Public

EUV High-NA scanner to extend EUV single exposure

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Sascha Migura[3] , Bernhard Kneer[3], Jens Timo Neumann[3], Winfried Kaiser[3]

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15 June 2016, EUVL Workshop, Berkeley

Public quotes from major customers on EUV adoption

Brian Krzanich CEO Intel

EUV to shorten time to yield in the next 5 yrs

EUV will be adopted for production at N5

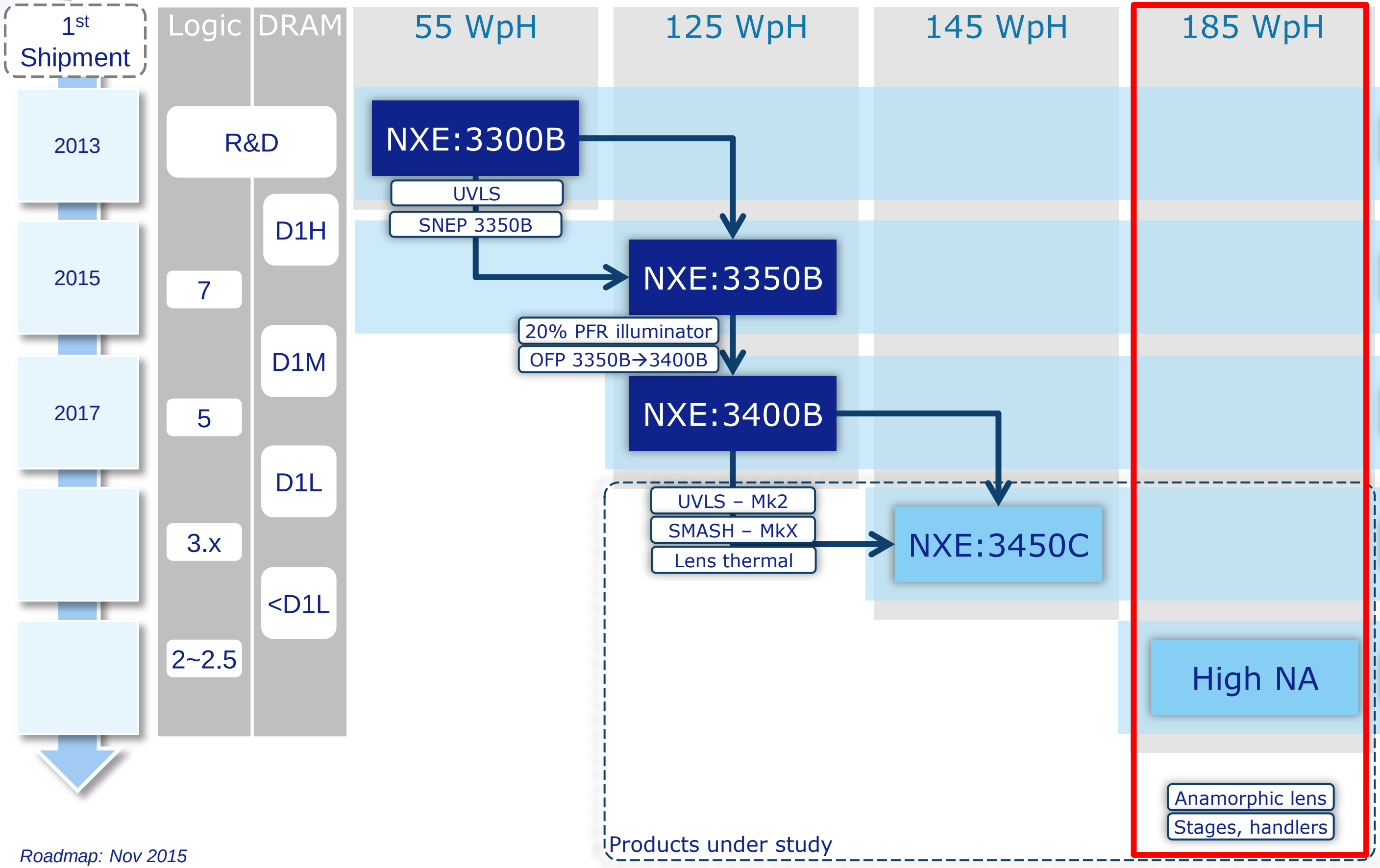
Mark Liu, Co-CEO TSMC

SAMSUNG

Intend do deploy EUV for 7 nm

Sources: Transcript, Intel Credit Suise Media conference, Brian Krzanich, December 2015, Source: Transcript, TSMC Q1 2016 earnings call, Mark Liu, April 2015, Joshua Ho, Anand tech, “Samsung Foundry Updates: 7 nm EUV, 10 LPP, and 14LPC, April 22 2016

NXE extension roadmap to optimize capital efficiency



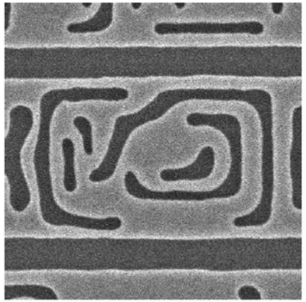
Half pitch	Focus	DCO/MMO	OPO
22 nm	110 nm	3.0/5.0 nm	7.0 nm
16 nm	70 nm	1.5/2.5 nm	3.5 nm
13 nm	60 nm	1.4/<2.0 nm	2.5 nm
13 nm	50 nm	1.2/<1.7 nm	2.0 nm
<8 nm	<40 nm	1.0/<1.4 nm	1.5 nm

Roadmap: Nov 2015

#Critical exposures for critical logic

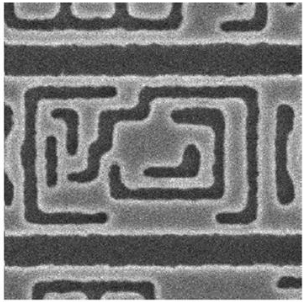
Further reduction of # exposures using EUV 0.55 NA

ArF **triple** patterning

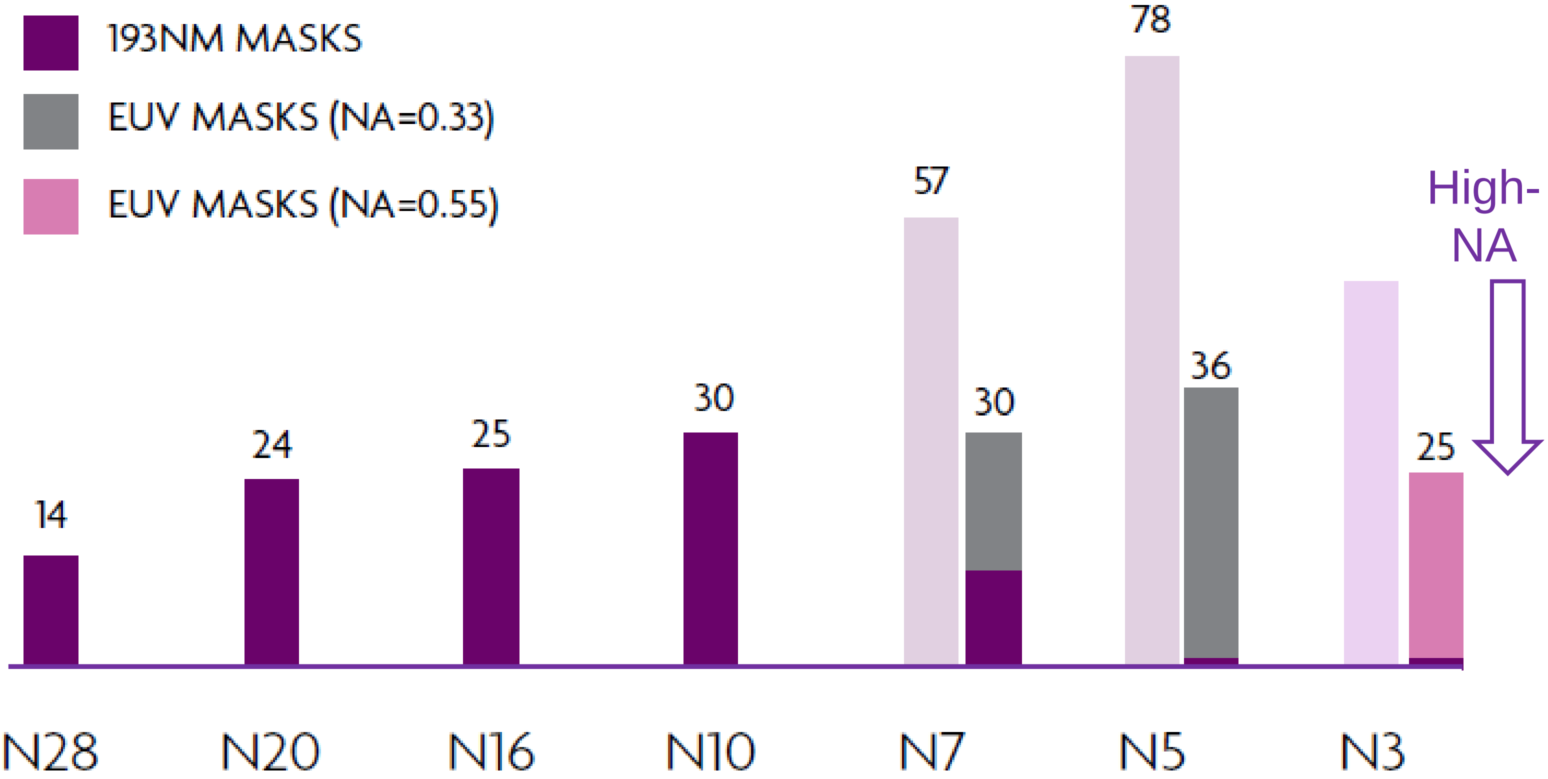


❑ E=39.5mJ, F=-30nm

EUV **single** patterning



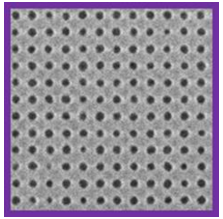
❑ E=16.0mJ, F=-50nm

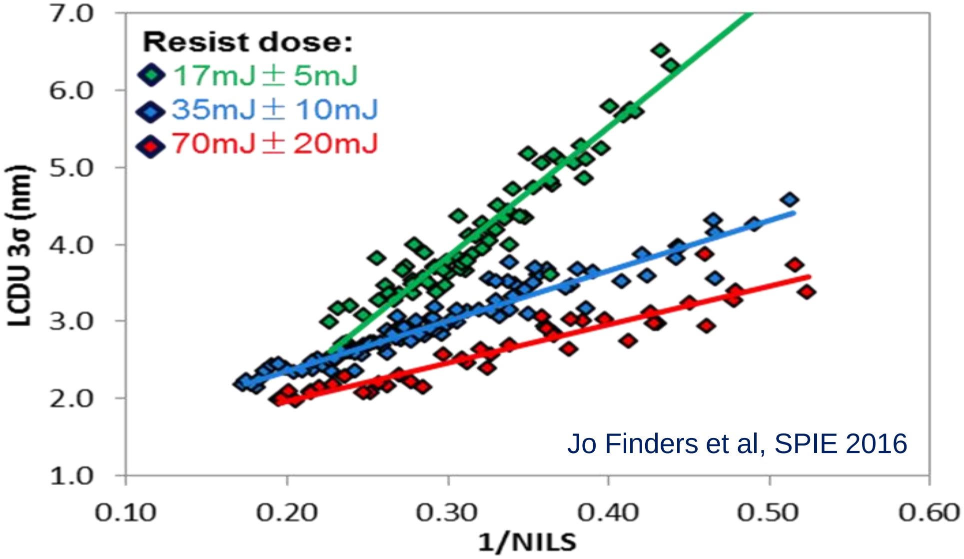


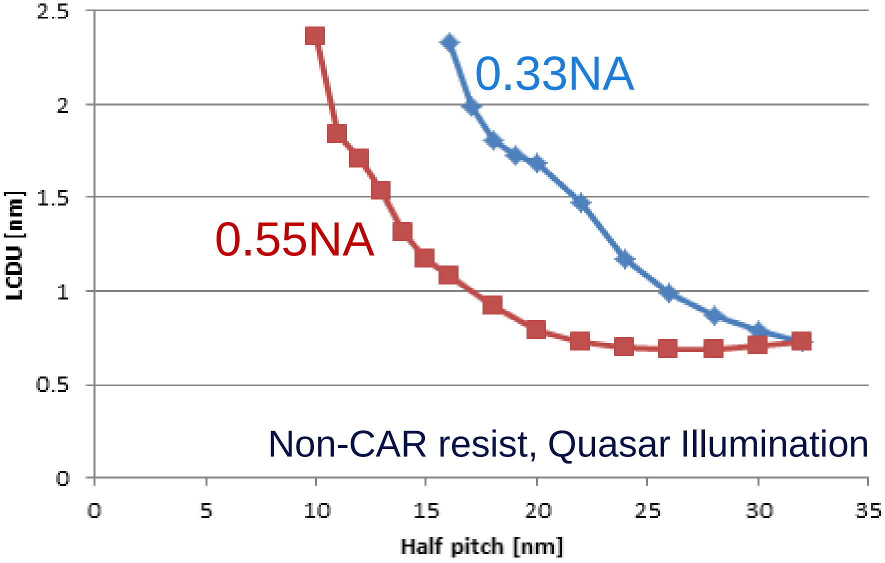
Source: Luc van den Hove, IMEC, ”Technologies for the intuitive internet of everything”, ITPC 2015,

