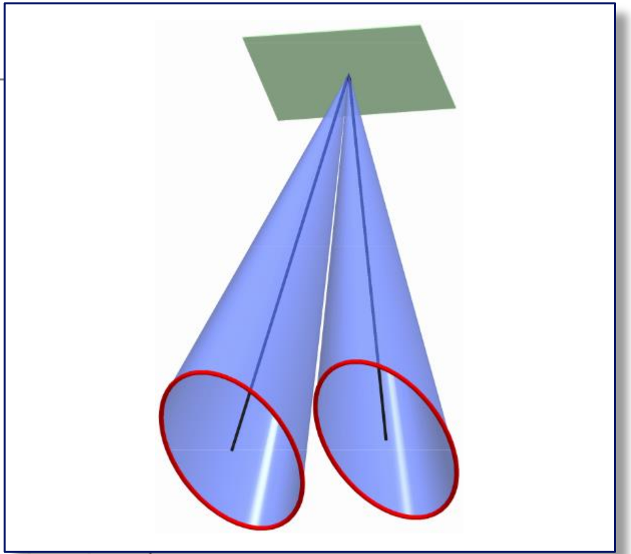
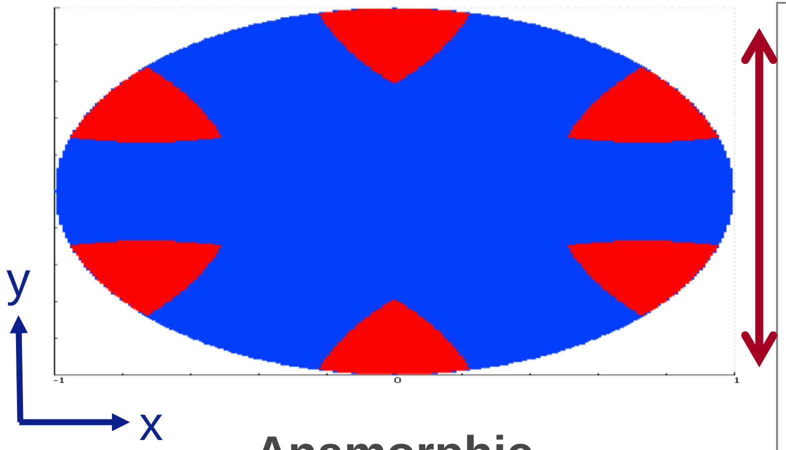


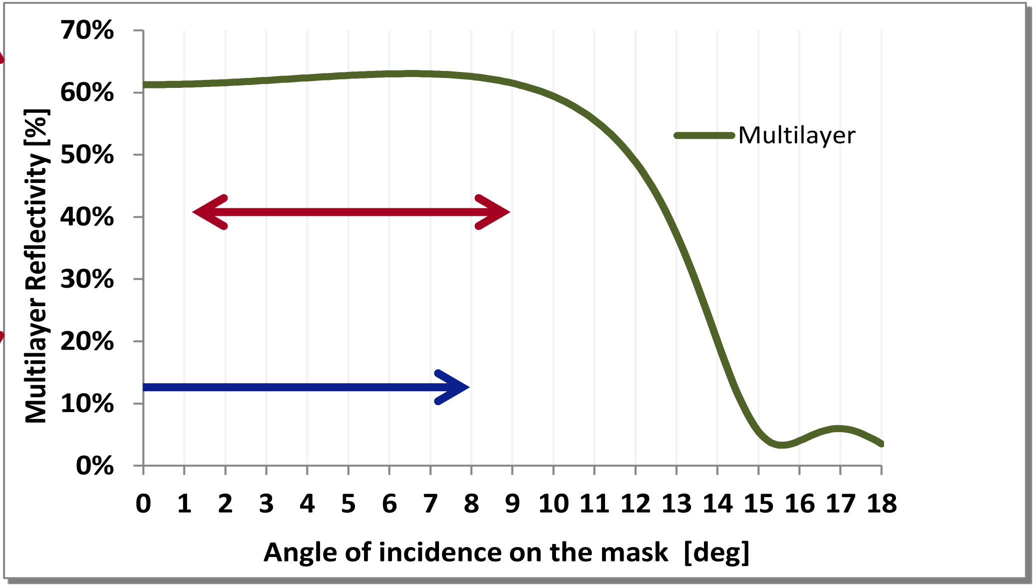


Anamorphic magnification: Circular exit pupil requires elliptical entrance pupil

Entrance pupil



Anamorphic MAG 4x/8x



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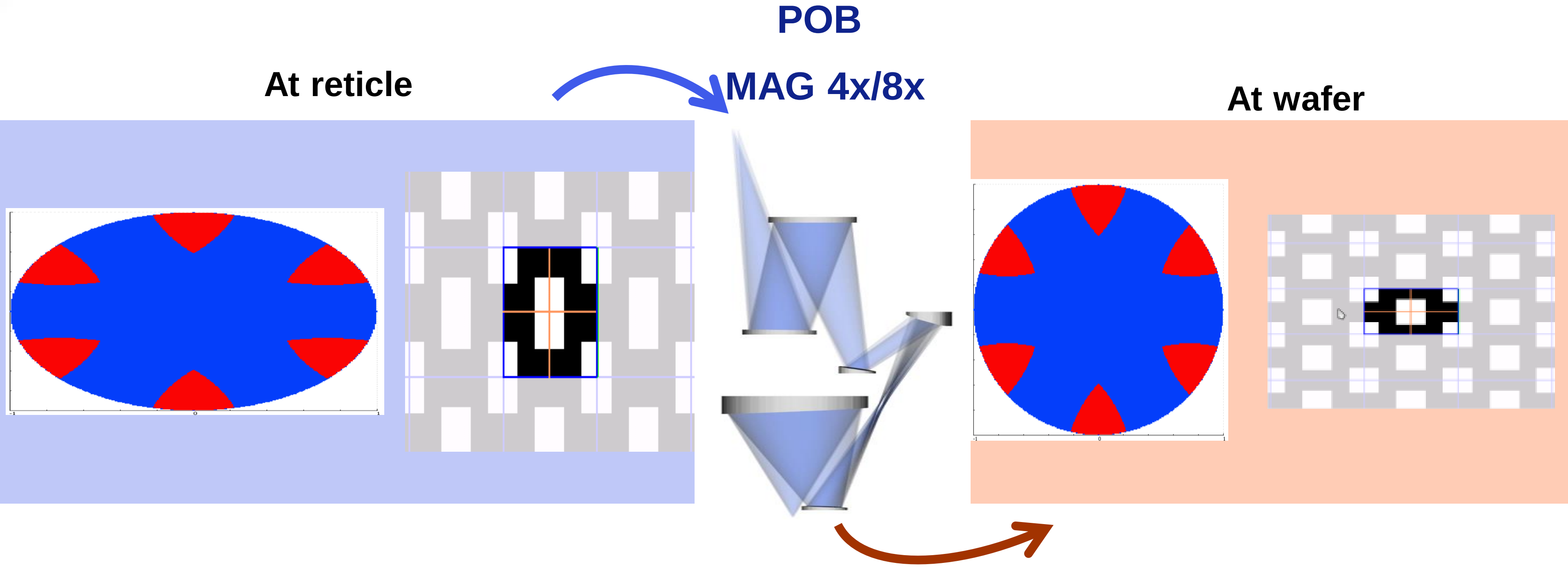
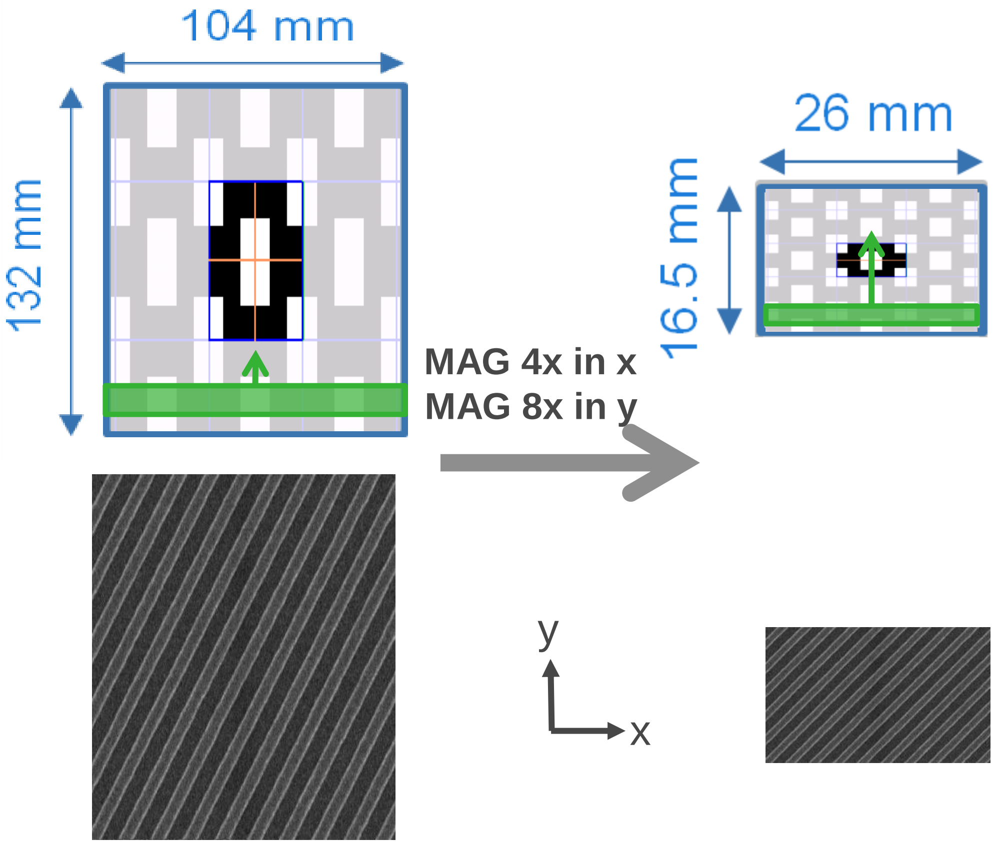


Contents

Main consequences: Half field imaging, mask pattern is stretched in scanning direction



