Public

High-NA EUV lithography

enabling Moore's law in the next decade

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15 June 2017, EUVL Workshop, Berkeley

Outline

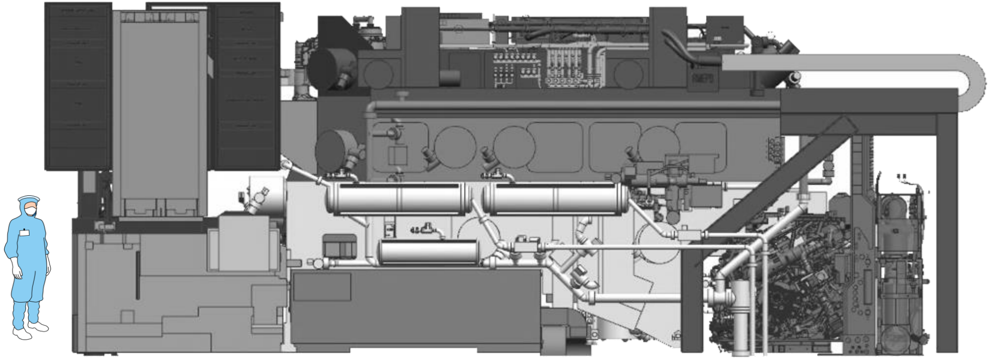
Why high-NA?

Anamorphic Optics

Imaging

System Architecture

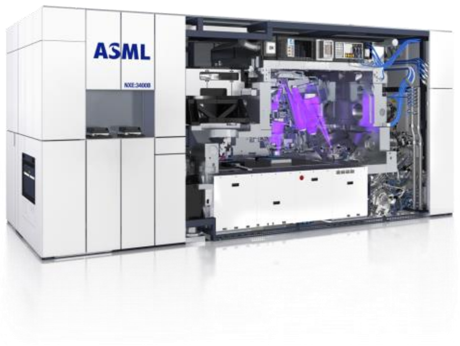
Conclusions



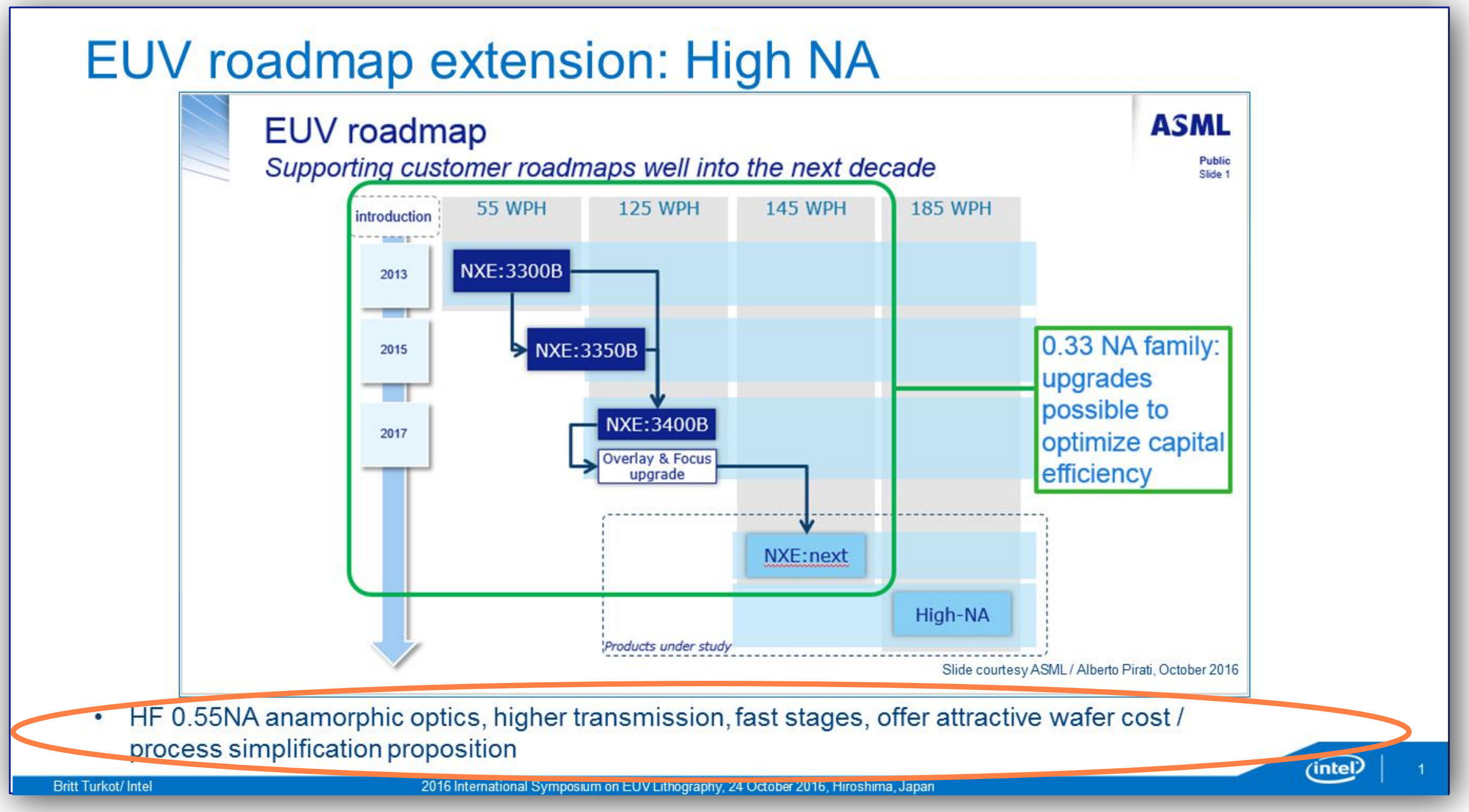
EUV extension roadmap

introduction	55 WPH	125 WPH	145 WPH	185 WPH	Overlay [nm]
2013	NXE:3300B				7
2015		NXE:3350B			3.5
2017		NXE:3400B			3
			NXE:next		<3
				High NA	<2

products under study



Slide presented this conference by Britt Turkot, INTEL



EUV roadmap extension: High NA

EUV roadmap

Supporting customer roadmaps well into the next decade

0.33 NA family: upgrades possible to optimize capital efficiency

Slide courtesy ASML / Alberto Pirati, October 2016

- HF 0.55NA anamorphic optics, higher transmission, fast stages, offer attractive wafer cost / process simplification proposition