Larger NA reduces Local CDU

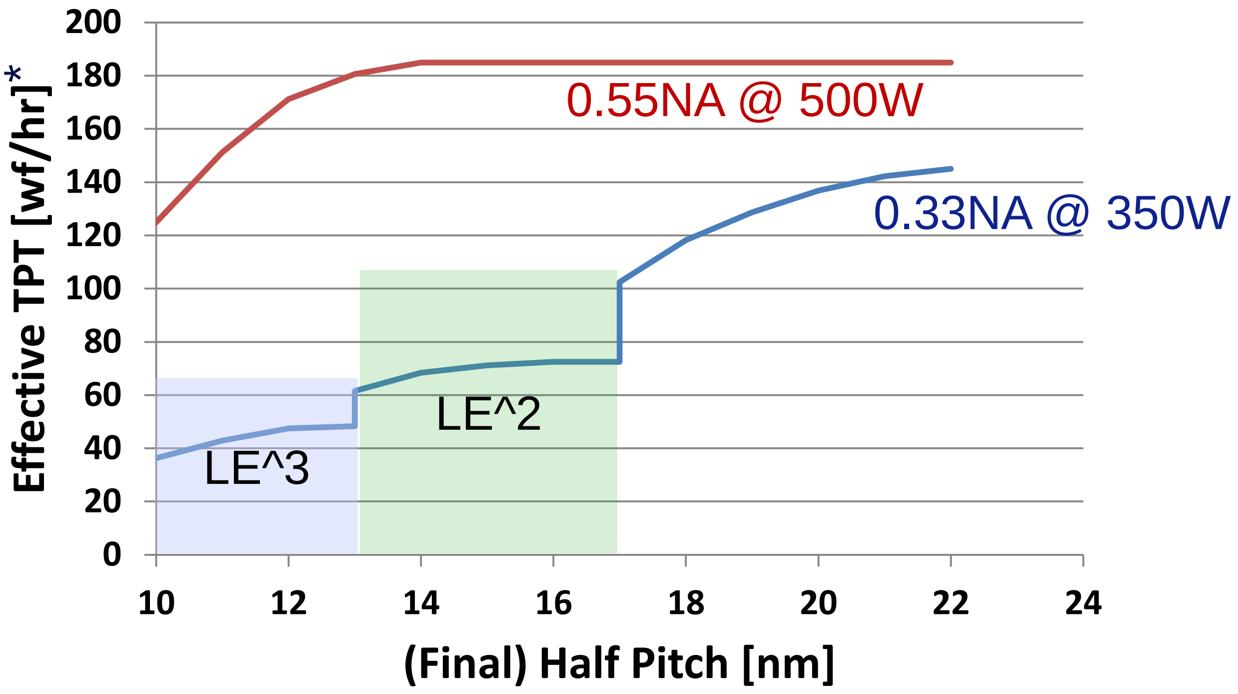
Due to larger aerial image contrast

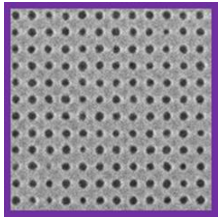






Larger NA results in higher effective throughput
NA limits dose and # of LE steps

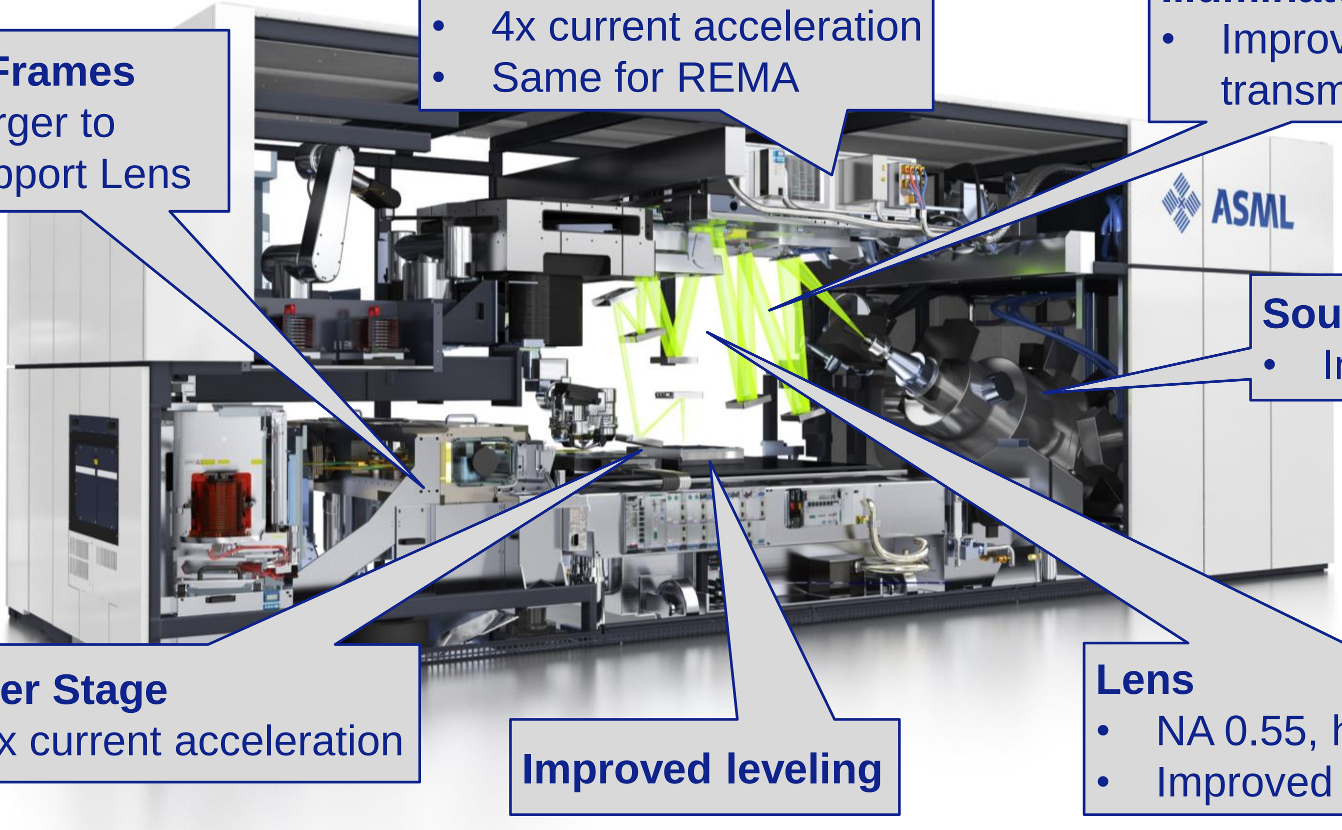




Quasar Illumination

* Effective throughput = throughput / # LE steps

Overview main System Changes High-NA tool



Mask Stage
- 4x current acceleration
- Same for REMA

Illuminator
- Improved transmission

New Frames
- Larger to support Lens

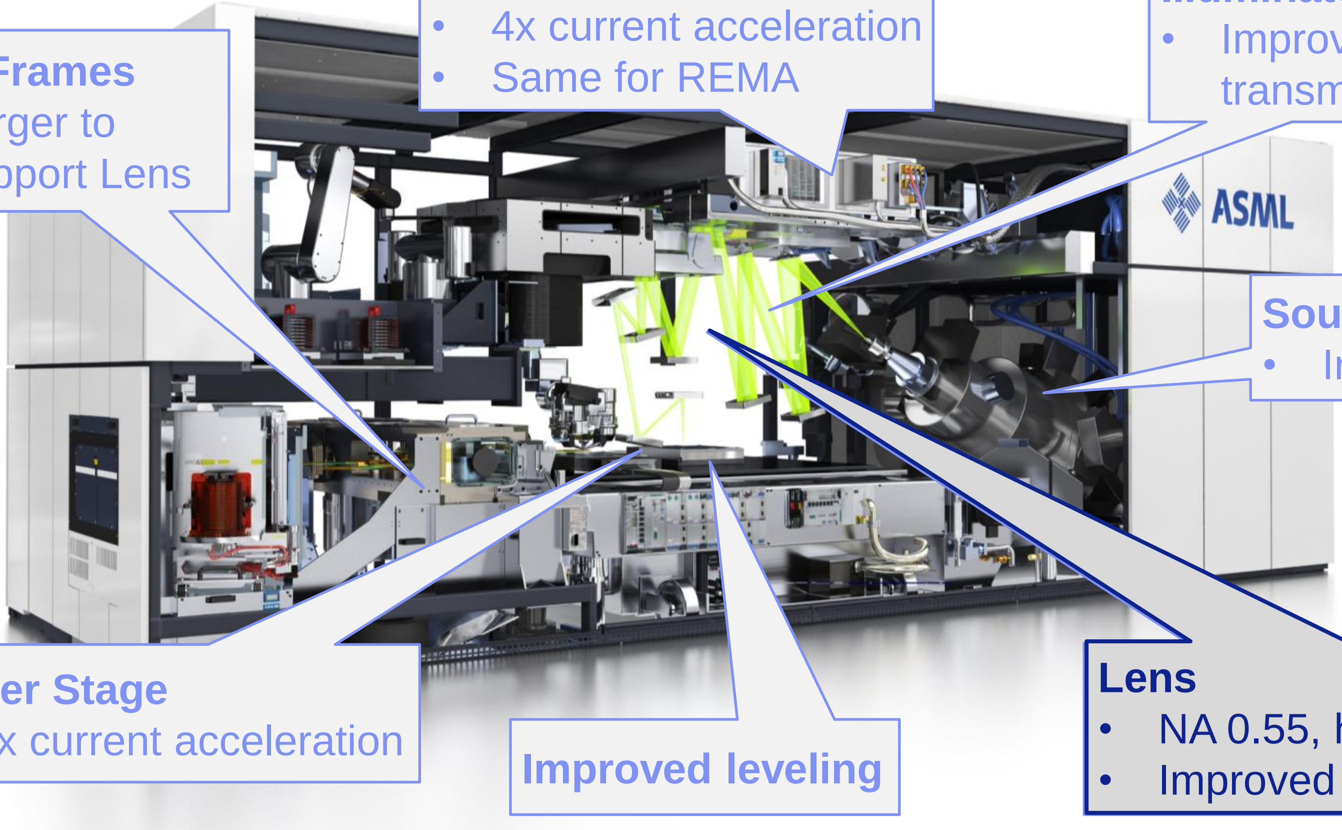
Source
- Increased power

Wafer Stage
- 2x current acceleration

Improved leveling

Lens
- NA 0.55, high transmission
- Improved Thermal Control

Overview main System Changes High-NA tool



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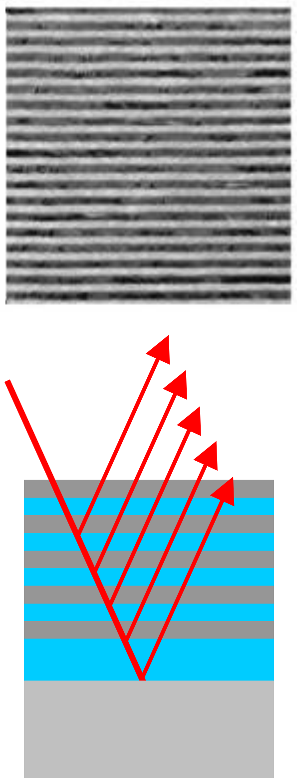
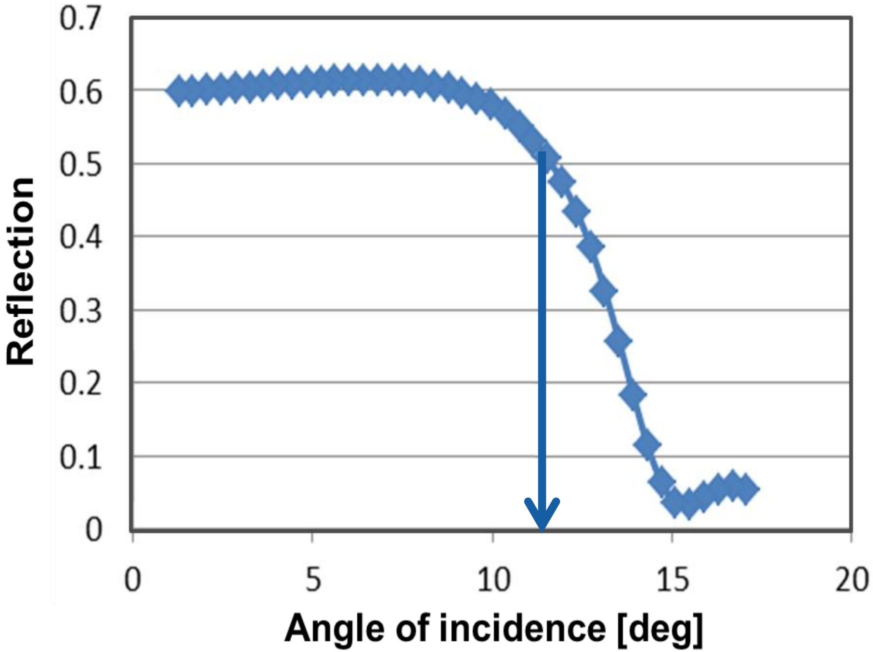
EUV: it's all about the angle