Anamorphic masks:

- Image field half of current size
- Mask pattern stretched → Feature distortions on mask
- 4x-direction will drive mask requirements (CD, registration and defectivity)

Note: rectangular slit shown for illustration purposes

New MEF definition to handle difference in X,Y-magnification

- Traditional Mask Error Factor (MEF) is normalized with the magnification:

$$MEF = \frac{\Delta CD_{wafer}}{\Delta CD_{mask} / mag}$$

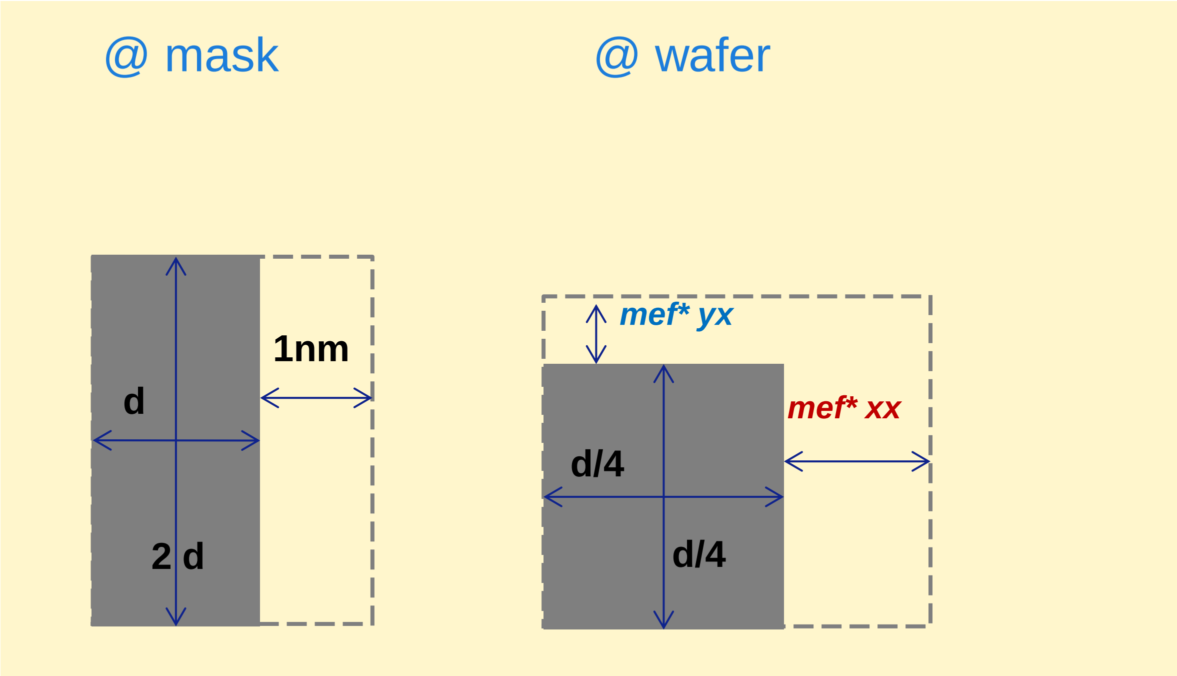
- Not convenient for anamorphic → Same MEF corresponds to different mask CD tolerance in X and Y

- A new Mask Error Factor, MEF*, is defined:

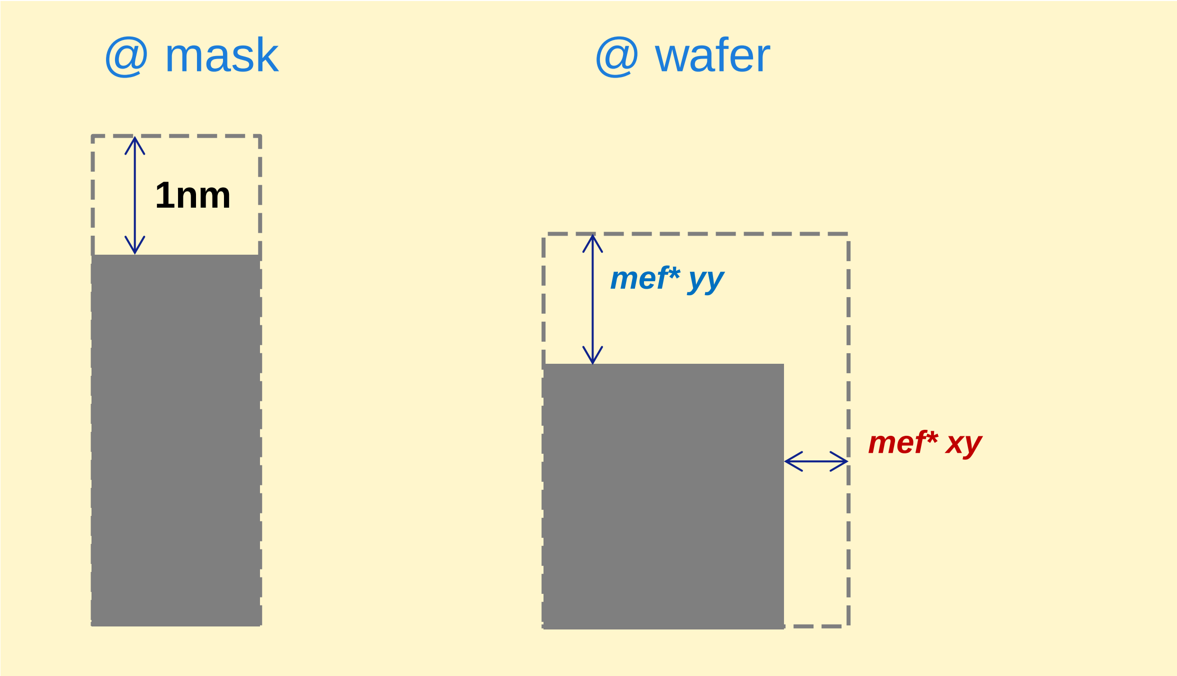
$$MEF^* = \frac{\Delta CD_{wafer}}{\Delta CD_{mask}}$$

→ 1nm mask CD error gives 'MEF*' nm wafer CD error

2D features experience strong X-Y interaction for mask CD errors



2D features experience strong X-Y interaction for mask CD errors



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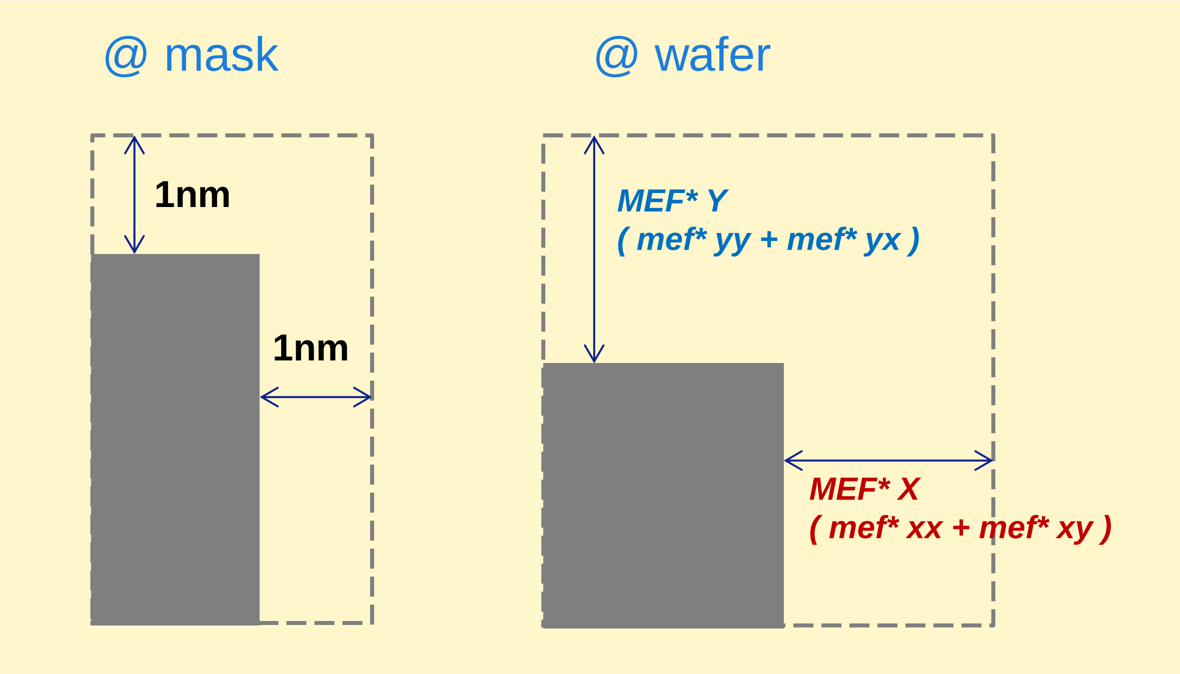
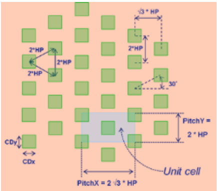
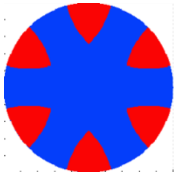
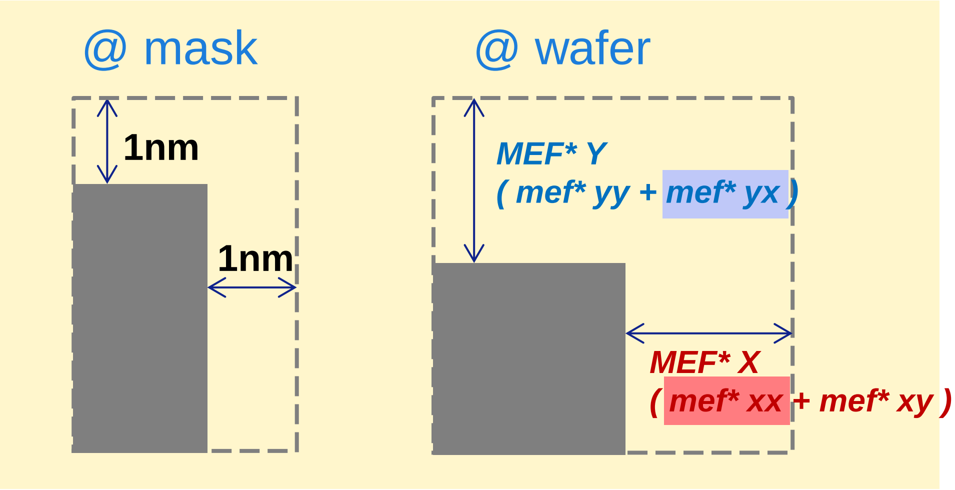
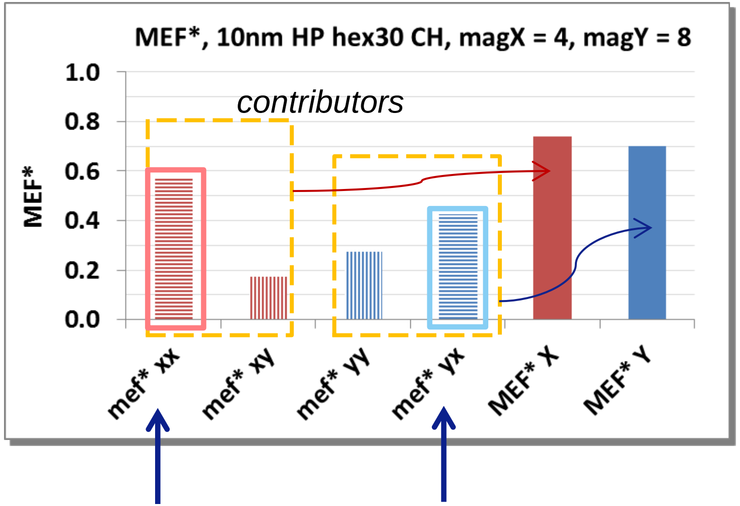