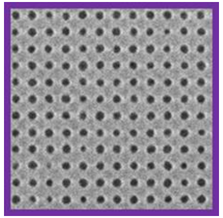
Britt Turkot/ Intel 2016 International Symposium on EUV Lithography, 24 October 2016, Hiroshima, Japan

Jan van Schoot et al, EUV roadmap extension by higher Numerical Aperture, EUVL conference 2016, Hiroshima, Japan

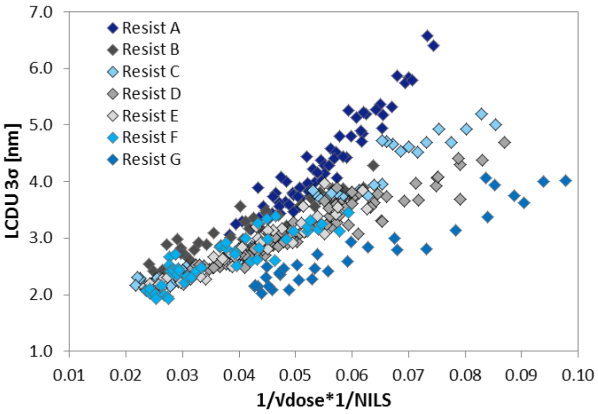
Courtesy Britt Turkot, INTEL, 2016-10-25

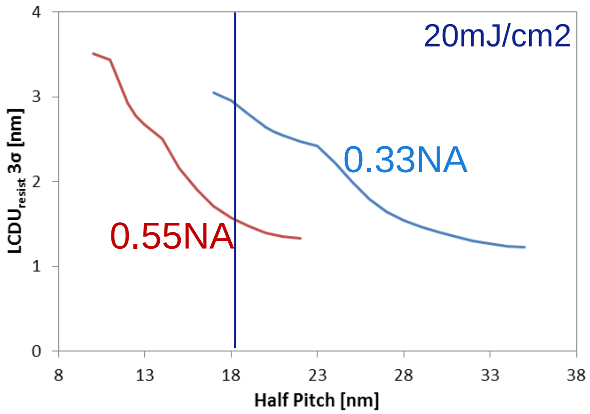
Larger NA reduces Local CDU

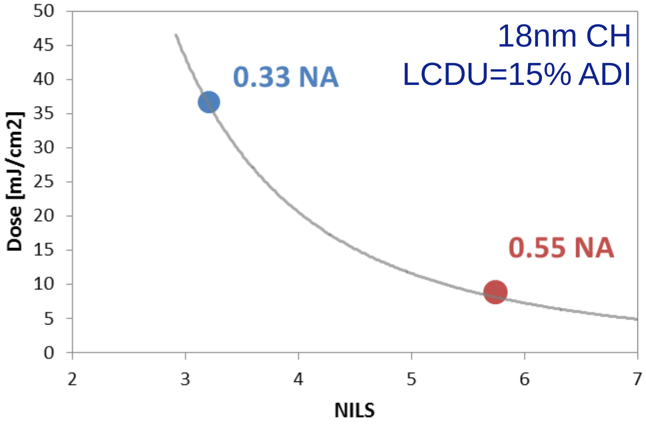
Due to larger aerial image contrast



Non-CAR resist, Quasar Illumination

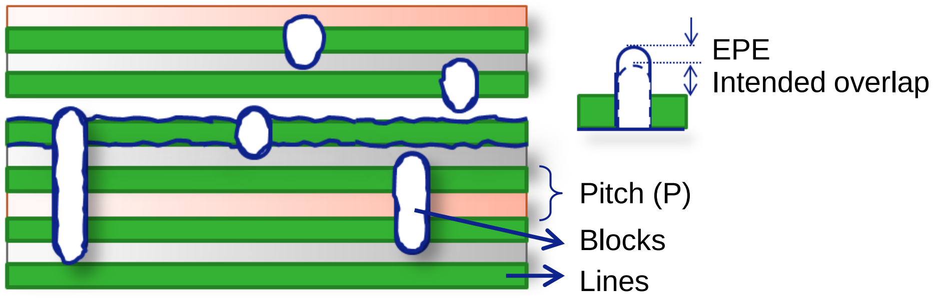






Edge Placement Error determining factor in litho performance

$$EPE_{max} = \text{'}systematics\text{'} + \text{'}local\text{'} + \text{'}global\text{'}$$



$$EPE_{max} = \frac{HR_{OPC}}{2} + \frac{3\sigma_{PBA}}{2} + \frac{6\sigma_{LWR}}{\sqrt{2}} + \sqrt{(3\sigma_{OVL})^2 + \left(\frac{3\sigma_{CDU}}{2}\right)^2}$$