High-NA comes with large angles

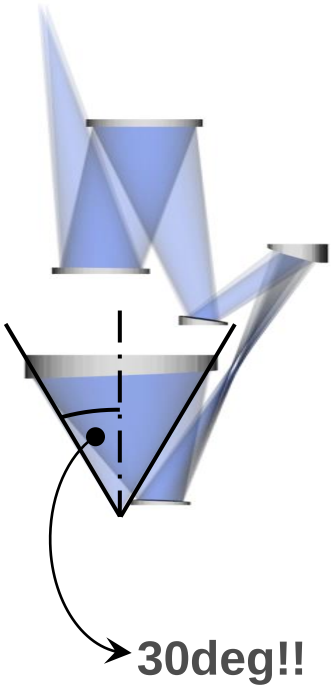
MoSi Multilayer



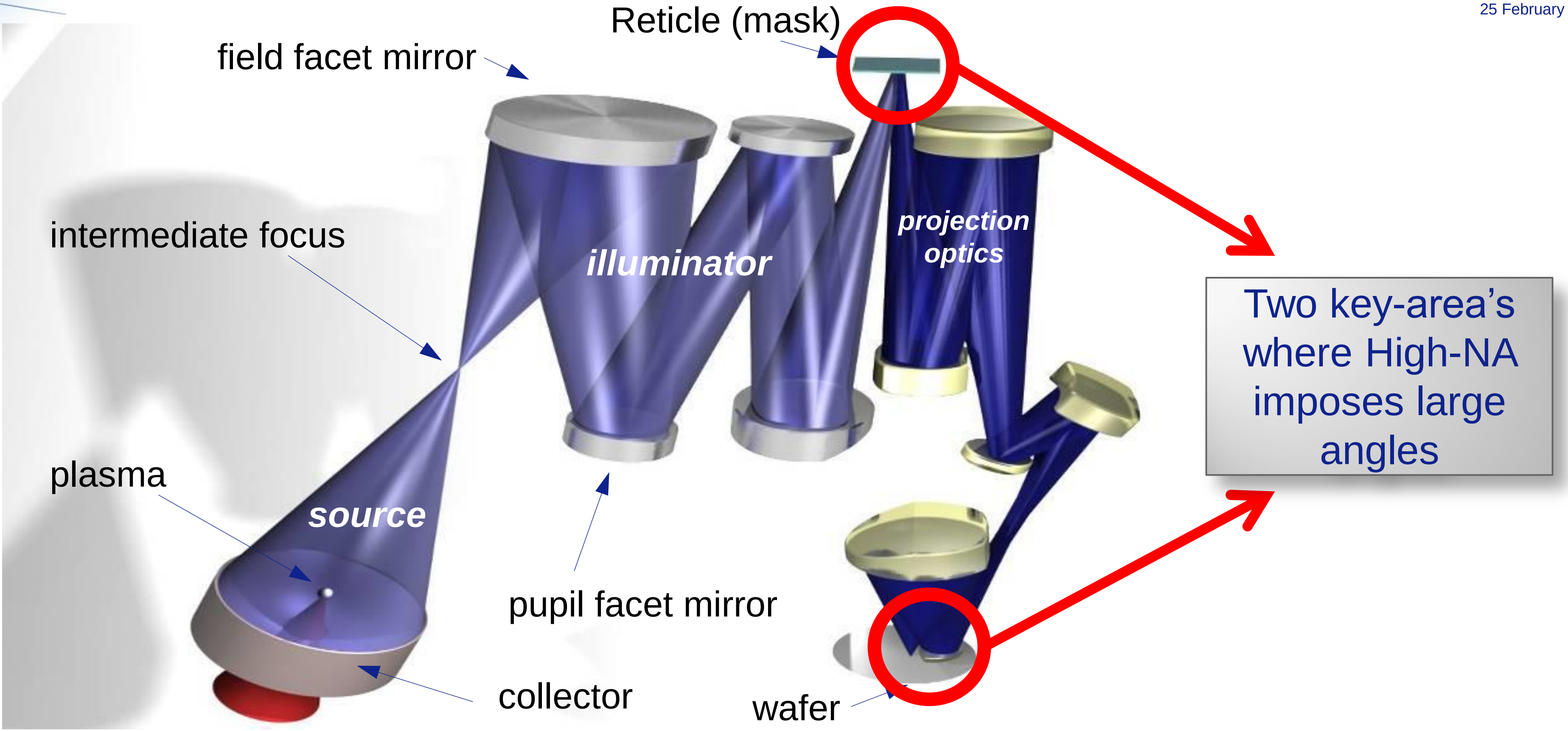
ML reflection



NA=0.5



EUV Optical Train

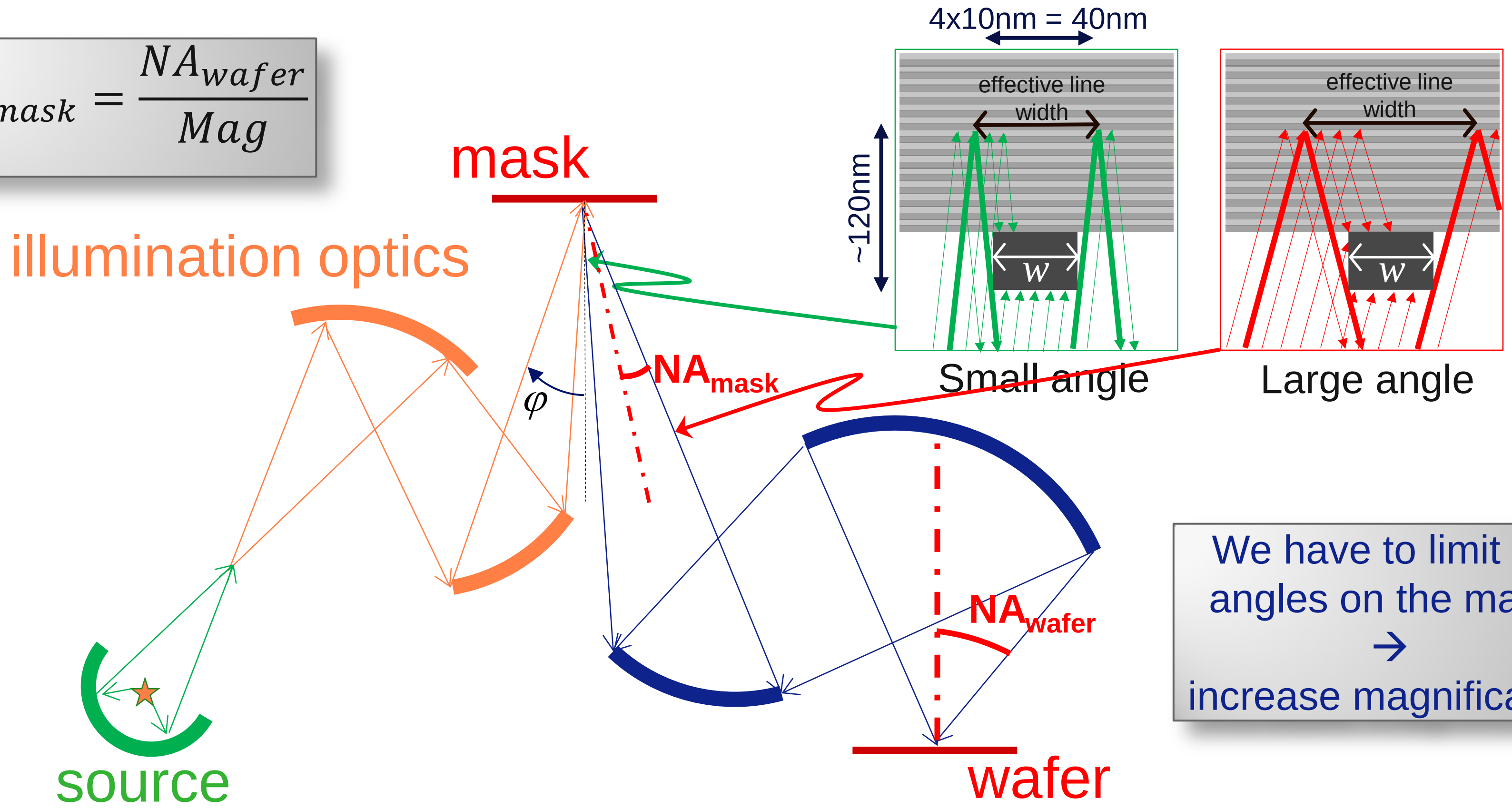


W. Kaiser, J. van Schoot, Sematech Workshop on High-NA, 9 July 2013

Simple model of the optical column

Bending out the light cones at the mask reduces contrast strongly

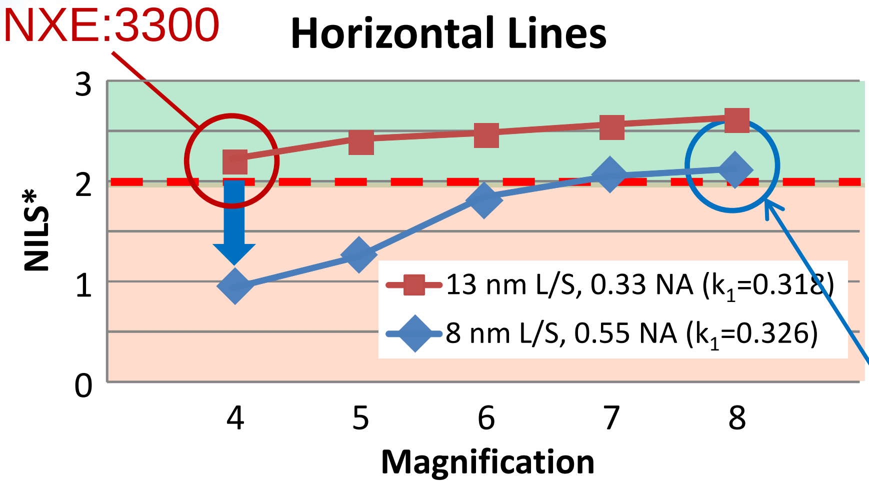
$$NA_{mask} = \frac{NA_{wafer}}{Mag}$$

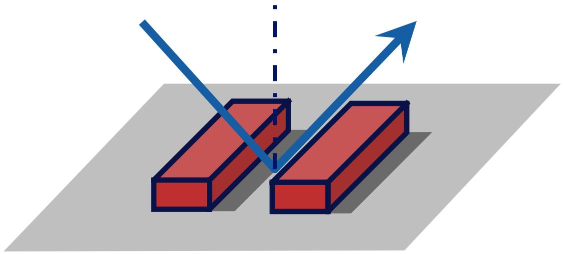


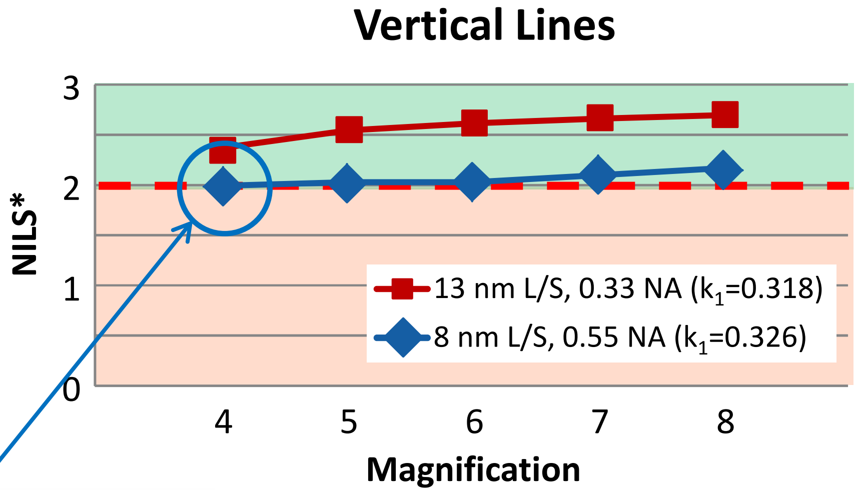
We have to limit the angles on the mask!
→
increase magnification

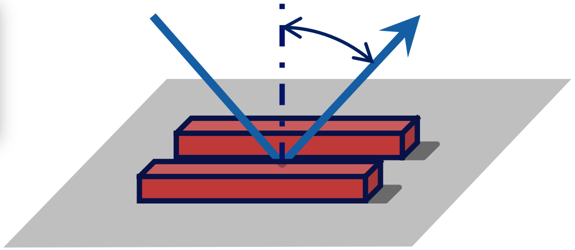
Image contrast increases with a larger magnification