Mask error in X-direction dominates error on wafer in both directions







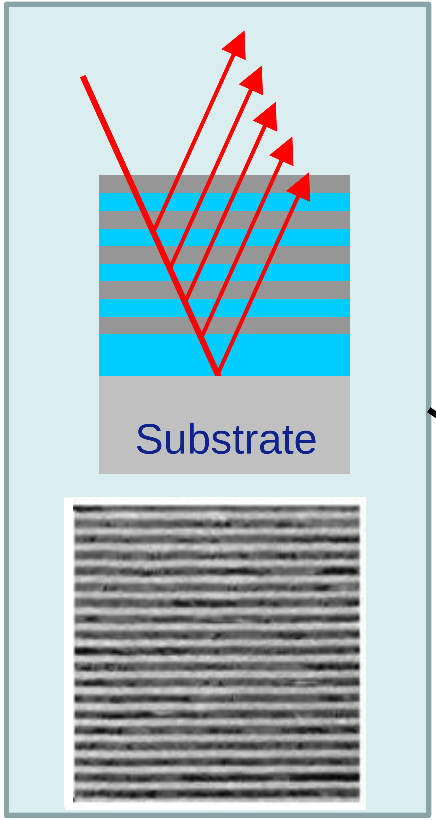


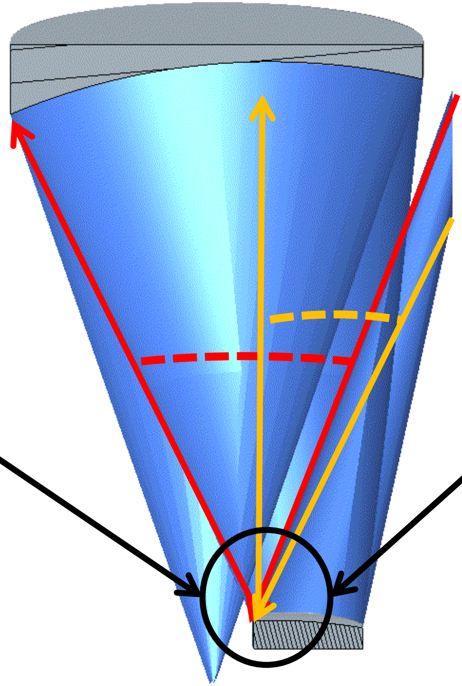
Mask error in X-direction

Contents

Multi-layers set limits to angles & angular spread

Angles must be reduced for high-NA optics



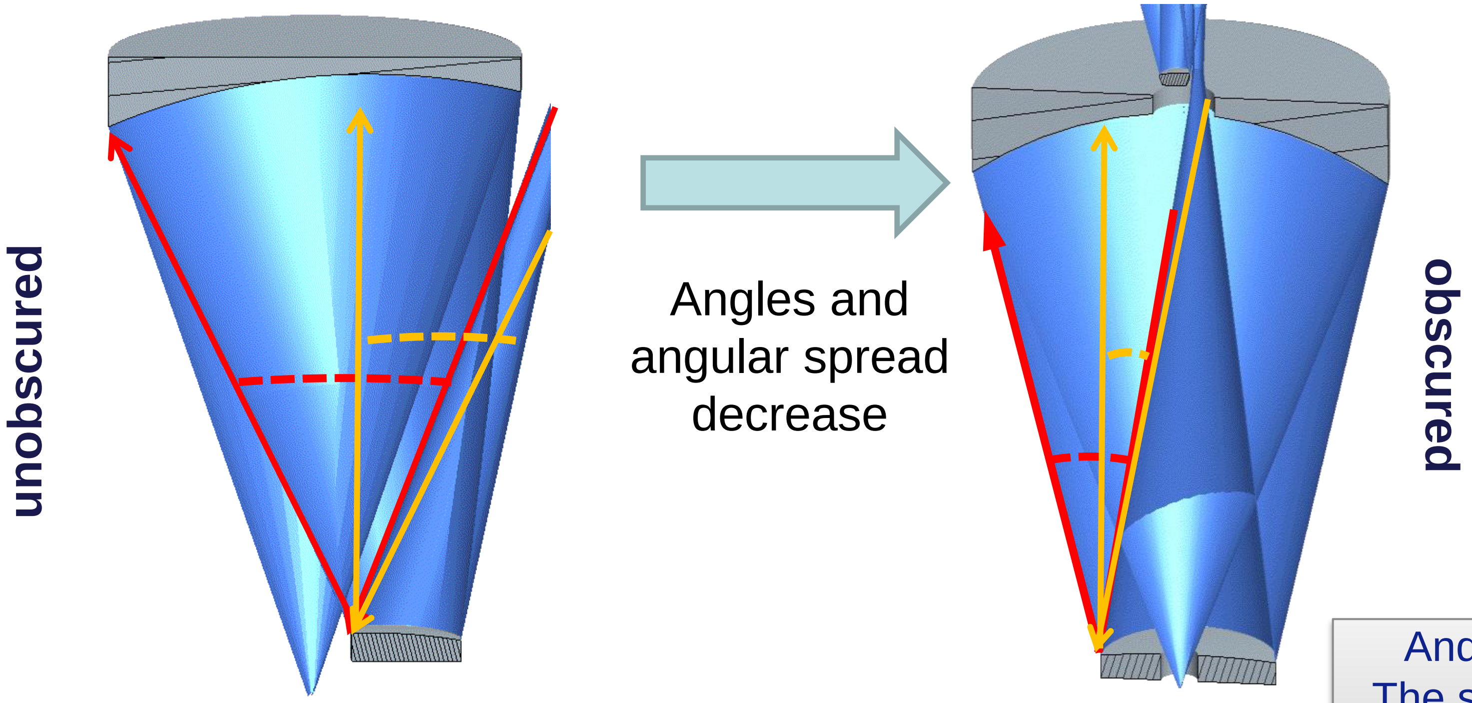


Standard EUV coatings cannot handle these large angles

We have to limit the angles on the mirror
→
we need another trick!

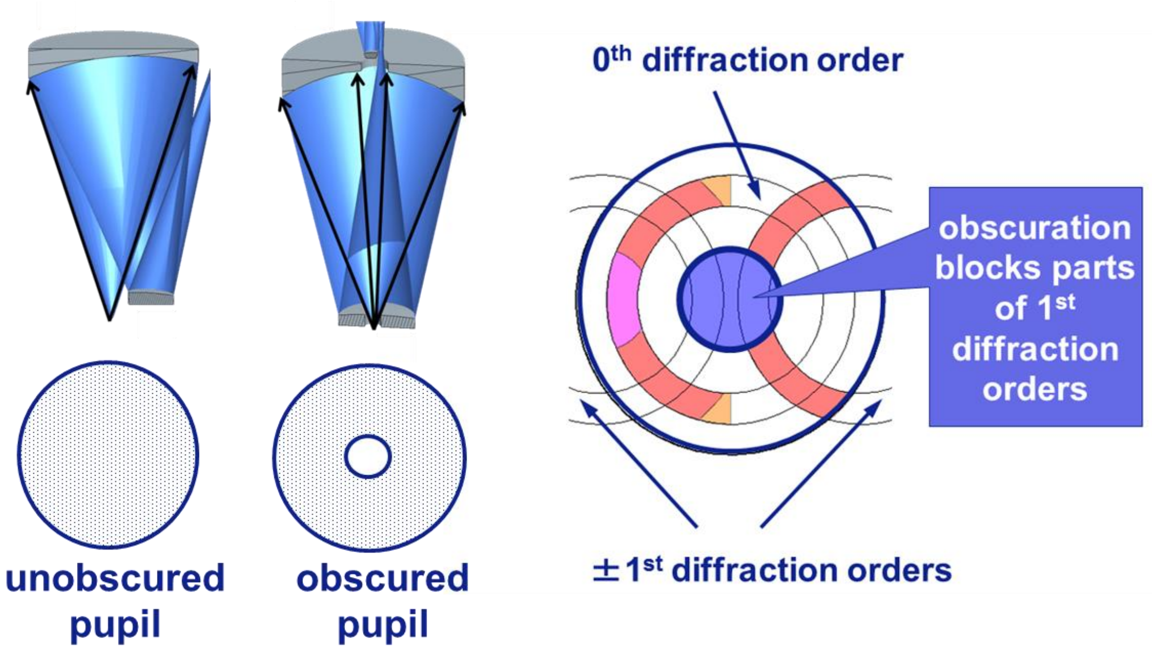
There is a solution: We drill a hole into the mirror.