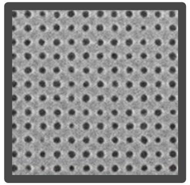
With $\sigma_{LWR} = \sqrt{\sigma^2_{LWR\_line} + \sigma^2_{LCDU\_cuts}}$

and $\sigma_{CDU} = \sqrt{\sigma^2_{CDU\_lines} + \sigma^2_{CDU\_cuts}}$

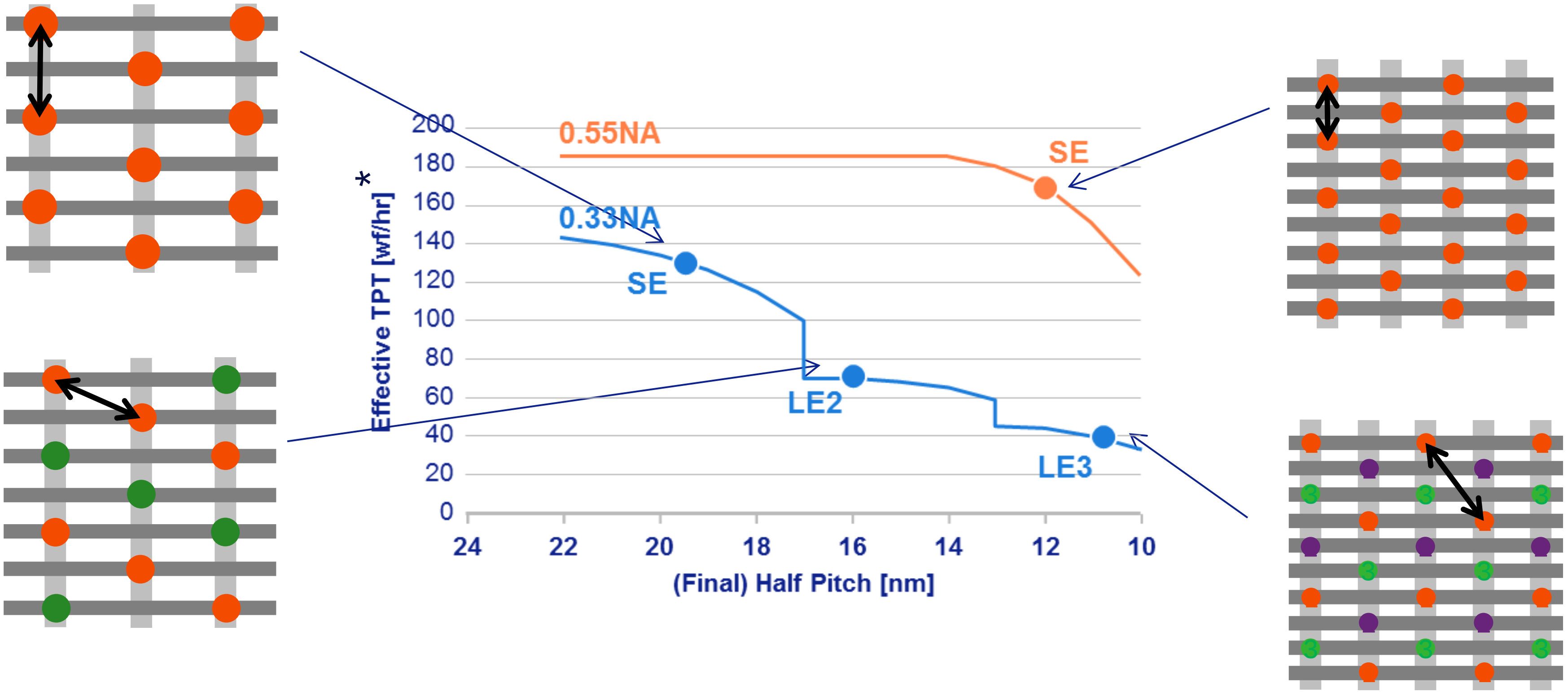
Bring system at EPE specifications by adapting the dose → Throughput

Larger NA results in higher effective throughput

NA limits dose and # of LE steps



Quasar Illumination



* Effective throughput = throughput / # LE steps

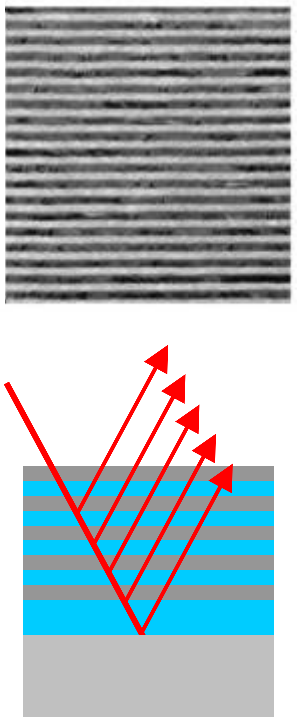
Jan van Schoot et al, EUV roadmap extension by higher Numerical Aperture, EUVL conference 2016, Hiroshima, Japan