But only needed in one orientation









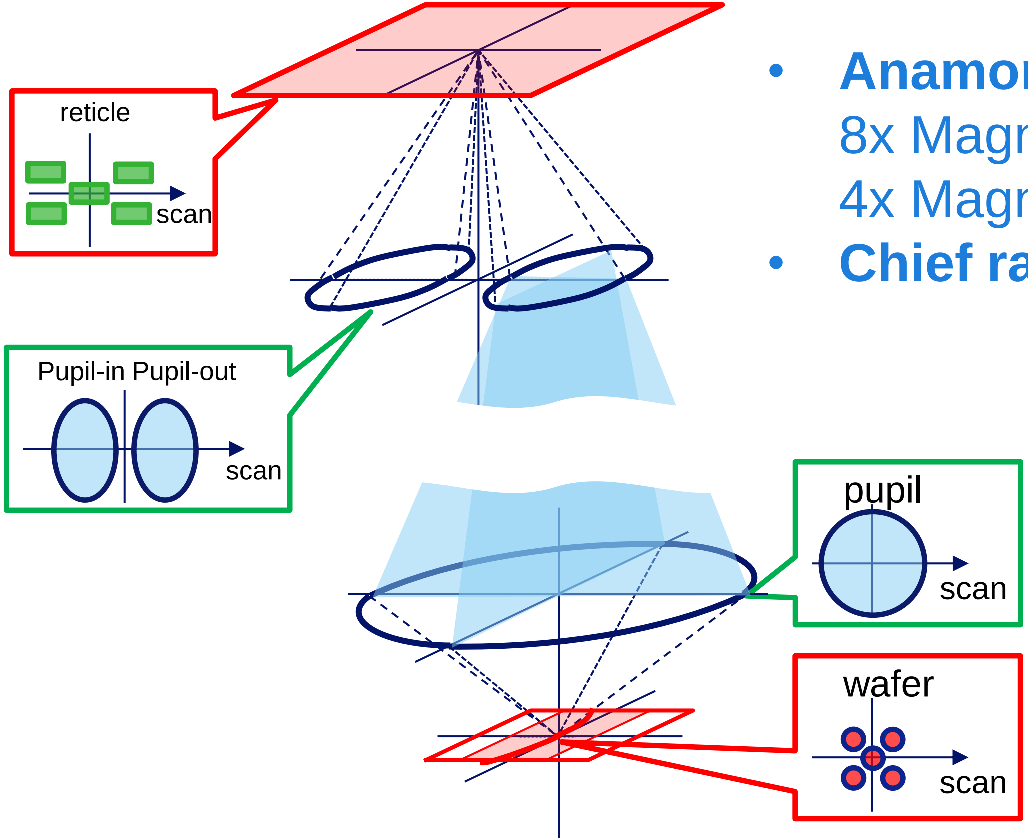
Anamorphic magnification needed for High-NA

*NILS = Normalized Image Log Slope, measure for image contrast

*J. Van Schoot, et al, "EUV lithography scanner for sub-8nm resolution," Proc. SPIE **9422**, (2015).*

High-NA >0.5NA 4x/8x anamorphic magnification

Chief Ray Angle at Mask can be maintained

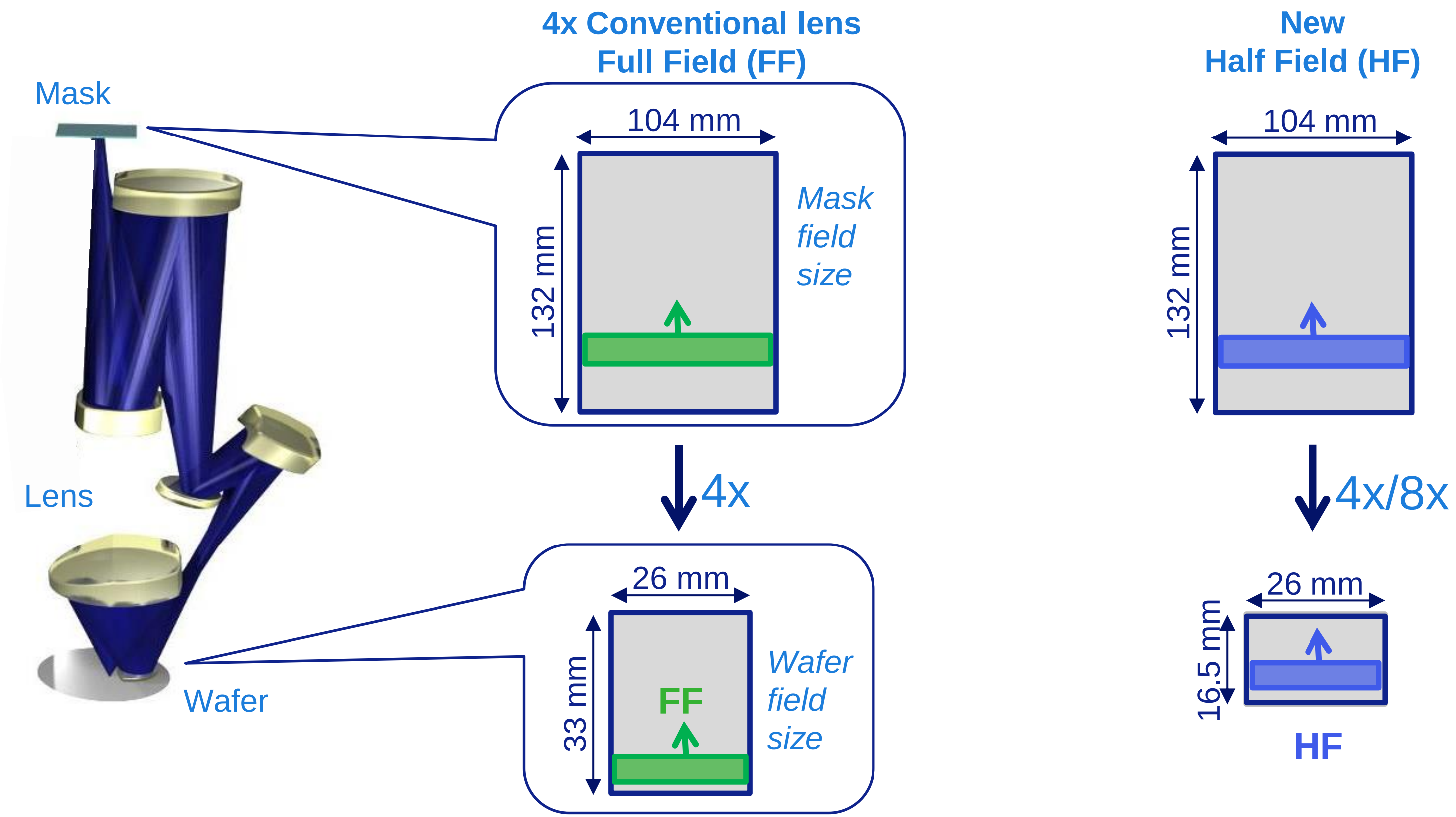


- **Anamorphic optics → half field:**
  8x Magnification in scan
  4x Magnification in other direction
- **Chief ray angle ok → Imaging ok**

The pattern at the mask needs to change

High-NA Anamorphic Lens prints a half field

By utilizing the current 6” mask



Note: rectangular slit shown for illustration purposes

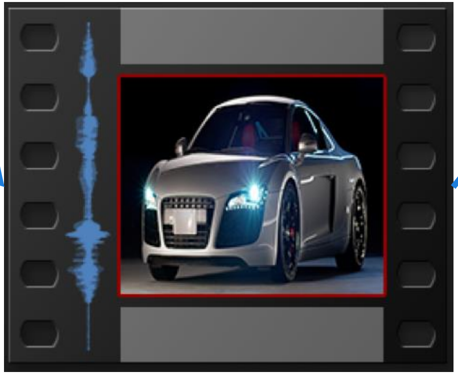
Anamorphic optics are used in cinematography

“Don’t change the mask”

16x9

Anamorphic Camera

“The Mask” (24x36mm^2)

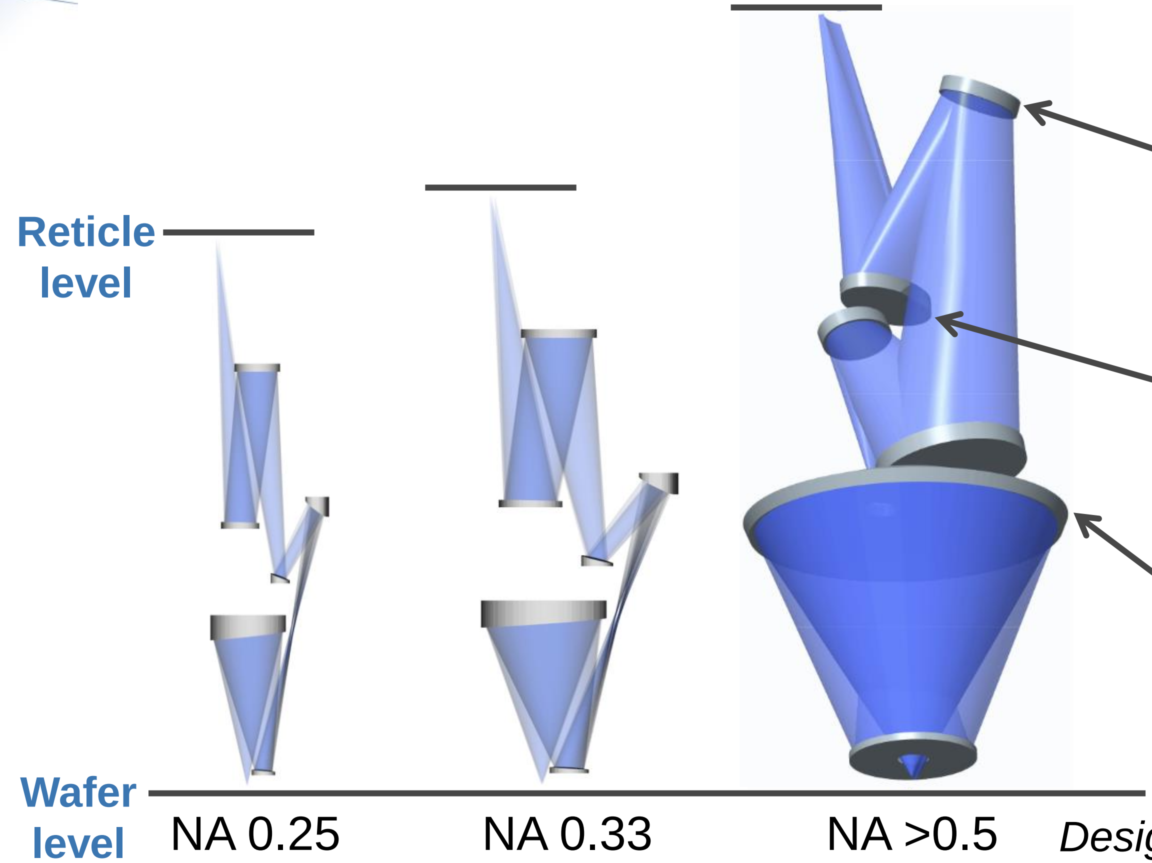


16x9

Anamorphic Projector

High-NA optics design concepts available

Larger elements with tighter specifications, no showstoppers



Extreme aspheres enabling **further improved wavefront / imaging performance**

Tight surface specifications enabling **low straylight / high contrast imaging**

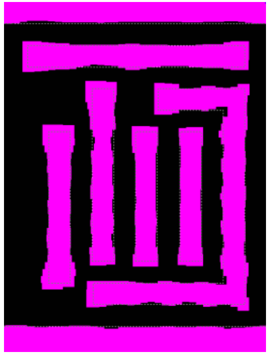
Big last mirror driven by **High NA**

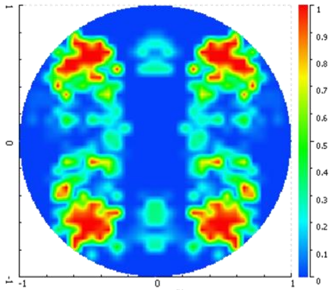
B. Kneer, et al, "EUV lithography optics for sub-9nm resolution," Proc. SPIE ***9422****, (2015).*

Imaging verification of the new Half Field concept

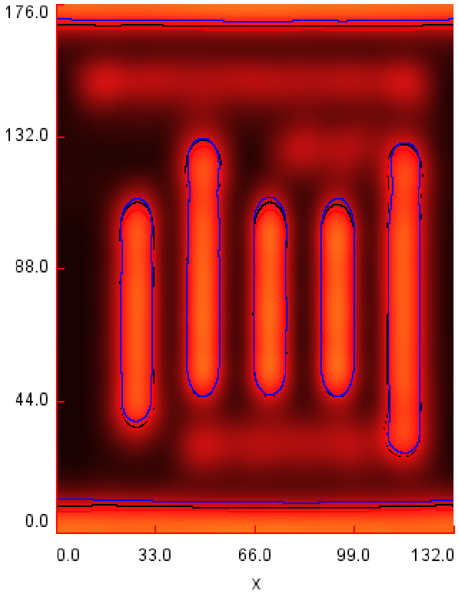
Logic N5 clip Metal-1, 11nm lines, SMO is done at 8x