Smaller angles enable transmission gain vs non-obscured NA 0.33



And even better: The smaller angular range increases the transmission

Obscuration comes at expense of blocking parts of diffraction orders

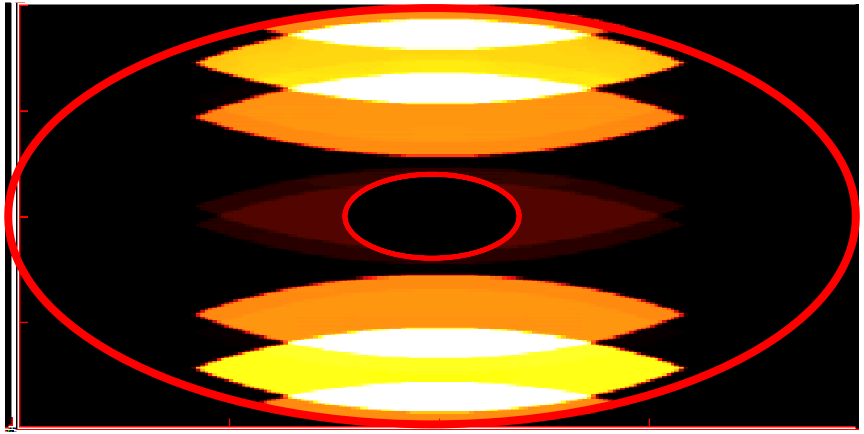


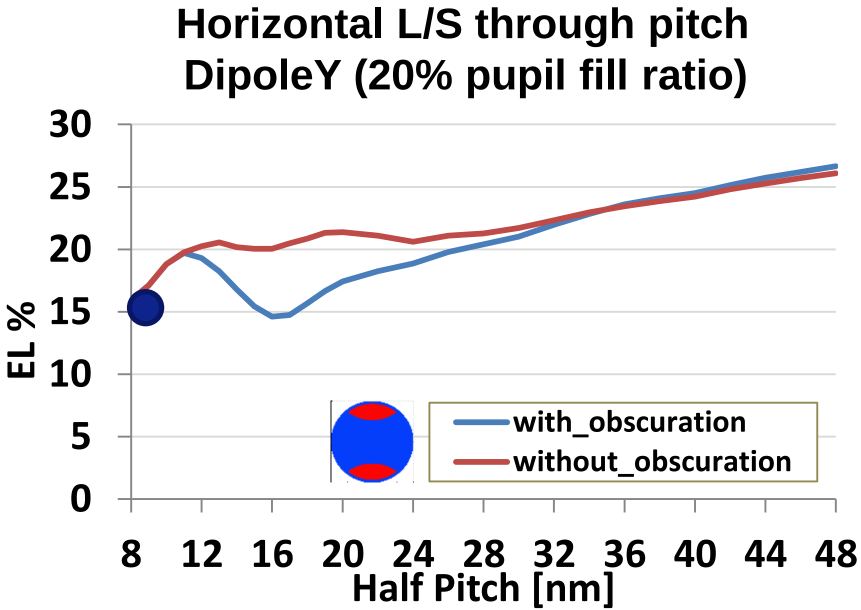
Obscuration may result in:

- application dependent contrast loss
- Non-telecentricity

Obscuration radius limited to 20% of the pupil radius
(= 4% of the pupil area)

Contrast loss for semi-dense pitches using Dipole illumination → large part diffraction order blocked





- Worst point has acceptable Exposure Latitude
- Mitigation by means of SMO and SRAFs (for 16nm HP and up)

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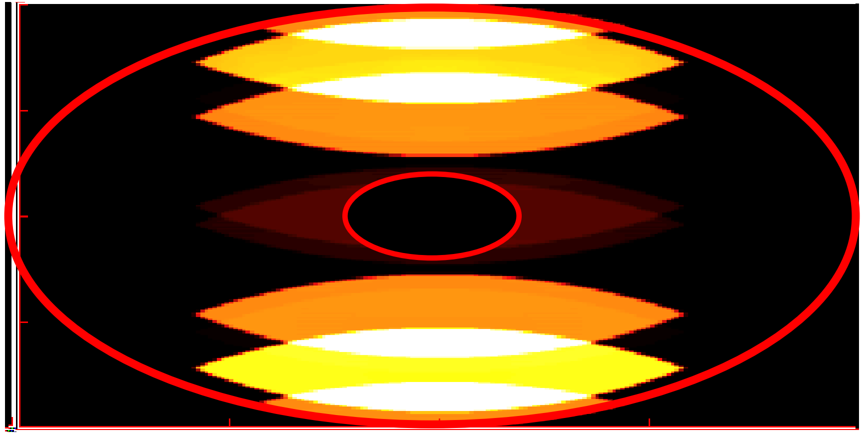
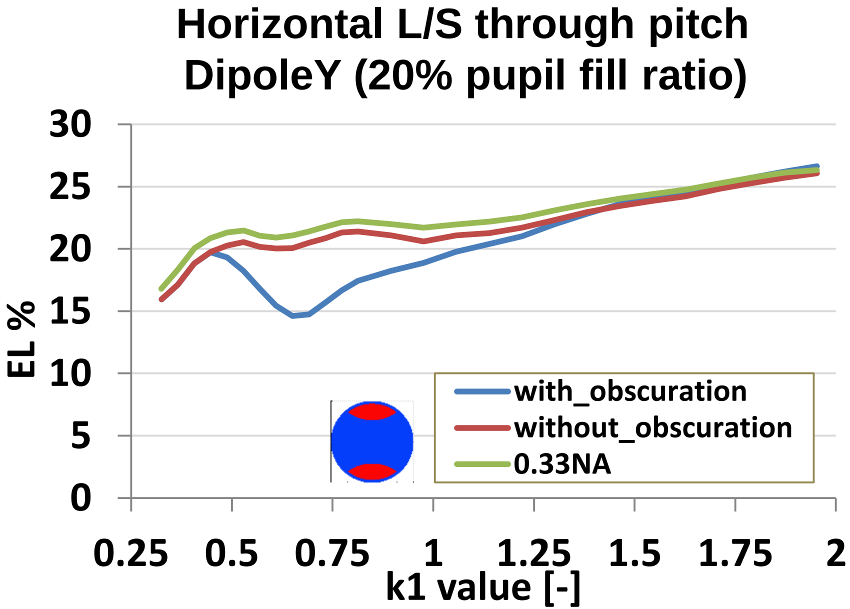
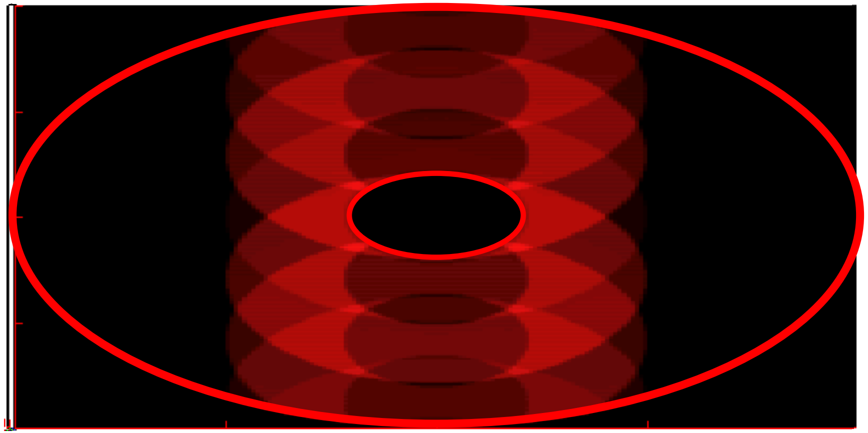
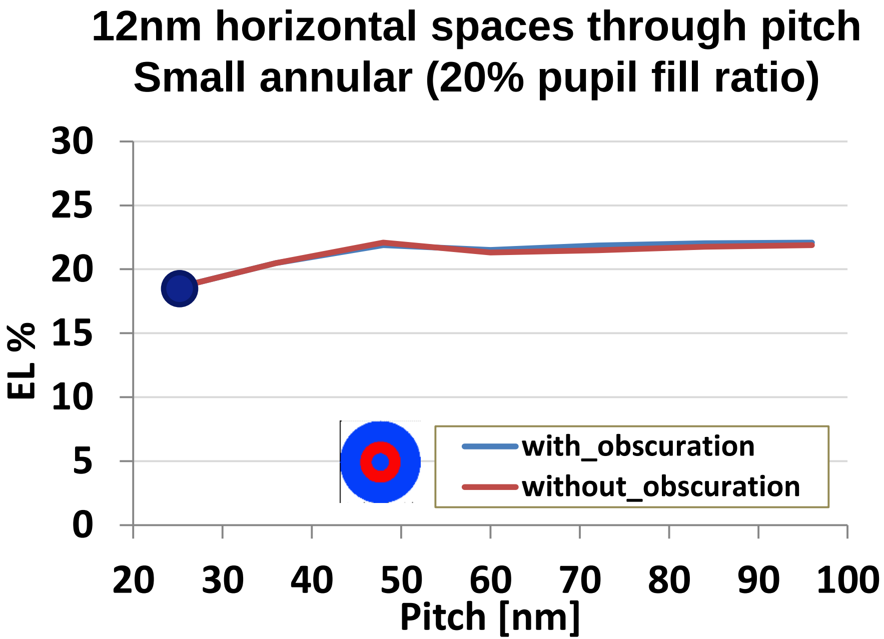




- Worst point has acceptable Exposure Latitude
- Mitigation by means of SMO and SRAFs (for 16nm HP and up)
- Contrast unobscured pitches very similar to 0.33NA for identical k1 values

Negligible contrast loss for illumination shapes of which small part diffraction orders is blocked