Anamorphic Optics

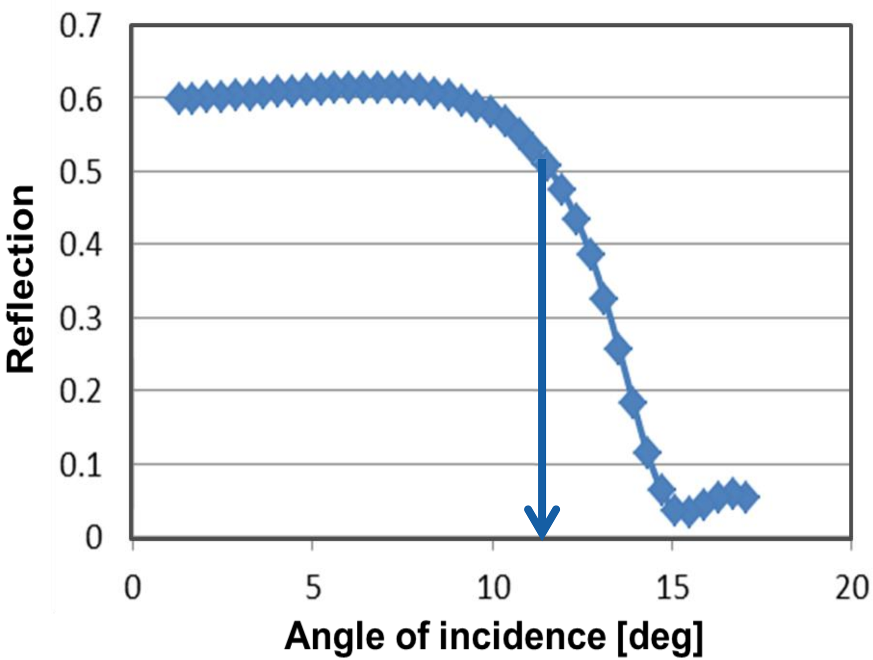
EUV: it’s all about the angle

High-NA comes with large angles

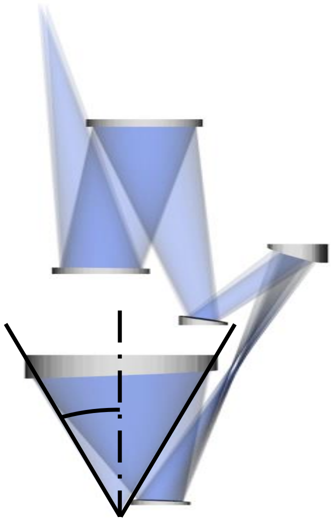
MoSi Multilayer



ML reflection



NA=0.55



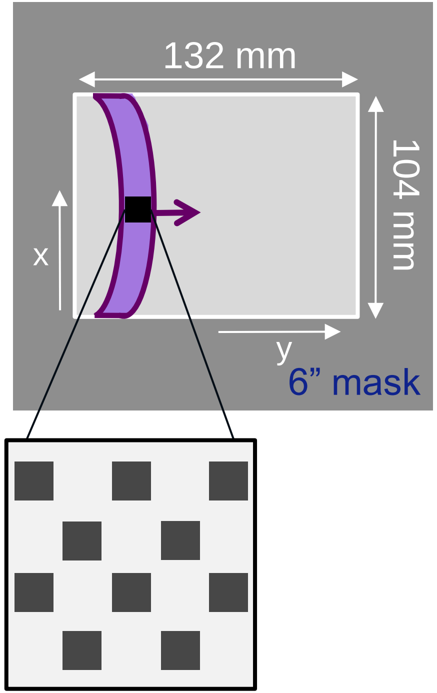
Jan van Schoot et al, EUV roadmap extension by higher Numerical Aperture, EUVL conference 2016, Hiroshima, Japan

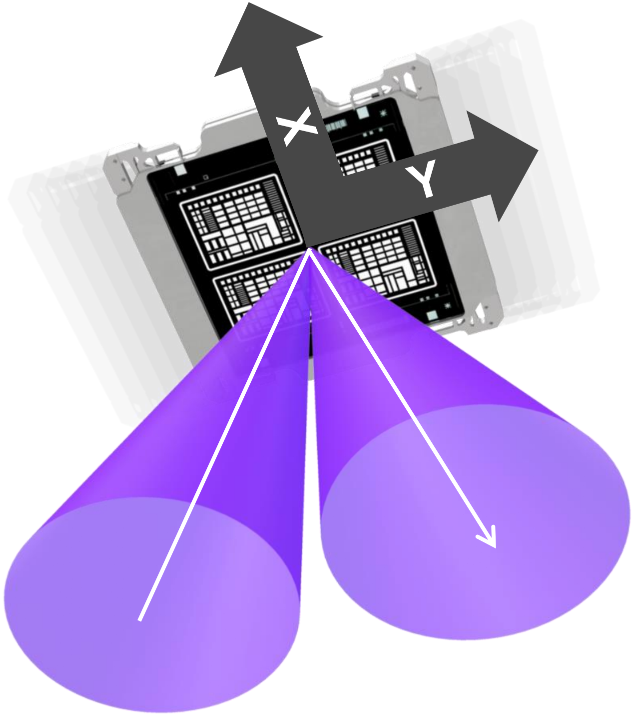
Light cones at the mask for a 0.33NA Scanner