Aerial Image Intensity in Hyperlith

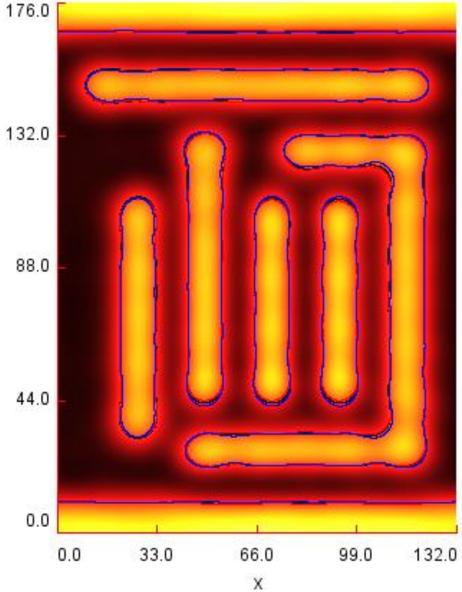




FF



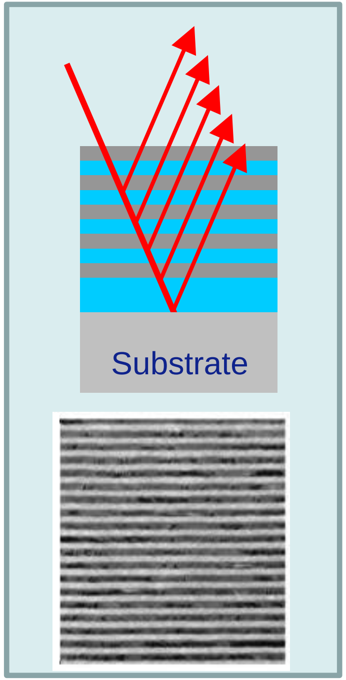
HF



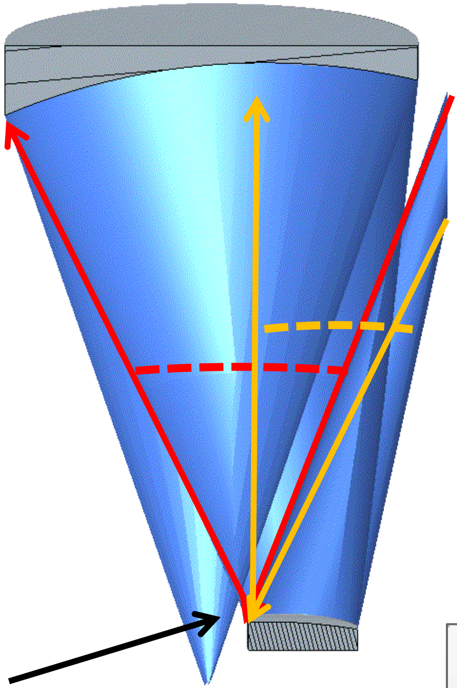
Note: pictures at same scale, smaller mask reflection is also visible

High-NA optics has ~2x transmission

Smaller angles enable transmission gain vs non-obscured NA 0.33

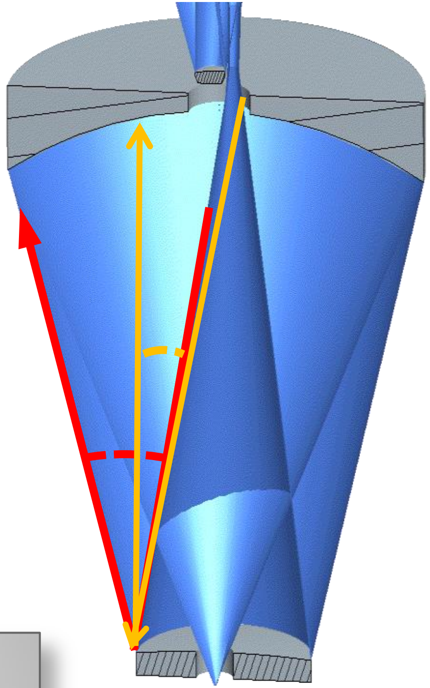


unobscured



Standard EUV coatings cannot handle these large angles

Angles and angular spread decrease

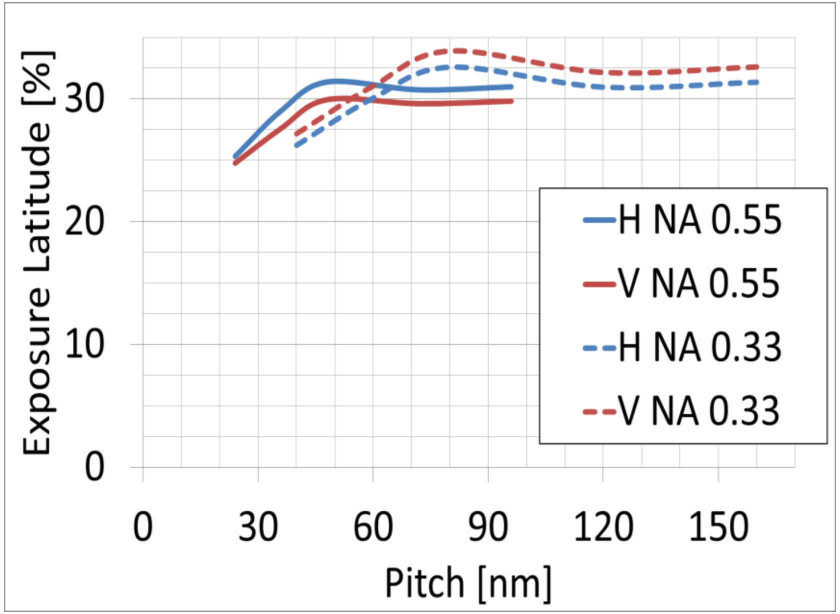


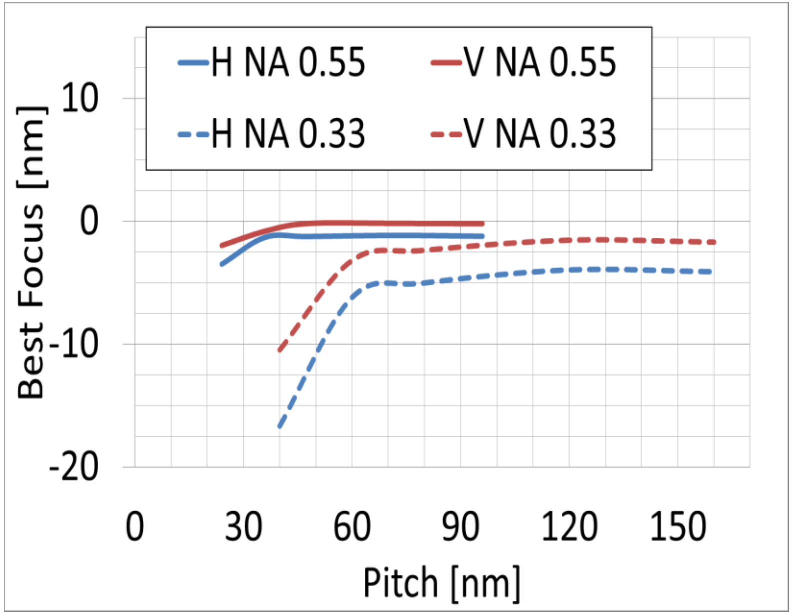
obscured

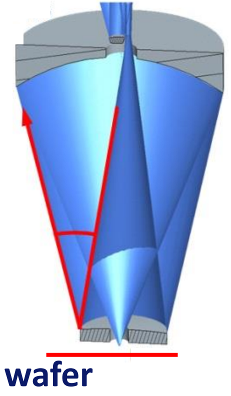
And even better:
The smaller angular range increases the transmission

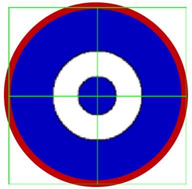
Proven imaging performance with High-NA optics

Spaces through pitch with small annular illumination





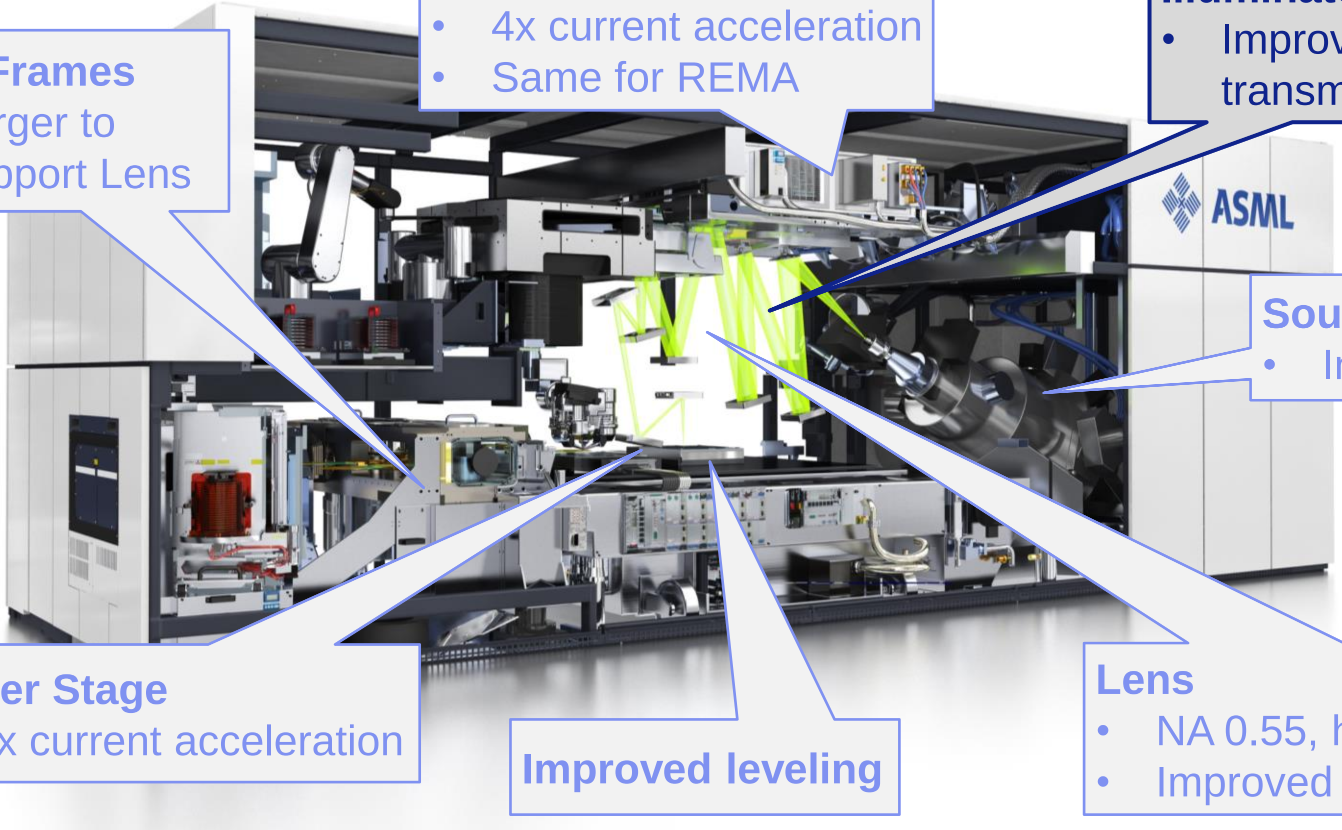




HighNA obscured pupil

- Start pitch: 24nm for high-NA, 40nm for NA 0.33 ➔ k1 = 0.49 in both cases.
- Anamorphic high NA w/ central obscuration: comparable exposure latitude, @ smaller pitches.
- Lower Best Focus variation for high NA.