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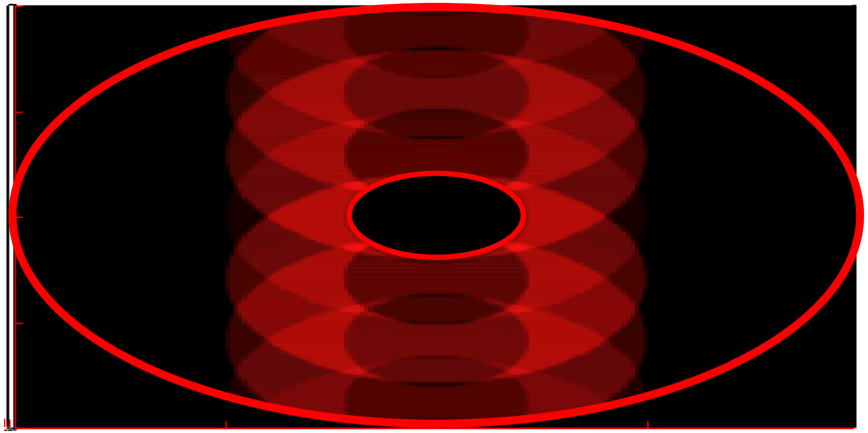
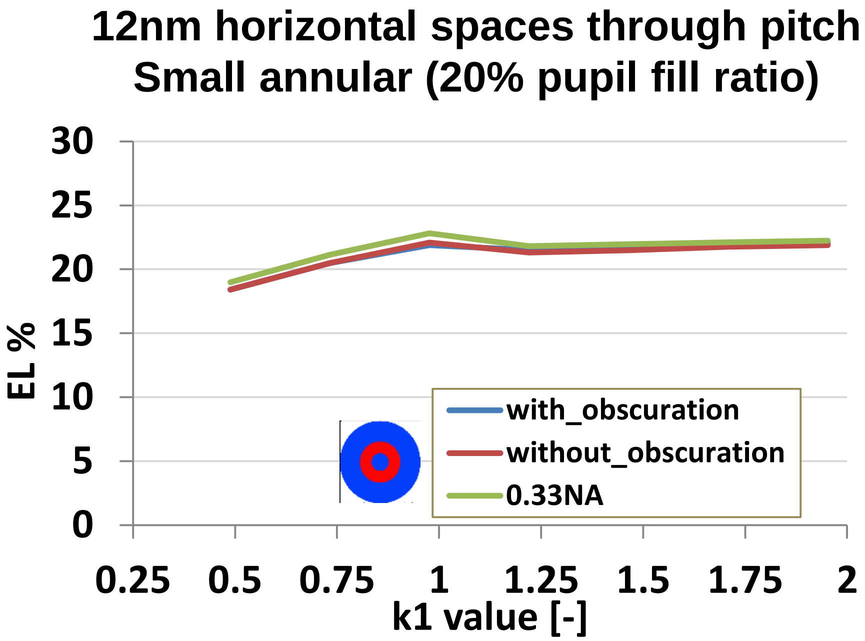
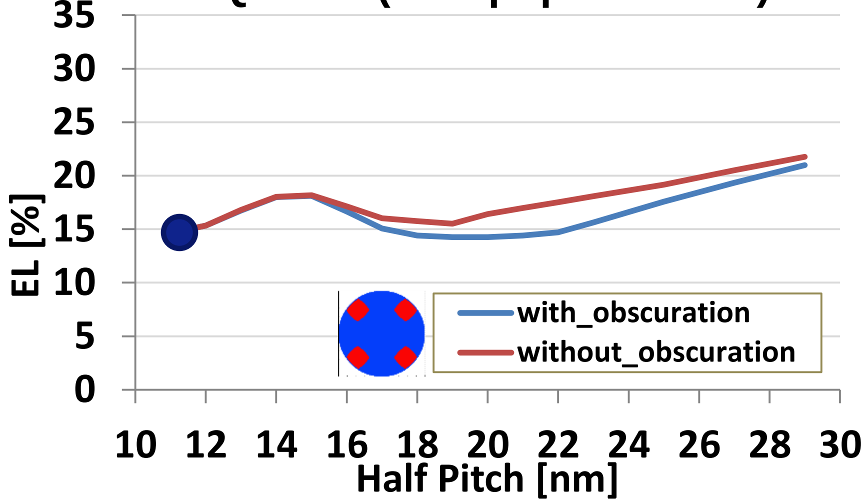




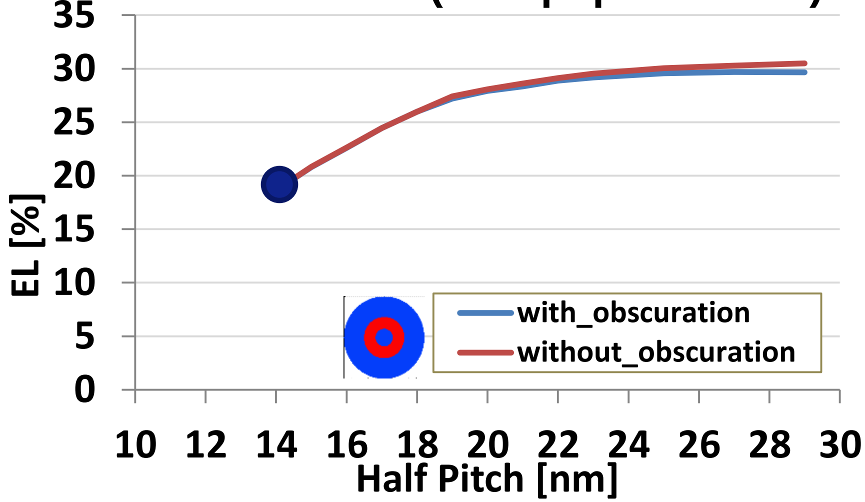
- Contrast very similar to 0.33NA for identical k1 values

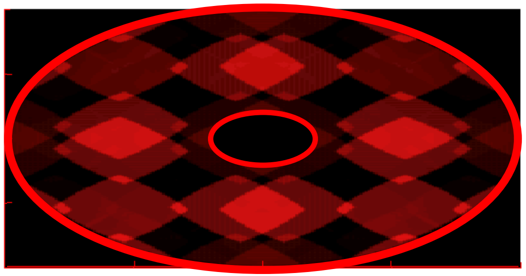
High contrast through pitch maintained for 2D features

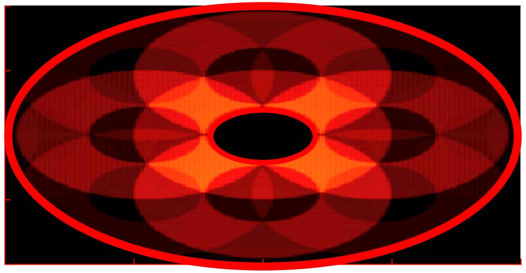
Dense contact holes through pitch
Quasar (20% pupil fill ratio)



Dense contact holes through pitch
Small annular (20% pupil fill ratio)

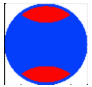


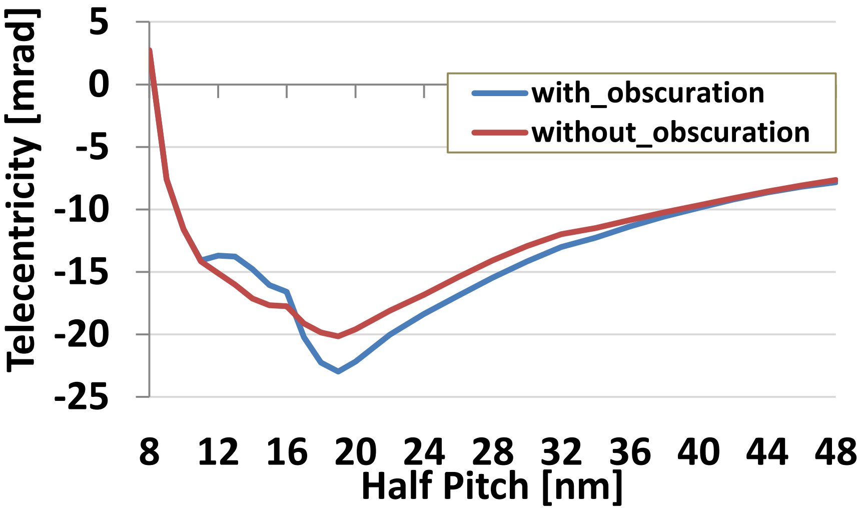




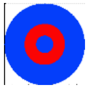
Obscuration has limited impact on non-telecentricity for 1D features→ driven by Mask3D effects

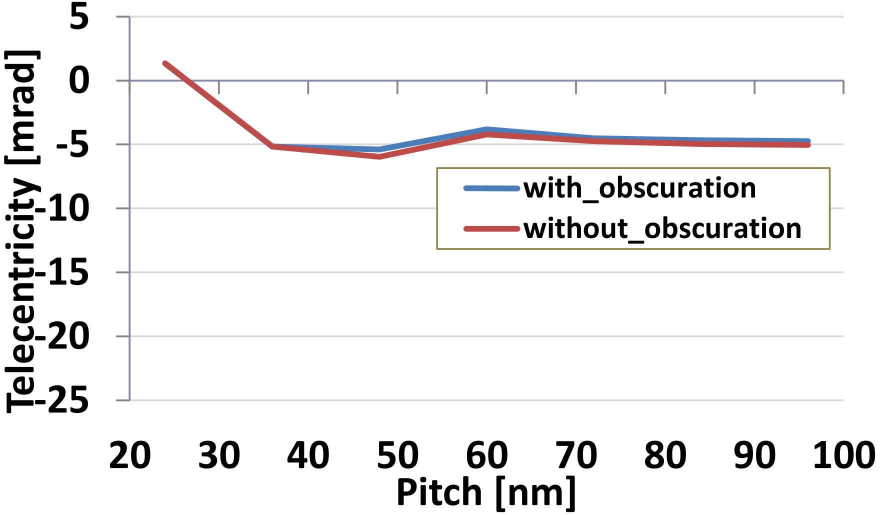
Horizontal L/S through pitch
DipoleY (20% PFR)





12nm horizontal spaces through pitch
Small annular (20% PFR)





- Compensation by SMO (asymmetric illumination) or mask stack optimization

Obscuration has limited impact on non-telecentricity for 1D features→ driven by Mask3D effects