Enabling a solution with 26 mm slit on 6" masks

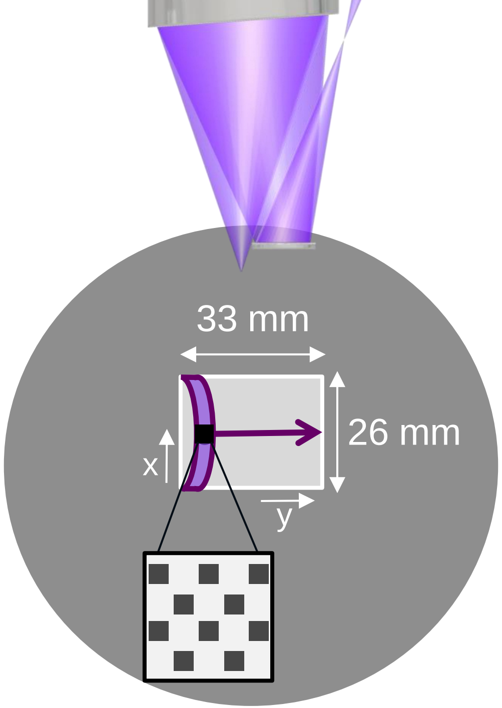
Reticle

Reticle layout compatible with
today 6" mask production





Projection with 0.33 NA
Mag X: 4x
Mag Y: 4x

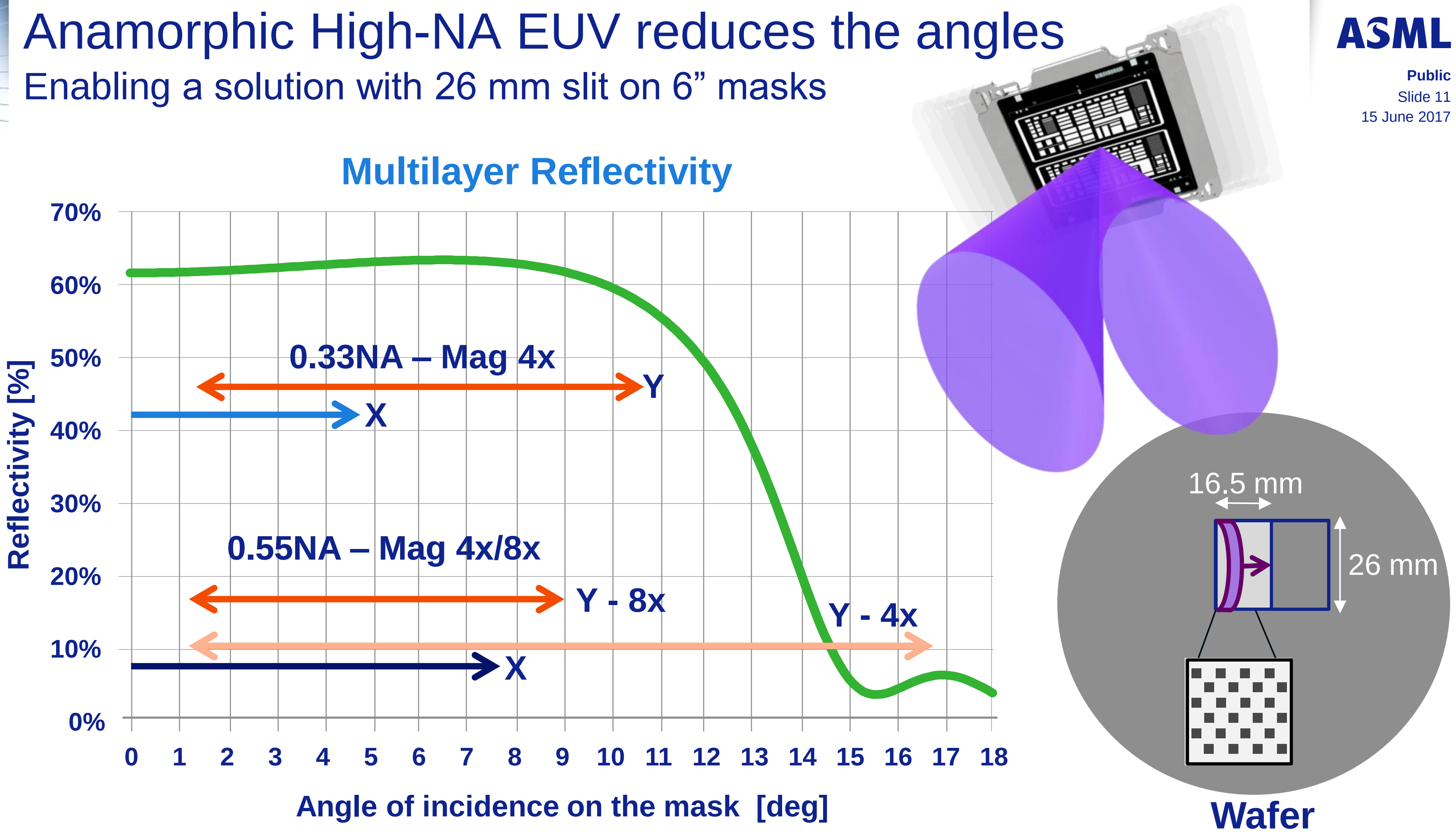


Wafer

Source: Jan van Schoot, ASML, "EUV roadmap extension by higher Numerical Aperture", 2016 international symposium on EUV, 24 October 2016, Hiroshima

Anamorphic High-NA EUV reduces the angles

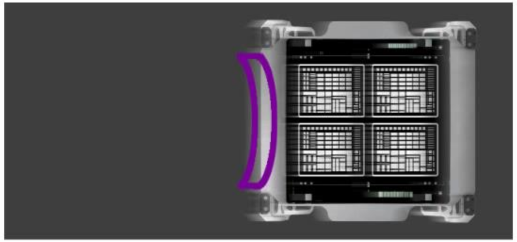
Enabling a solution with 26 mm slit on 6” masks



Multilayer Reflectivity

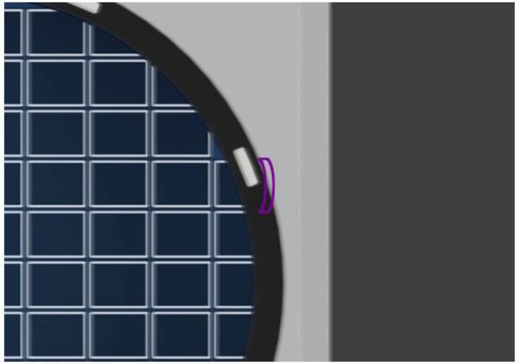
High-NA anamorphic Half Field concept

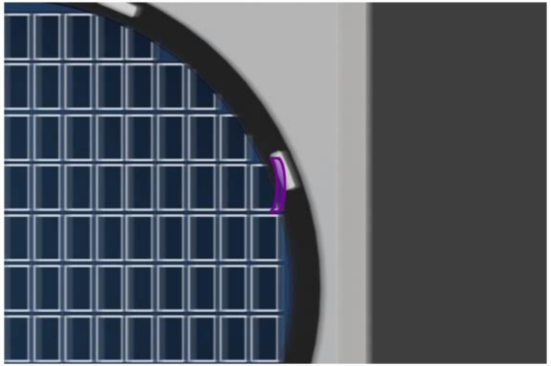
Faster stages required to obtain high productivity half-field scanner