Overview main System Changes High-NA tool



New Frames
- Larger to support Lens

Mask Stage
- 4x current acceleration
- Same for REMA

Illuminator
- Improved transmission

Source
- Increased power

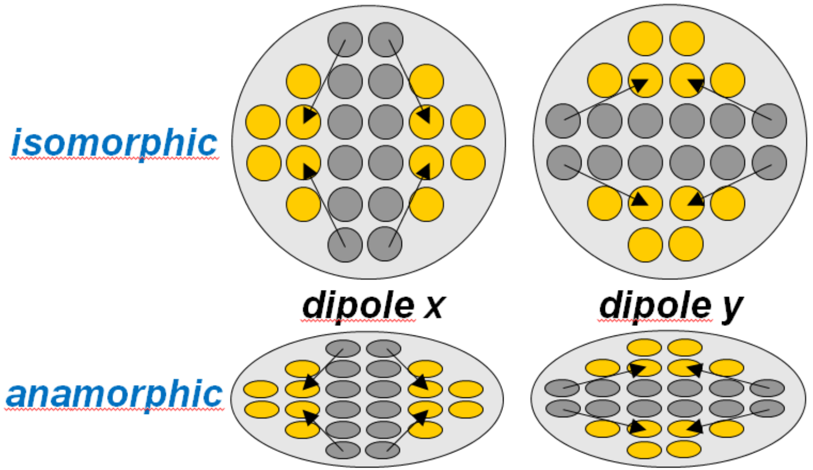
Wafer Stage
- 2x current acceleration

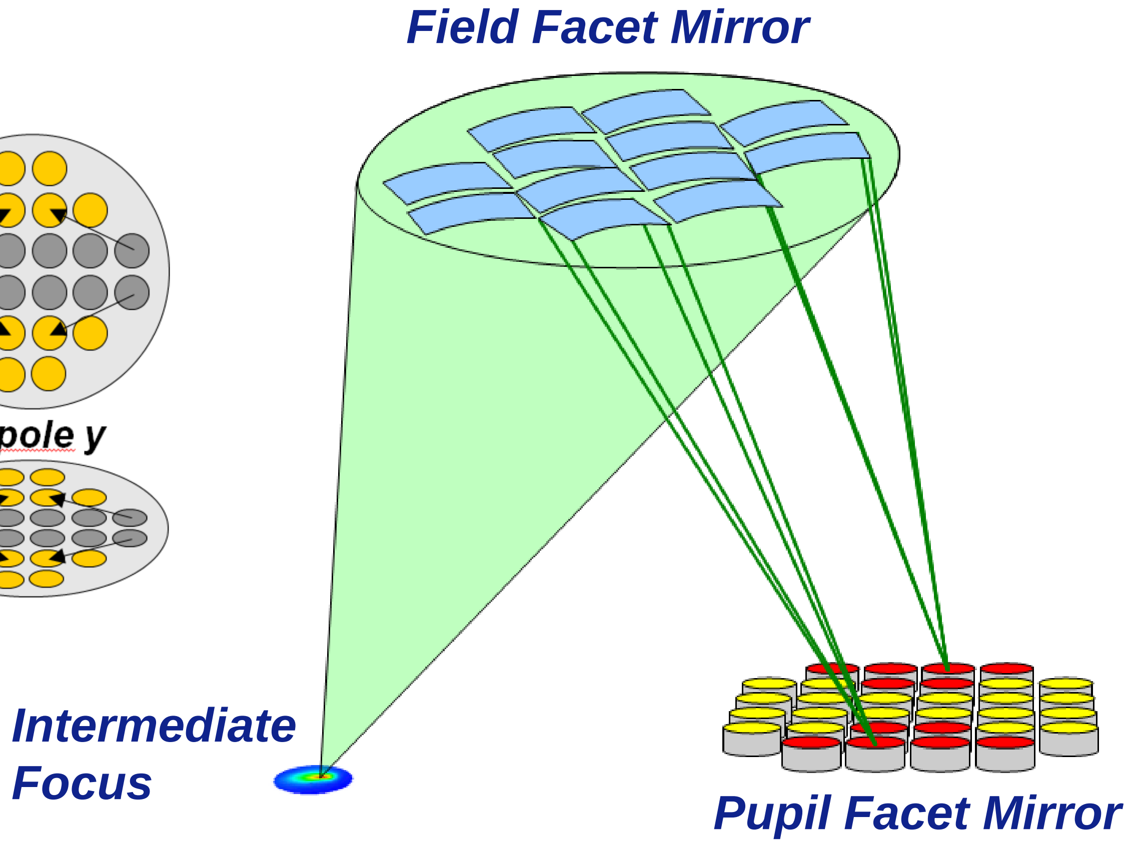
Improved leveling

Lens
- NA 0.55, high transmission
- Improved Thermal Control

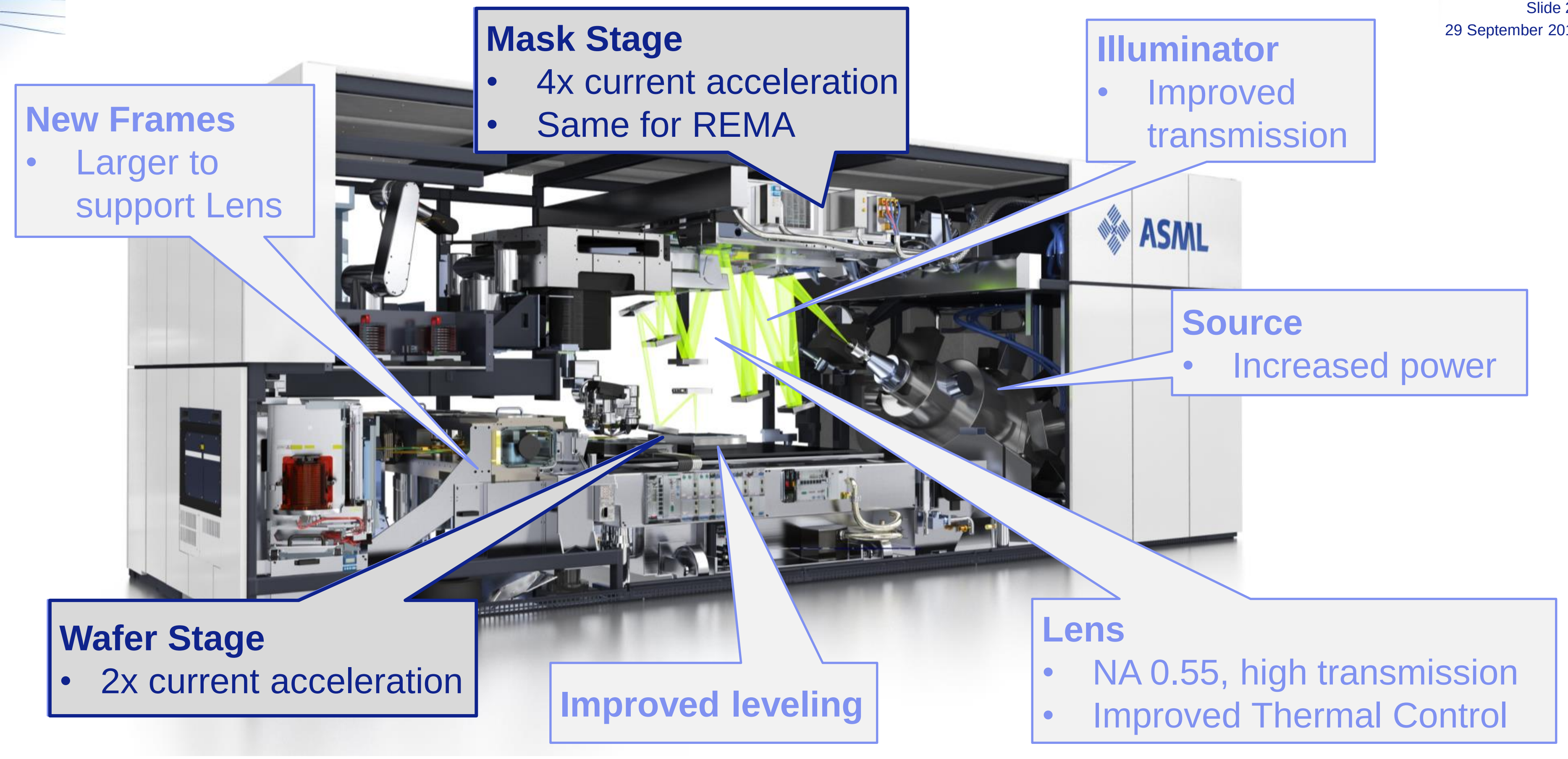
Principle NXE:3300/3400 illuminator can be reused

For anamorphic lithography pupil facet mirror becomes asymmetric





Overview main System Changes High-NA tool



High-NA anamorphic Half Field concept

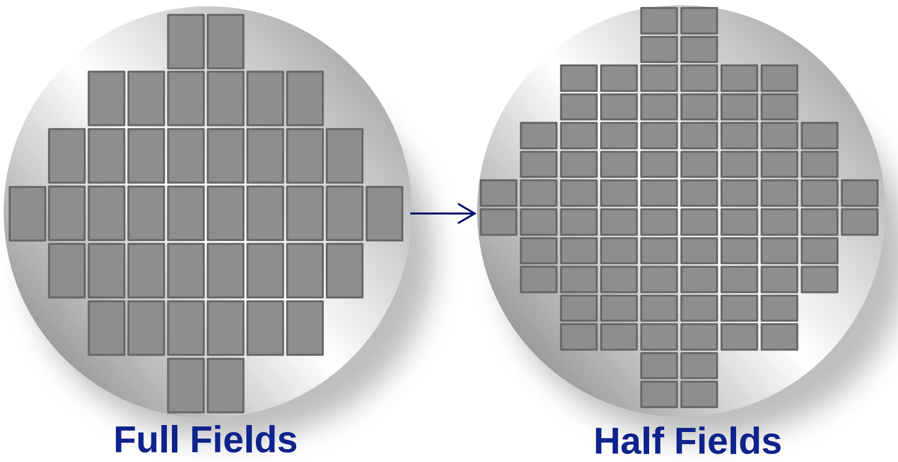
Faster stages enable high productivity

Half Field yields 2x more fields

- 2x wafer stage acceleration maintains overhead while going to twice number of scans

Y-magnification 4x → 8x

- 2x wafer acceleration results in 4x mask acceleration

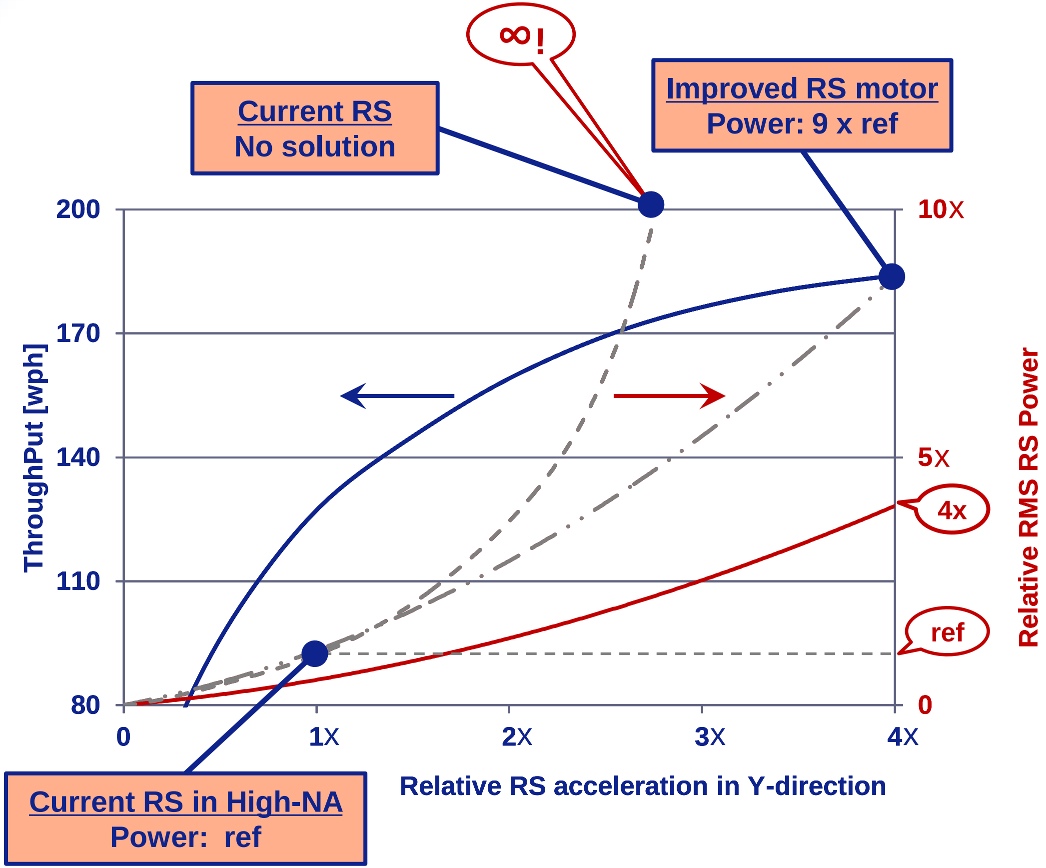


Acceleration of wafer stage ~2x

Acceleration of mask stage ~4x

High-NA Mask Stage solution for increased acceleration

Improved motor technology & different architecture



$$\text{Power} \sim I^2 \cdot R$$
$$= k \cdot (acc \cdot mass)^2 \cdot R_{motor}$$

Limiting increasing power by:

- Improved motor technology (k, R)
- Reduce mass

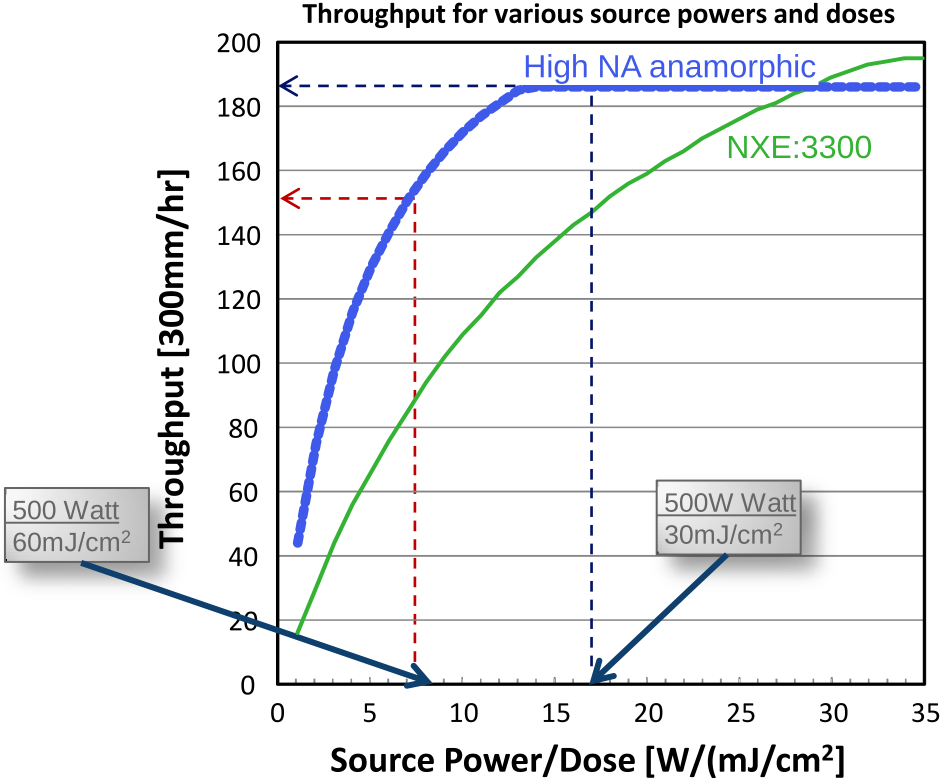
Further Optimizing power consumption:

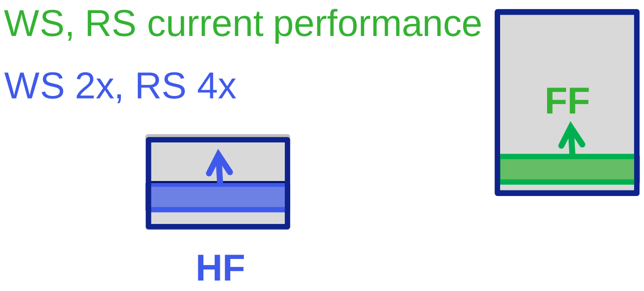
- New stage architecture with lower mass

Courtesy Chris Hoogendam, ASML

High-NA Field and Mask Size productivity

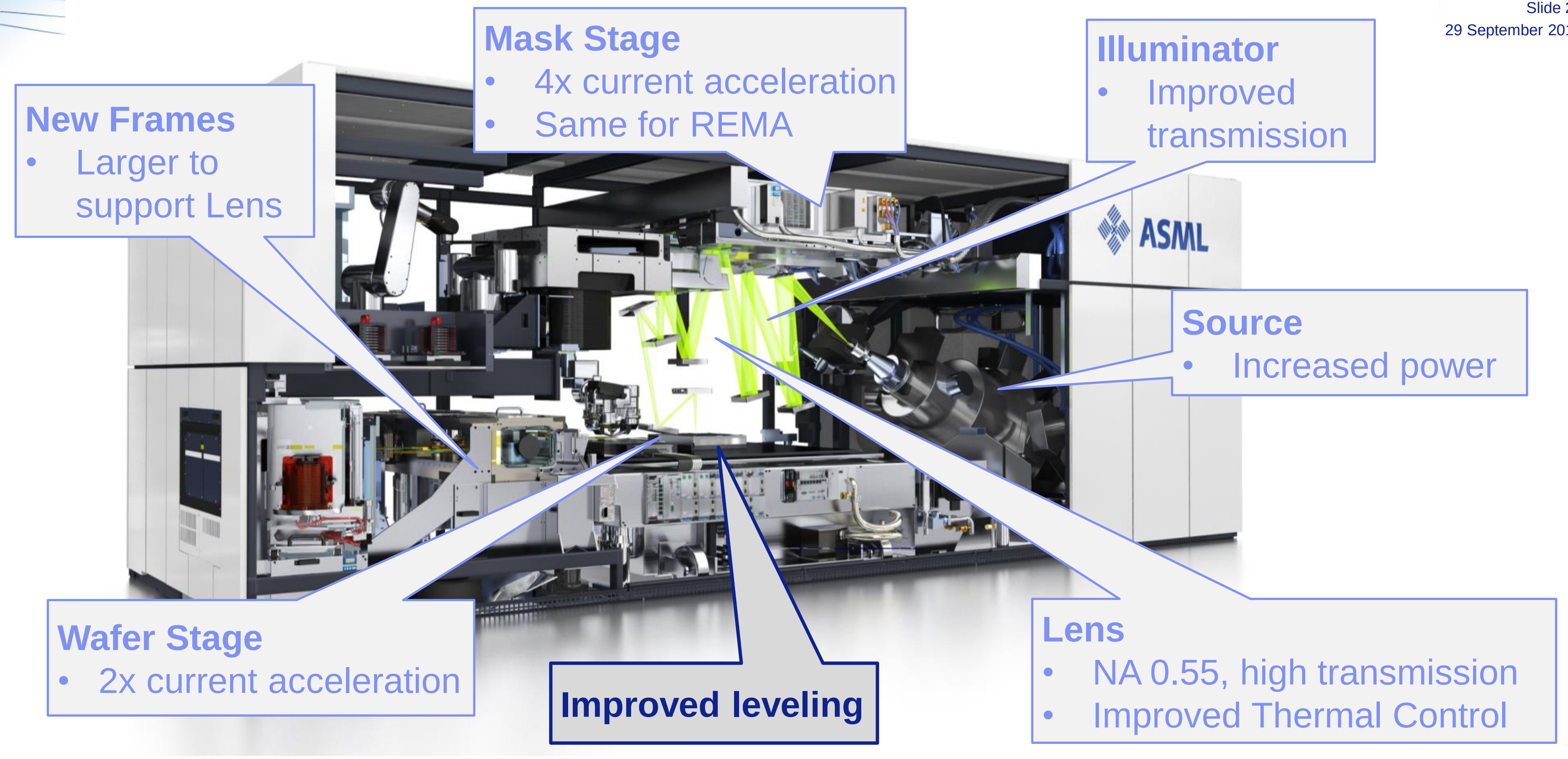
500W enables throughput of >150wph with anamorphic HF





High-NA Half Field scanner needs 500W for 150wph at 60mJ/cm²

Overview main System Changes High-NA tool

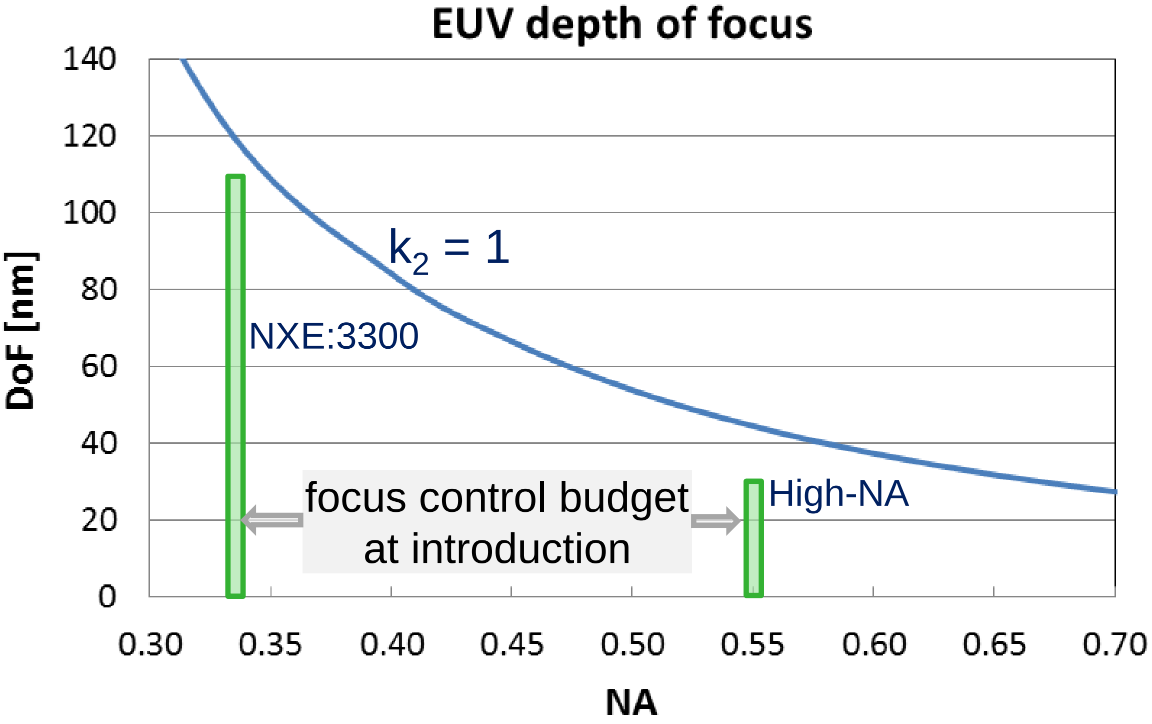


High-NA calls for tight focus control

High-NA scanner will be introduced in line with focus scaling

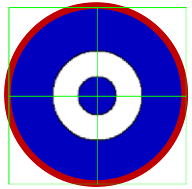
Rayleigh

$$DoF = k_2 \frac{\lambda}{NA^2}$$

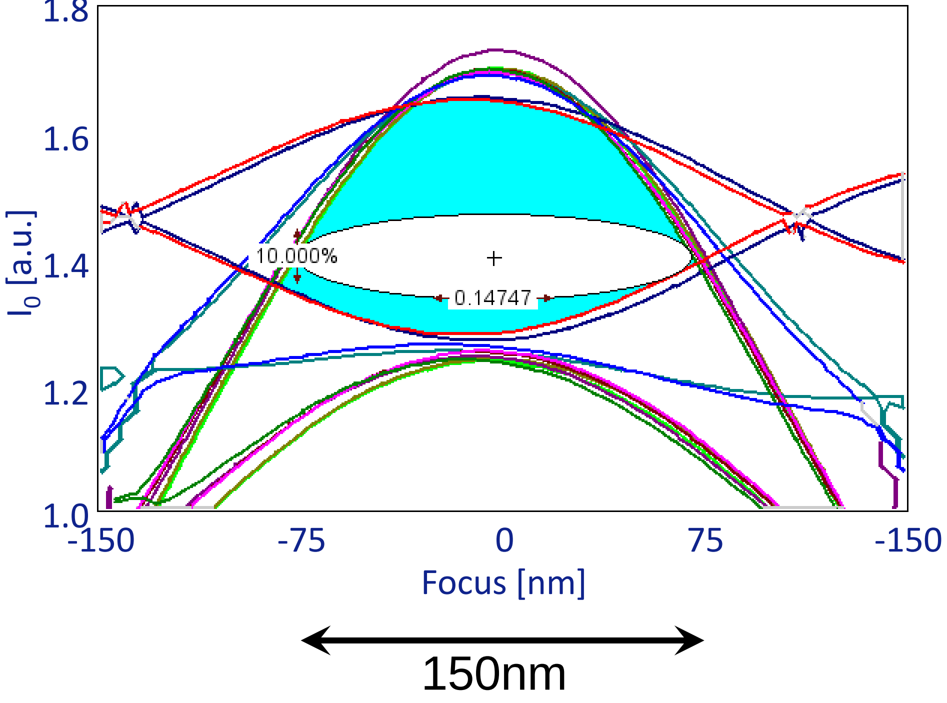


Focus latitude scales according expectation

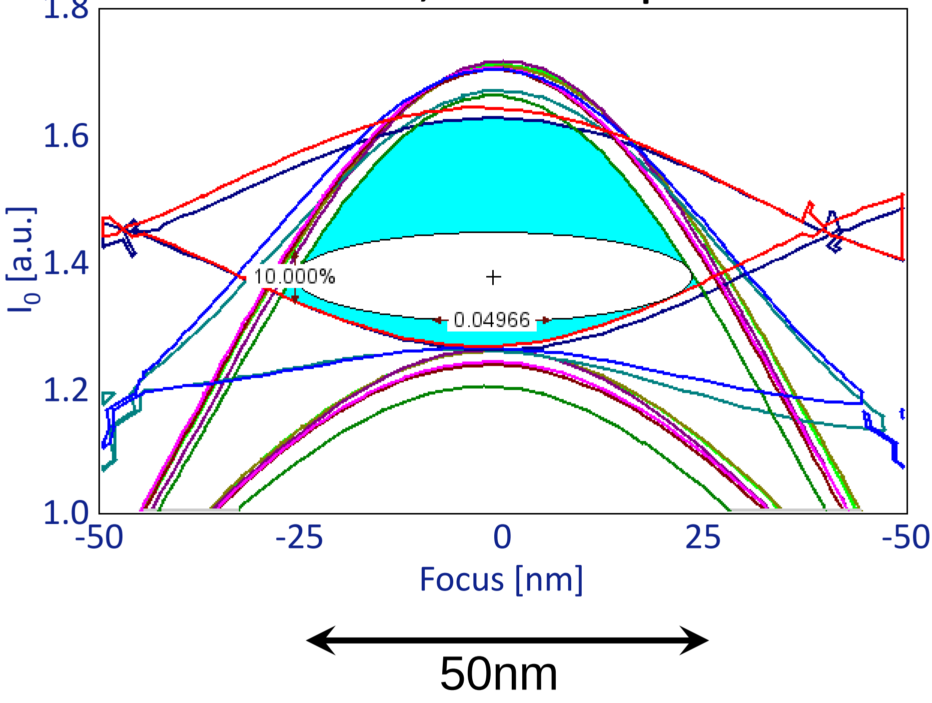
Spaces through pitch with small annular illumination