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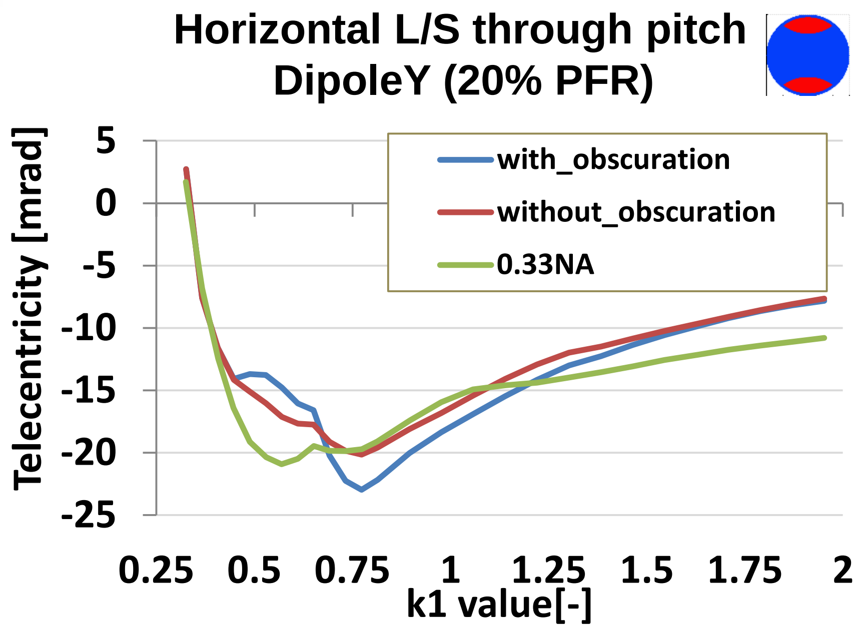
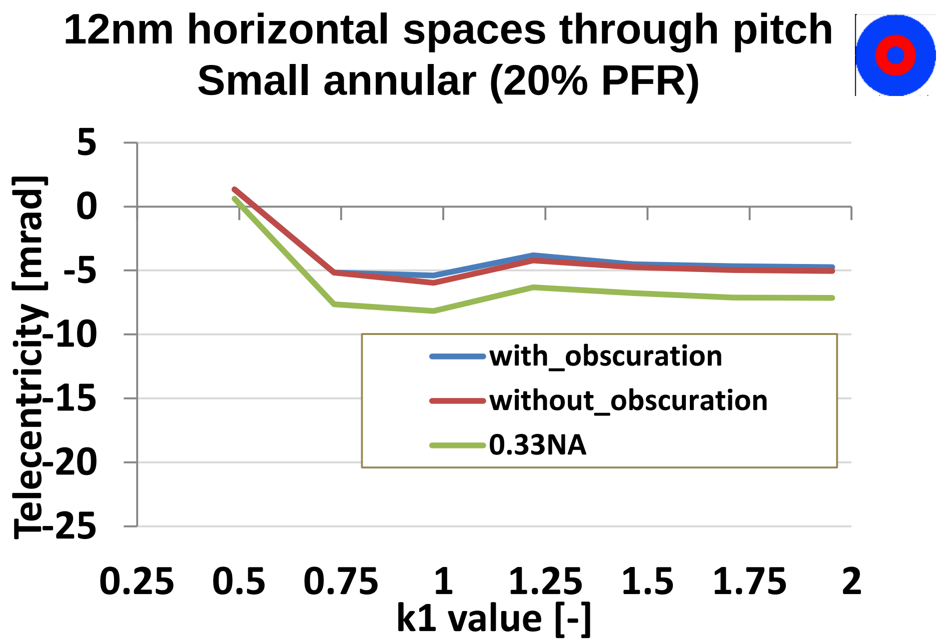
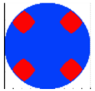


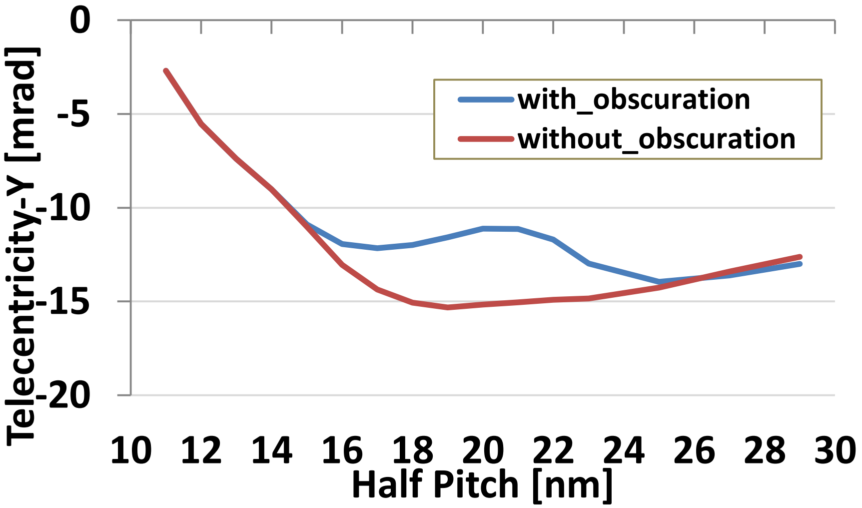


- Compensation by SMO (asymmetric illumination) or mask stack optimization

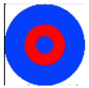
Obscuration has limited impact on non-telecentricity for 2D features → driven by Mask3D effects

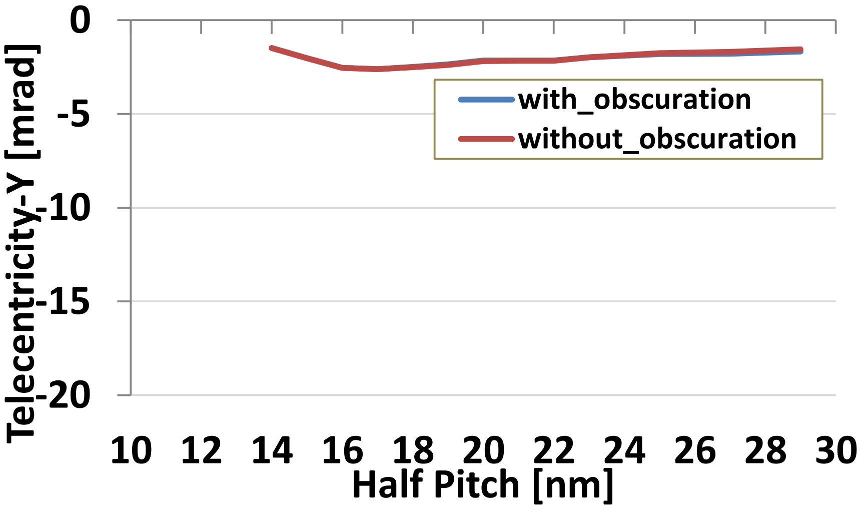
Dense contact holes through pitch
Quasar (20% pupil fill ratio)





Dense contact holes through pitch
Small annular (20% pupil fill ratio)

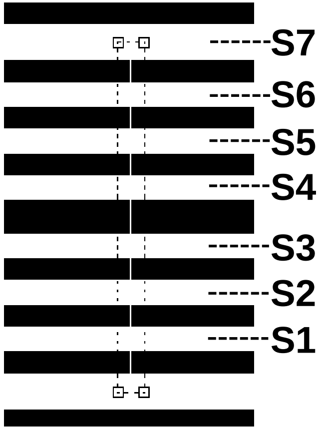




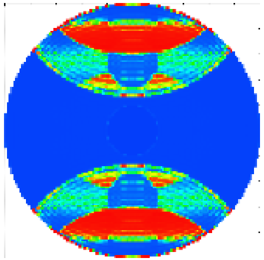
- Small compensation effect observed for semi-dense pitches