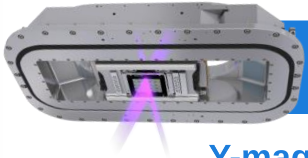


Projection: 0.33 NA

Projection: > 0.5 NA

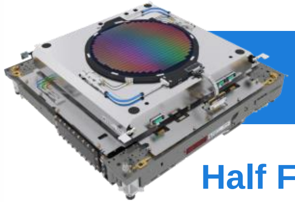






Acceleration of mask stage ~4x

Y-magnification 4x → 8x:
2x wafer acceleration results
in 4x mask acceleration

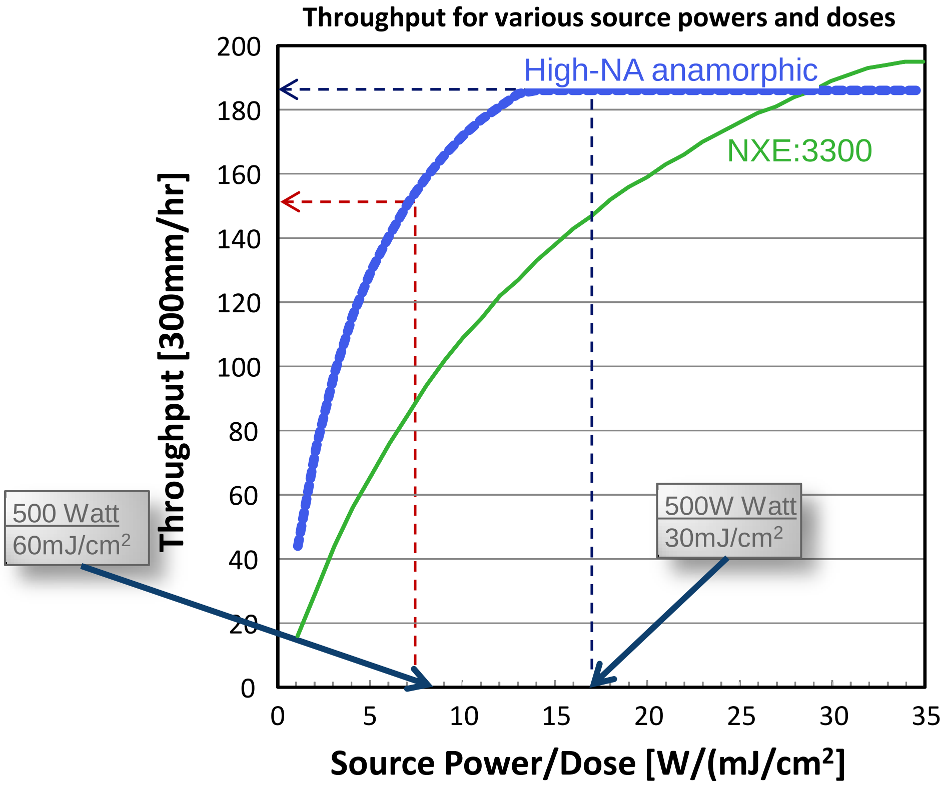


Acceleration of wafer stage ~2x

Half Field yields 2x more fields:
2x wafer stage acceleration maintains
overhead while going
to twice number of scans

High-NA Field and Mask Size productivity

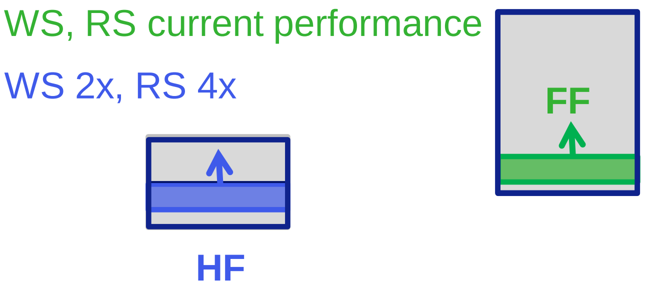
Throughput of >185wph with anamorphic HF