NA 0.33, 20nm spaces

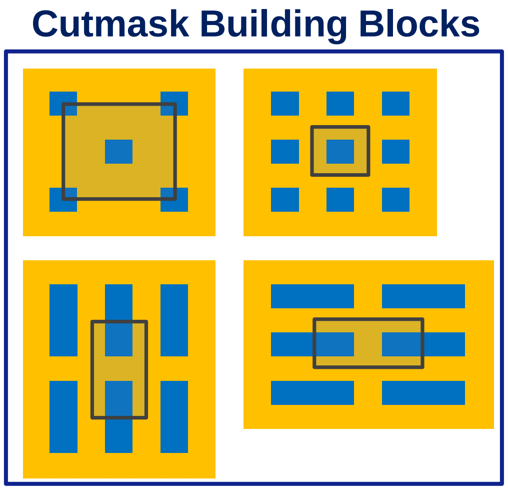


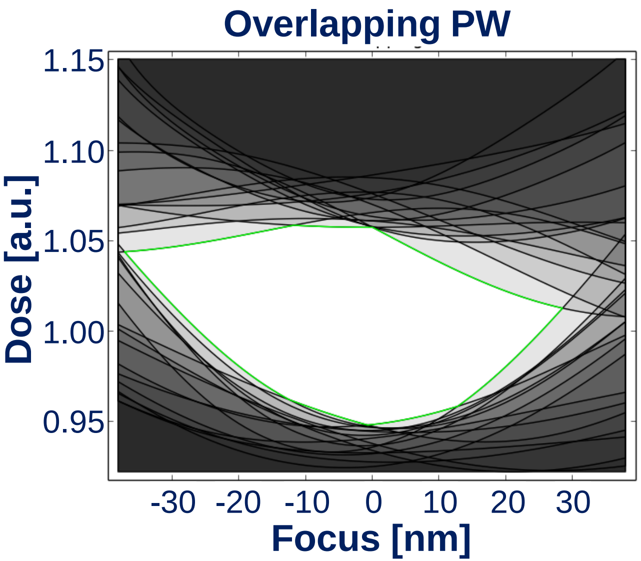
NA 0.55, 12nm spaces

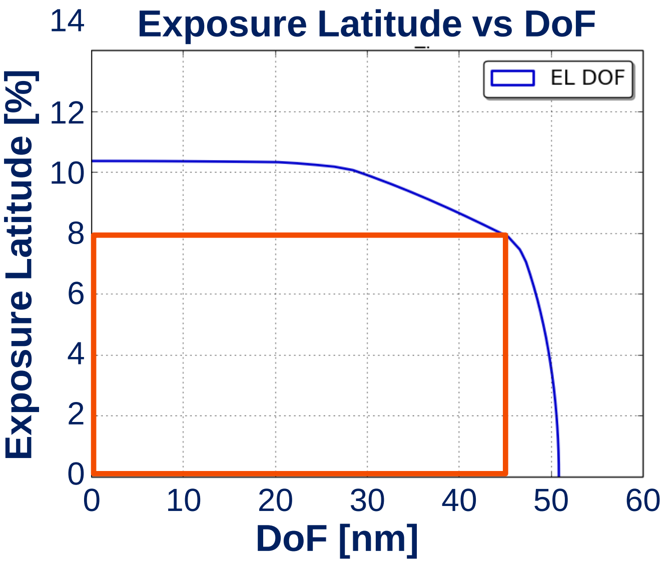


Overlapping process window @ 8%EL → 45nm

NA=0.55, Random cuts, 24nm minimum pitch



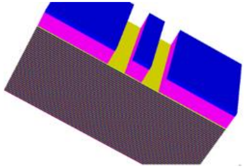




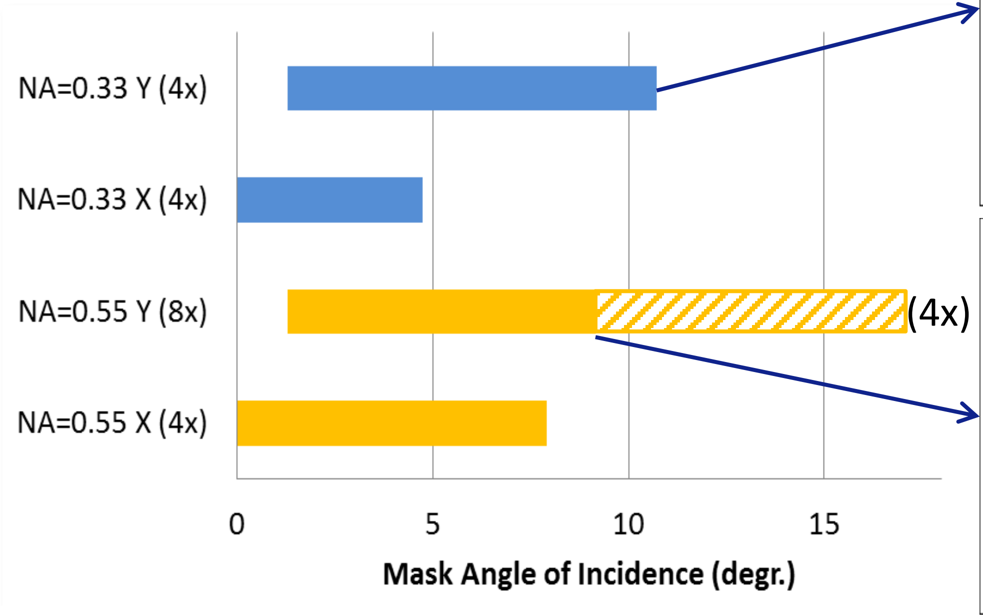
- Combined set of 4 building blocks, 24nm minimum pitch
  - Annular illumination used
  - Overlapping process windows calculated

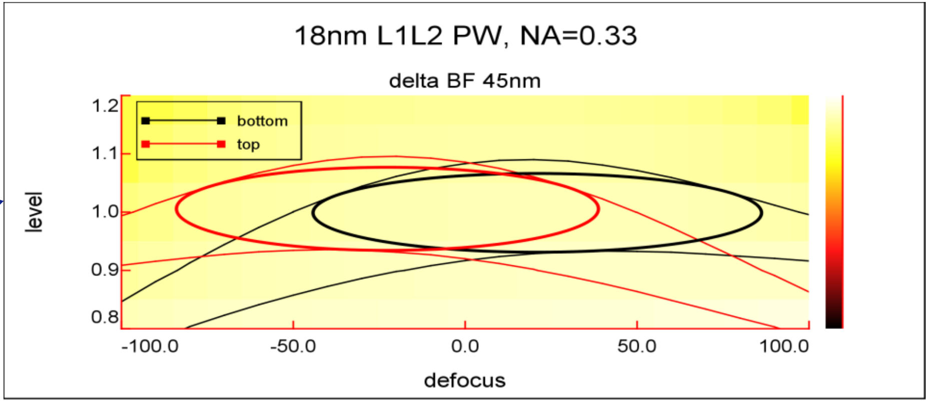
High-NA system has smaller M3D effects than 0.33NA

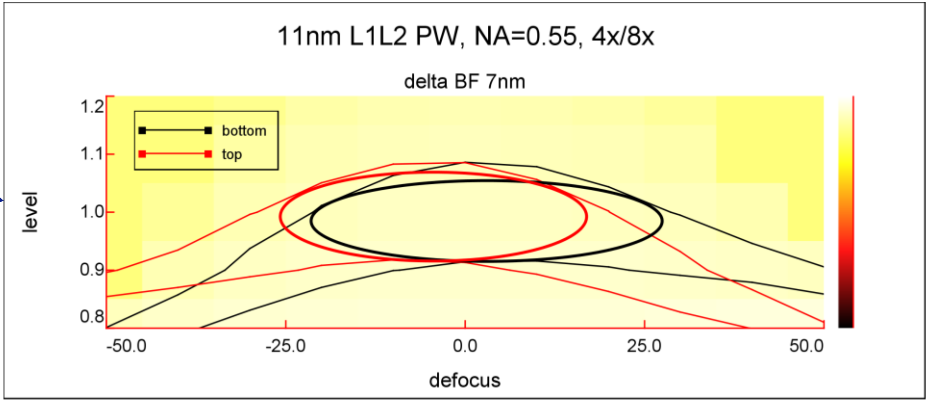
Smaller mask angles of incidence due to anamorphic system



Two-bar trenches are a canary for M3D effects

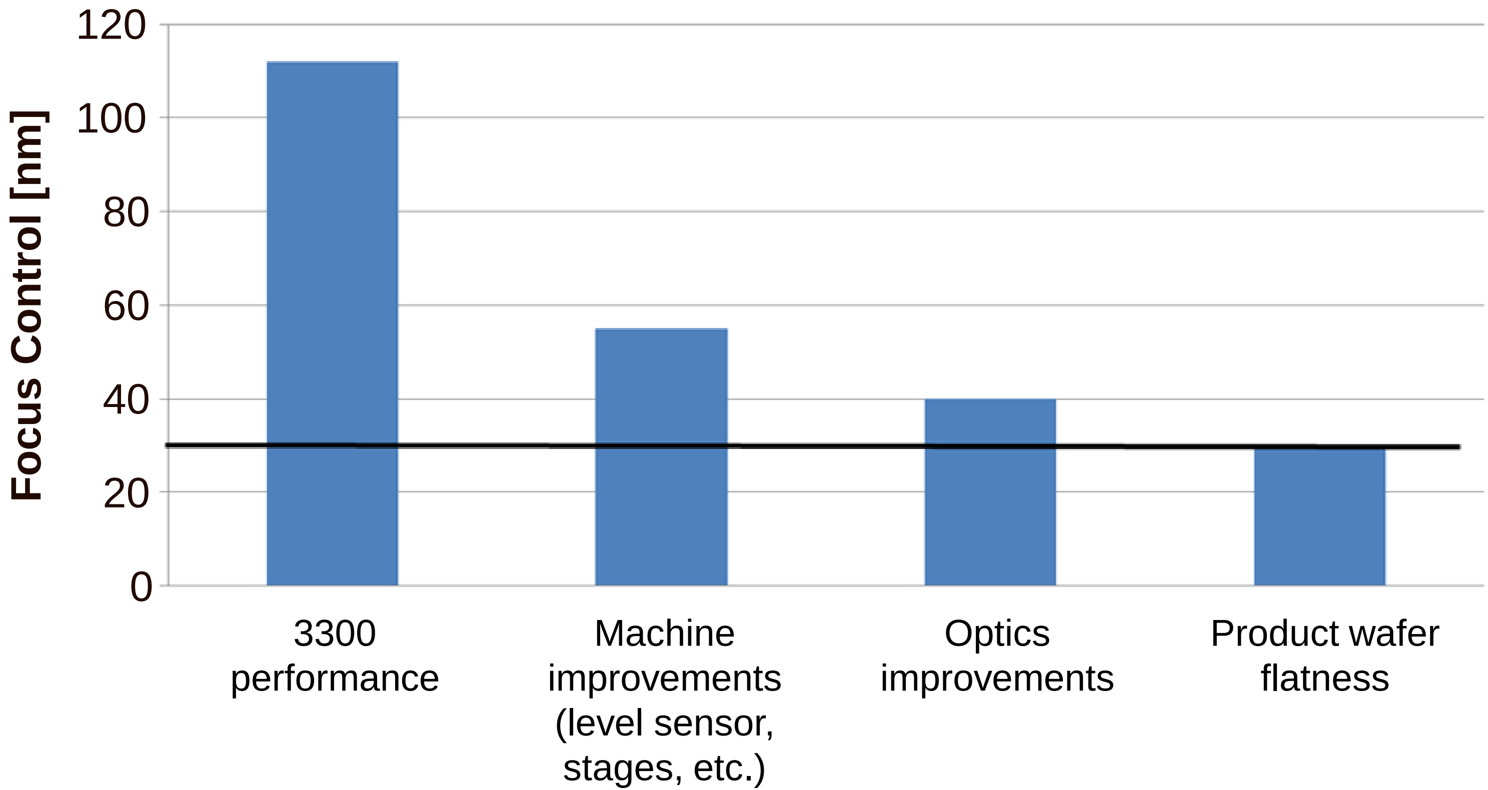






*L. de Winter, Understanding the Litho-impact of Phase due to 3D Mask-Effects when using off-axis illumination, EMLC 2015

Way forward to 30 nm focus control



Summary

- **High-NA extends Moore's Law into the next decade**
  - Larger contrast of High-NA helps mitigating LCDU
  - New anamorphic concept enables good imaging with existing mask infrastructure resulting in a Half Field image
  - New stages technologies and high transmission enable throughput ~185WpH
  - We identified measures to meet the tight focus budget

The authors would like to thank the High-NA teams in
- Oberkochen
- Wilton
- Veldhoven

ASML ZEISS

Thank you for your attention