Anamorphic Placement aware SMO mitigates non-telecentricity

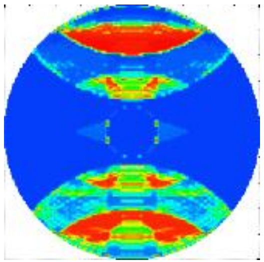
Multi-pitch L/S pattern 18nm min. pitch



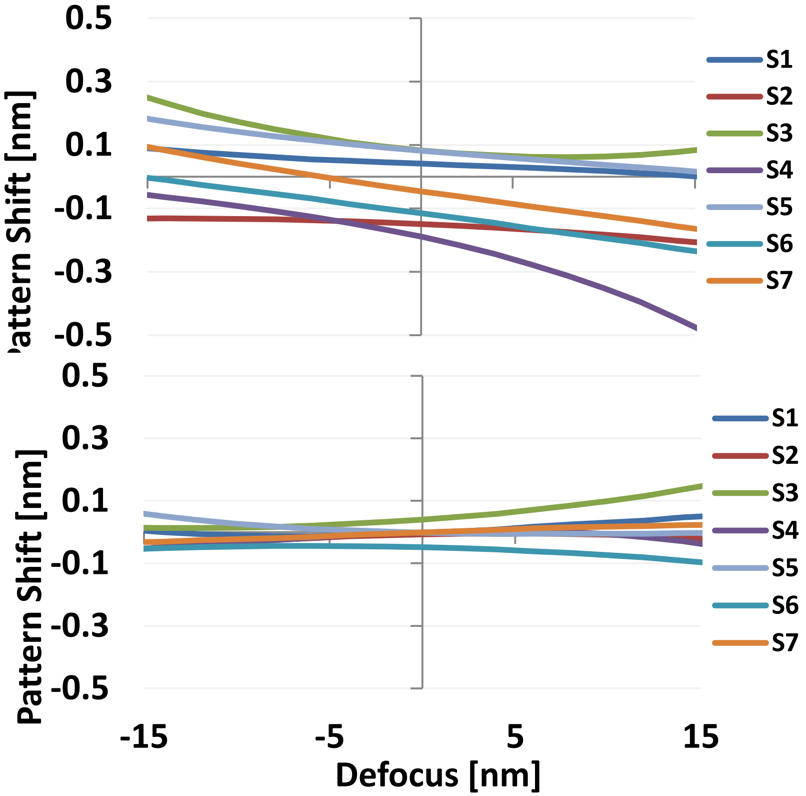
Flat-Mask SMO source



Placement aware SMO source



Pattern shift through focus



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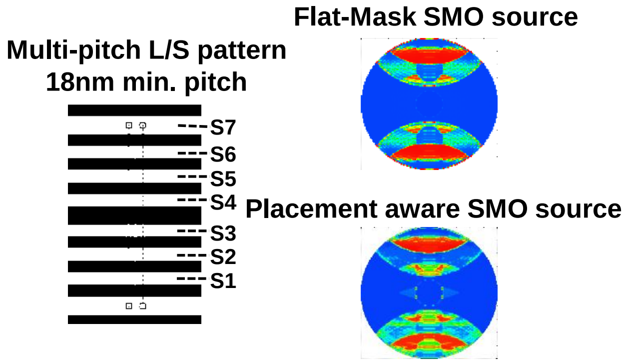
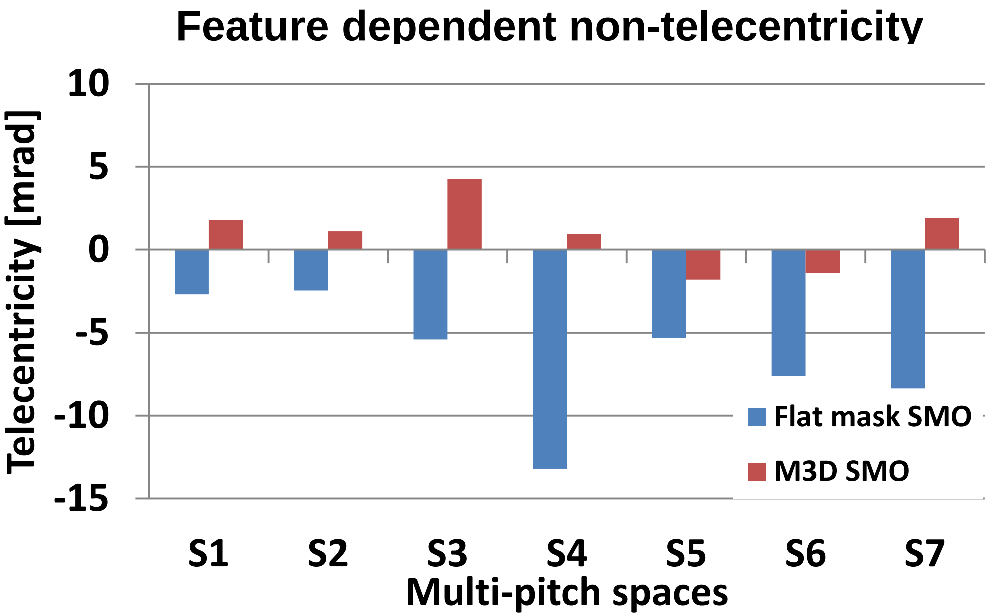
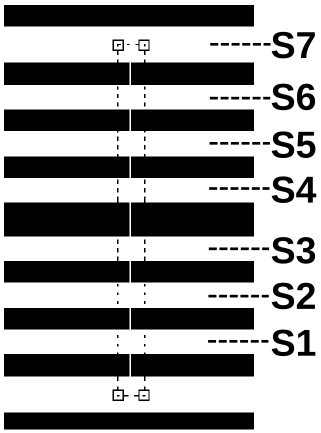




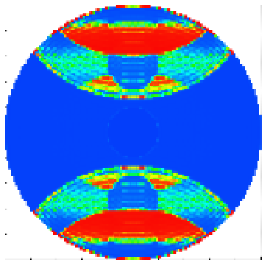
- Max non-telecentricity reduces from 13 to 4mrad

Anamorphic Placement aware SMO restores overlapping Process window

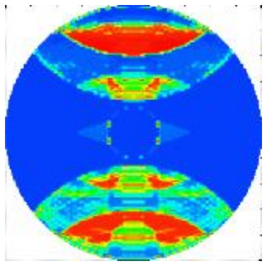
Multi-pitch L/S pattern 18nm min. pitch



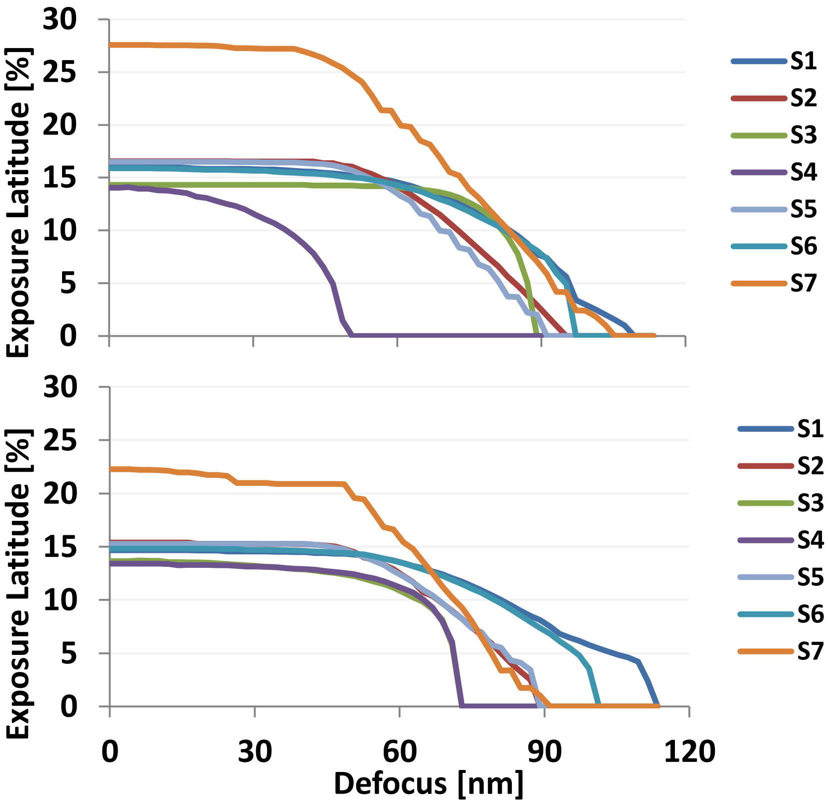
Flat-Mask SMO source



Placement aware SMO source



Exposure Latitude vs DoF



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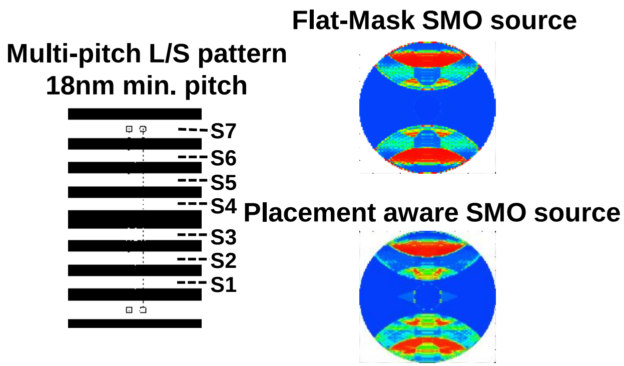
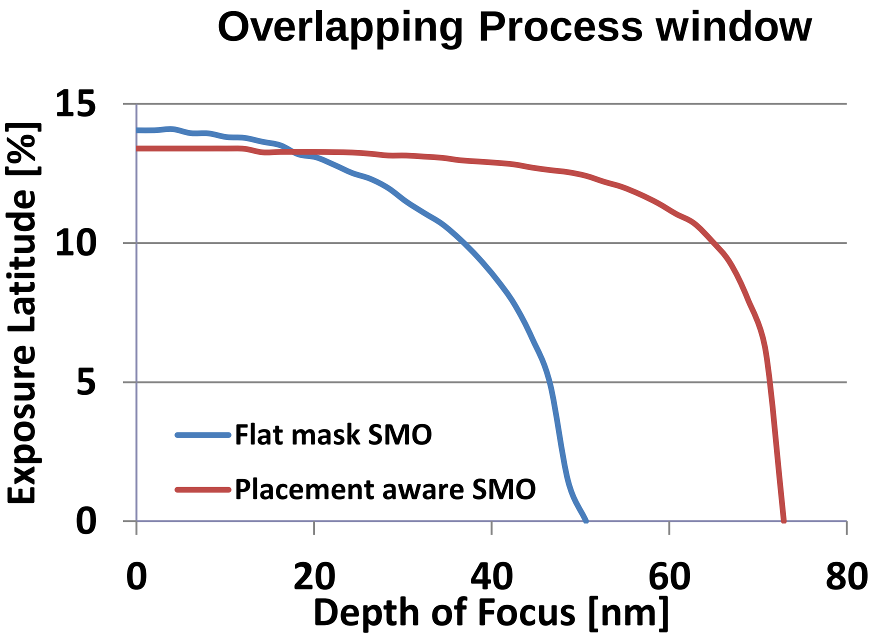
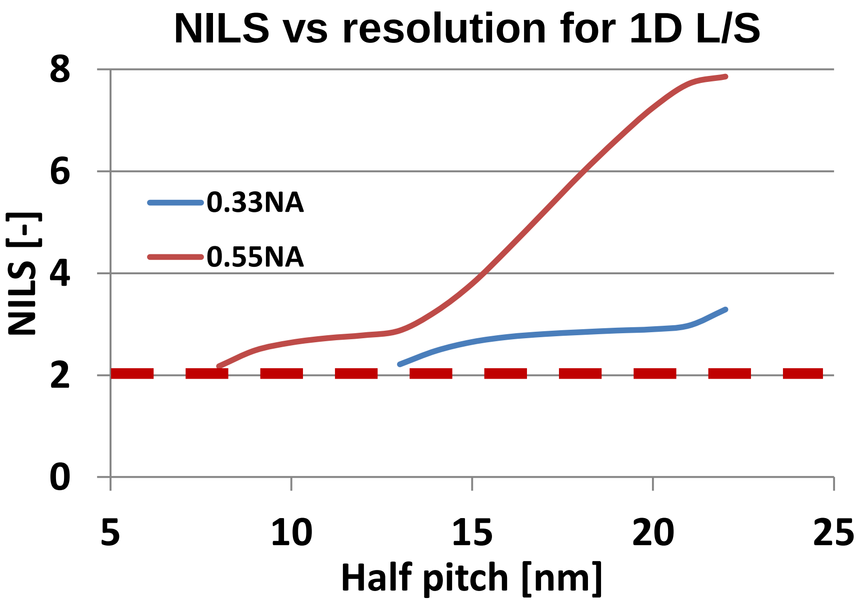