Throughput for various source powers and doses

500 Watt
$60mJ/cm^2$

500W Watt
$30mJ/cm^2$



WS, RS current performance

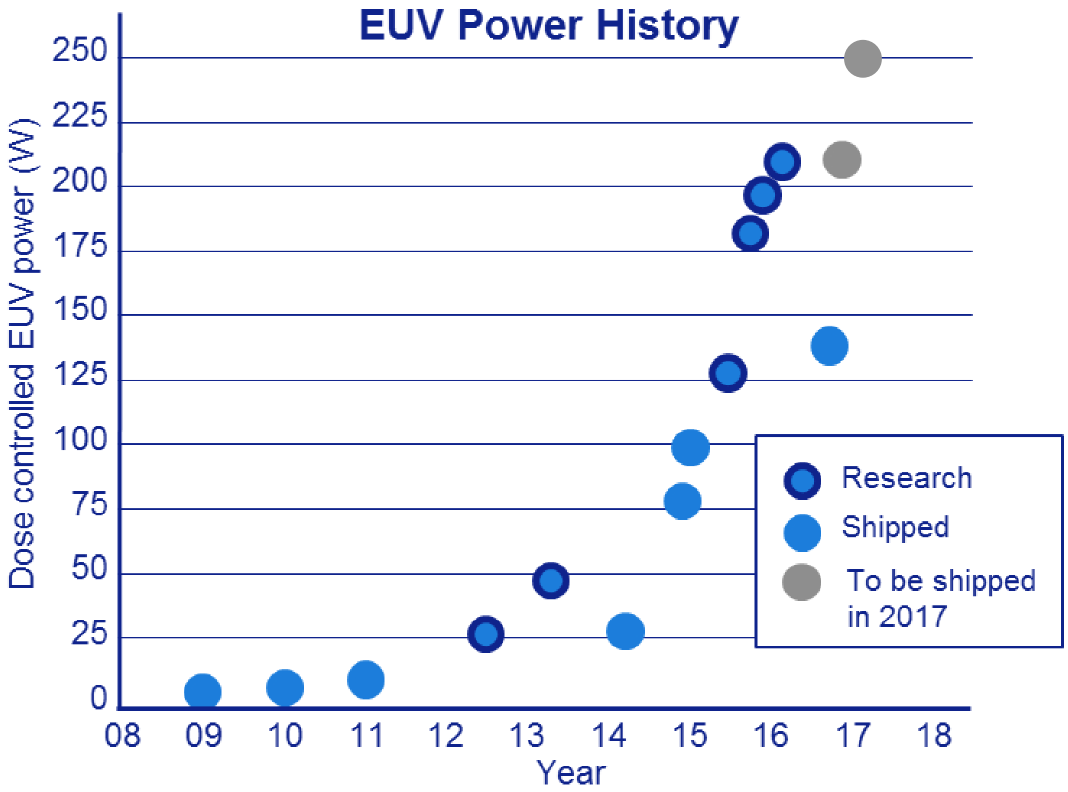
WS 2x, RS 4x

High-NA Half Field scanner

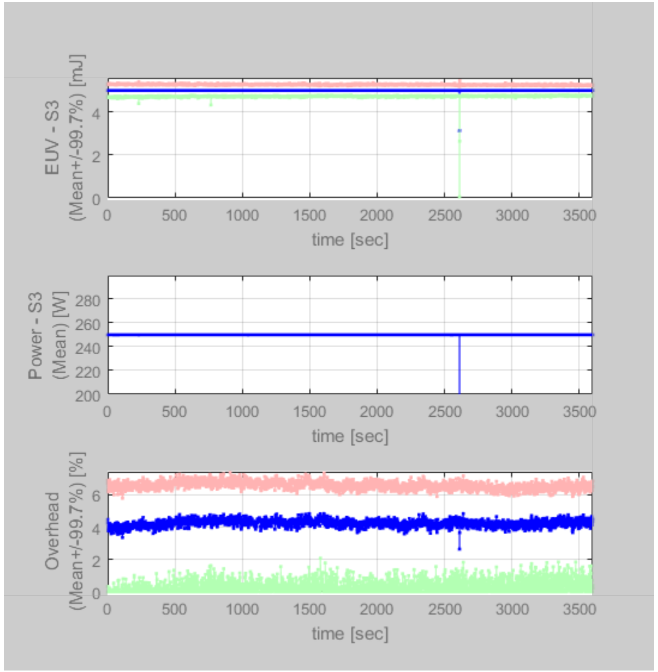
needs 500W for

150wph at $60mJ/cm^2$

Source power: 250W demonstrated,10x improvement in five years



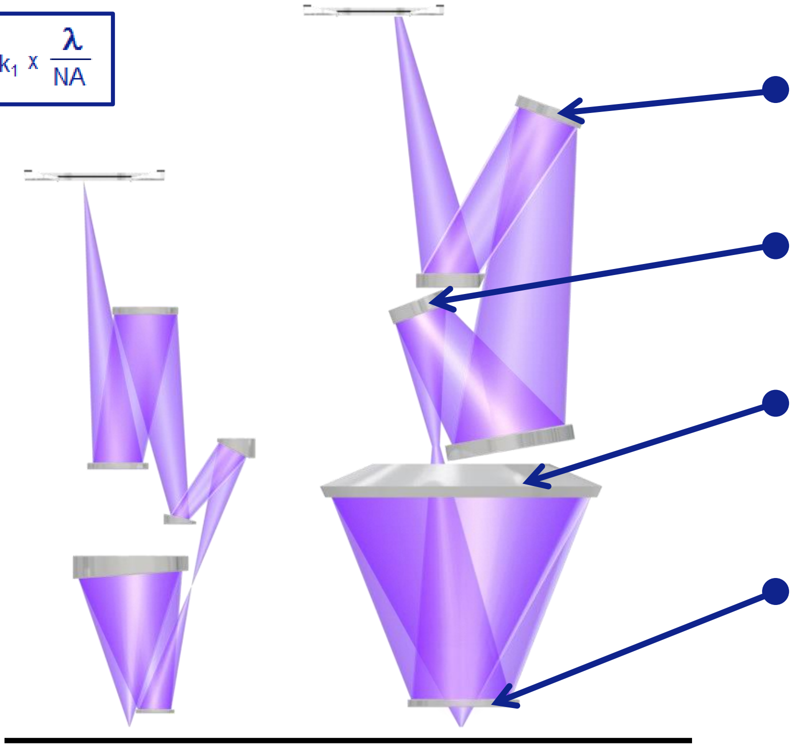
250W with dose in specifications obtained on development source



High-NA optics design available

Larger elements with tighter specifications

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



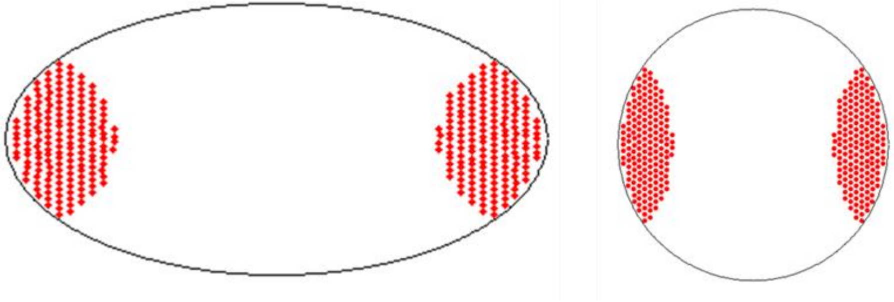
- Extreme aspheres enabling **further improved wavefront / imaging performance**
- Tight surface specifications enabling **low straylight / high contrast imaging**
- Big last mirror driven by **High-NA**
- Obscuration enables **higher optics transmission**
  ➔ Potential of up to 2x vs 3300