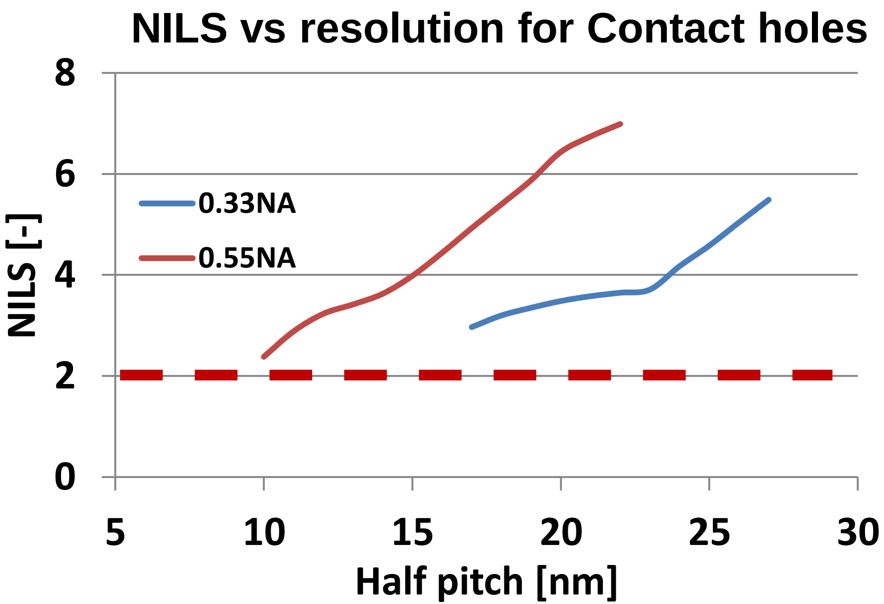


- Overlapping PW @ 10% EL increases from 36 to 64nm

Contents

0.55NA gives high image contrast down to 8nm L/S and 10nm contact holes





Local CDU dominant contributor to EPE – Mitigation via image contrast enhancement

What are the important imaging metrics

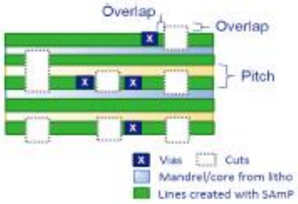
Importance of LCDU and LWR

- LCDU contributes significantly in EPE budget

$$3\sigma_{EPE} = \sqrt{(3\sigma)^2{}_{overlay} + \left(\frac{3\sigma_{CDU\ lines}}{2}\right)^2 + \left(\frac{3\sigma_{CDU\ cuts}}{2}\right)^2 + \frac{3(\sigma_{LCDU\ cuts})^2 + 3(\sigma_{LWR\ lines})^2}{2}}$$

J. Mulkens et al., Proc. SPIE 9522 (2015)

"… edge placement error (EPE) is the most important parameter of concern for lithography." **Jongwook Kye, Global Foundries**
http://electroiq.com/blog/2015/07/tackling-advanced-litho-challenges-on-the-path-to-node-5/



Local CDU dominant contributor to EPE – Mitigation via image contrast enhancement

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- LCDU contributes significantly in EI

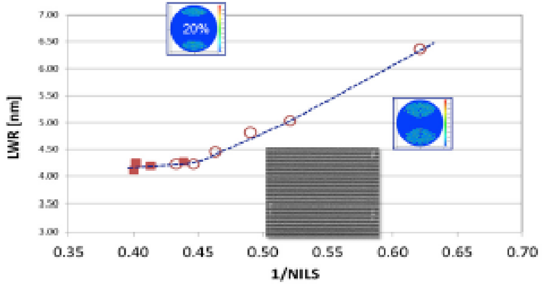
$$3\sigma_{EPE} = \sqrt{(3\sigma)^2_{overlay} + \left(\frac{3\sigma_{CDU\ lines}}{2}\right)^2 + \ldots}$$

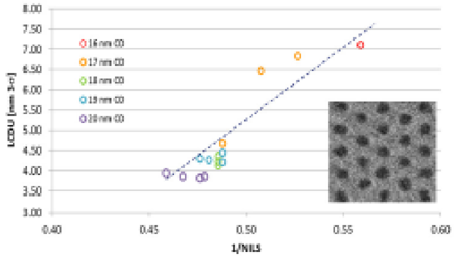
J. M

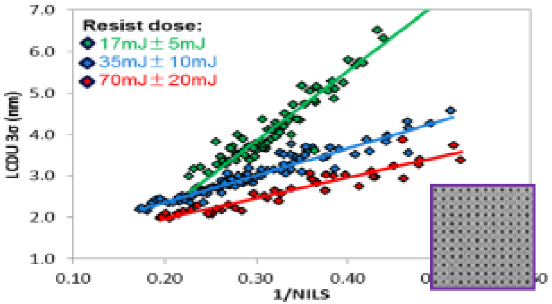
"... edge placement error (EP concern for lithography." Jon
http://electroiq.com/blog/2015/07/ta

For a given resist local CDU is uniquely linked to image contrast

Public
Slide 8
<Date>







SMO has to optimize contrast, while not sacrificing DoF and pattern shift at best focus and through focus

From "contrast optimization for 0.33NA lithography", SPIE 2016

Jo Finders, SPIE 2016 and Fraunhofer IISB Litho simulation workshop 2016

High NA most powerful knob to control Local CDU and dose requirements

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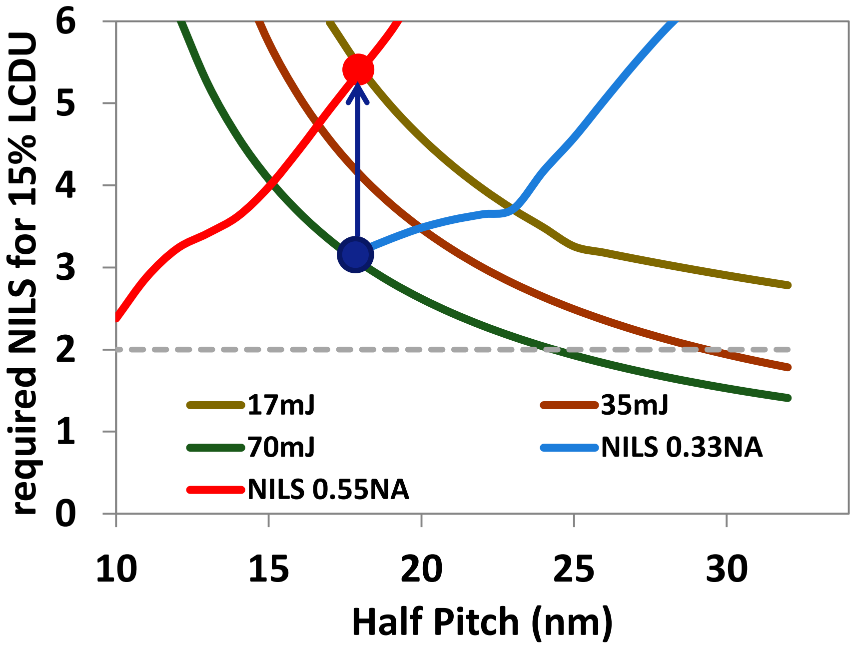
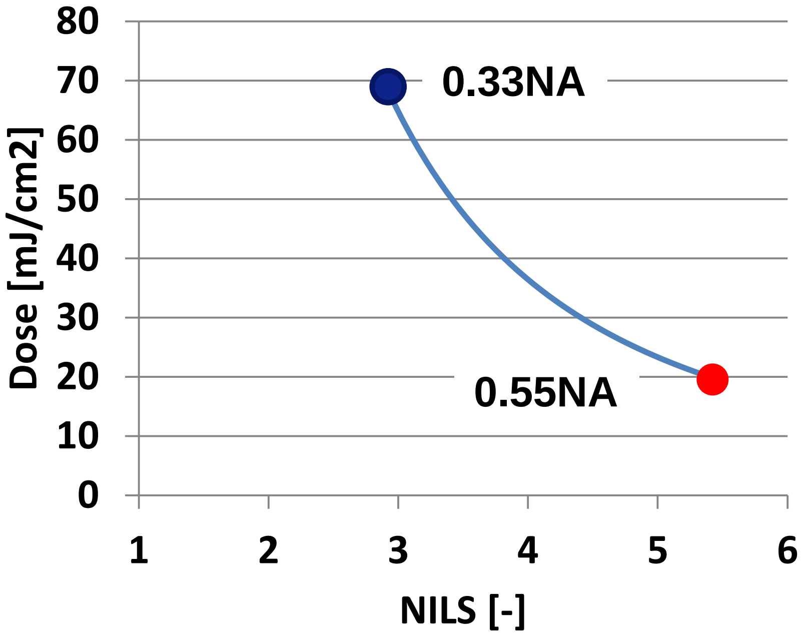
Confidential
Slide 35



Dose to meet 15% LCDU requirement for 18nm dense holes



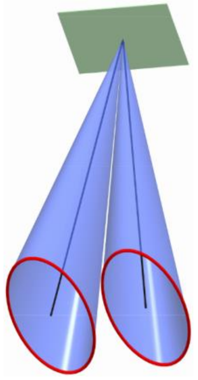
Courtesy: Sander Wuister, Gijsbert Rispens

Contents

Summary and conclusions

It's all about the angles

- Anamorphic imaging solves the angular spread at the mask
  - M3D effects similar to 0.33NA
- Central obscuration enables high throughput with good imaging performance
  - Anamorphic SMO does the rest



EUV High NA

- Increased resolution enabling 8nm HP imaging
- Above all… superior **contrast**
  - Key for reducing LCDU and EPE budget for maintaining shrink roadmap

The authors would like to thank:

ASML

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Thank you for your attention !