Design examples

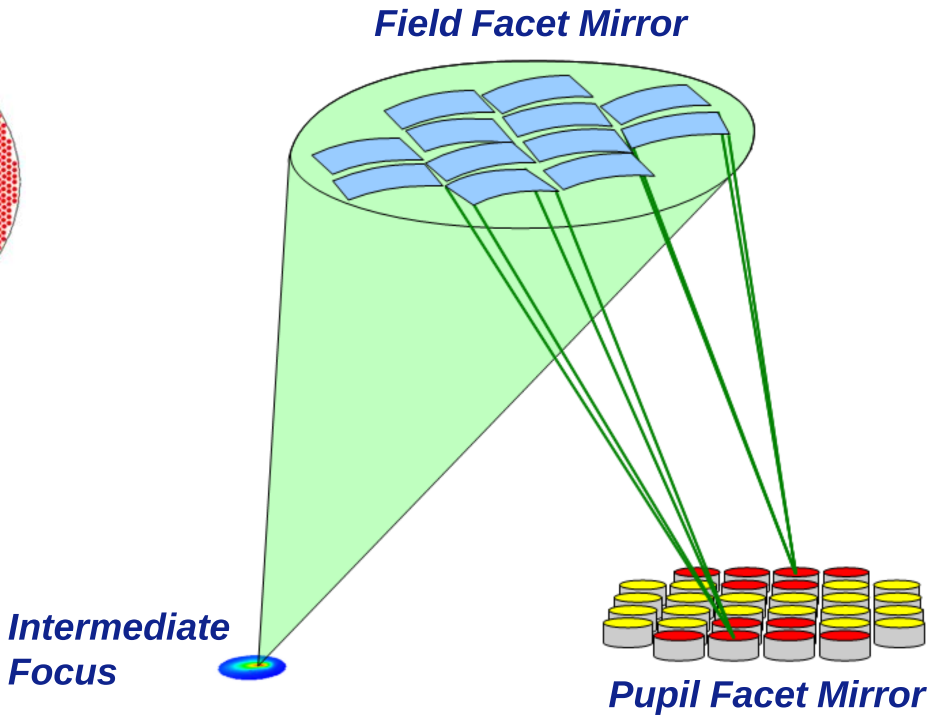
Source: Zeiss, “EUV lithography optics for sub-9nm resolution,” Proc. SPIE 9422, (2015).

High-NA flexible illuminator

Principle NXE:3300/3400 illuminator can be reused



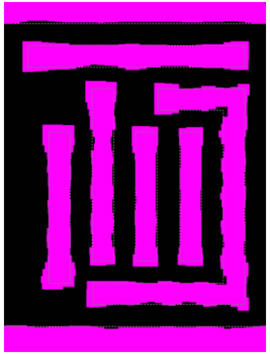
Illuminator elliptical pupil is projected in a circular pupil at the wafer

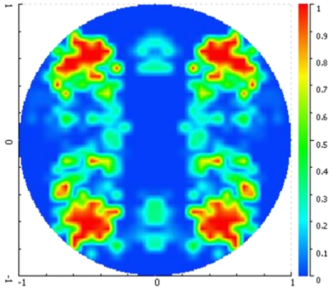


See Joerg Zimmermann et al. “Flexible illumination for ultra-fine resolution with 0.33 NA EUV lithography”, EUVL Symposium 2016

Imaging verification of the new Half Field concept

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

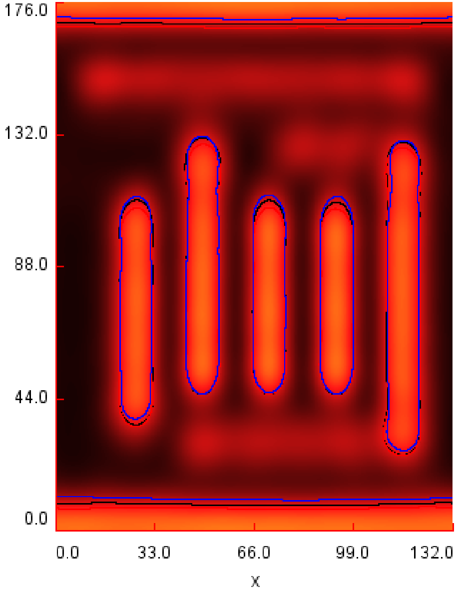




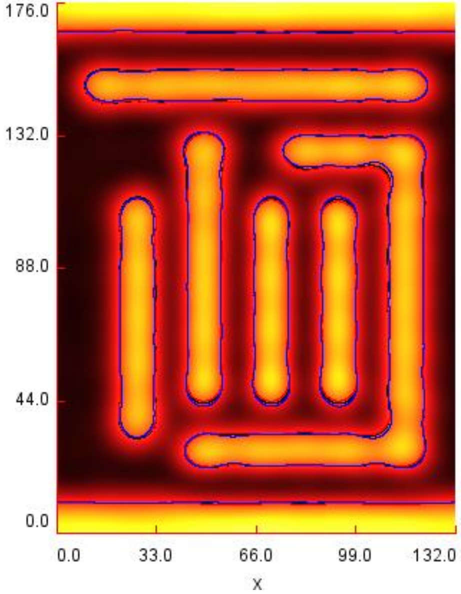
Note: pictures at same scale, smaller mask reflection is also visible

Aerial Image Intensity in Hyperlith

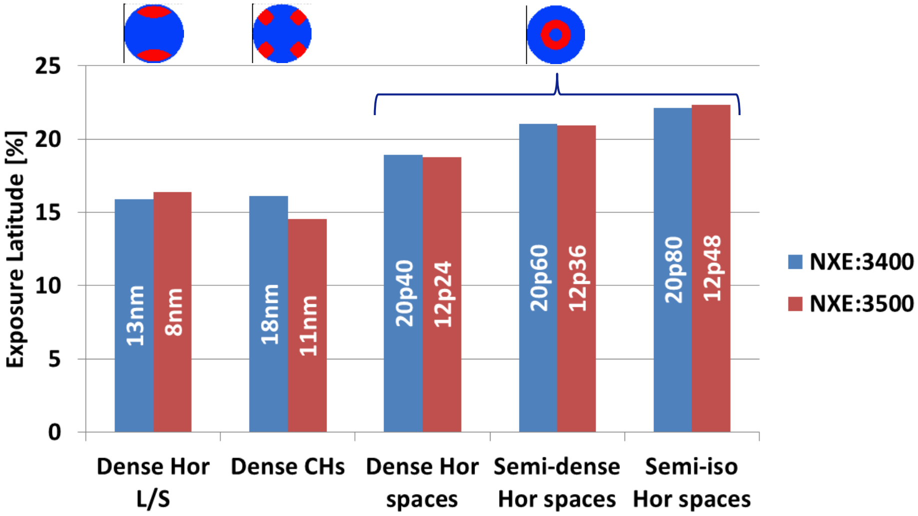
FF

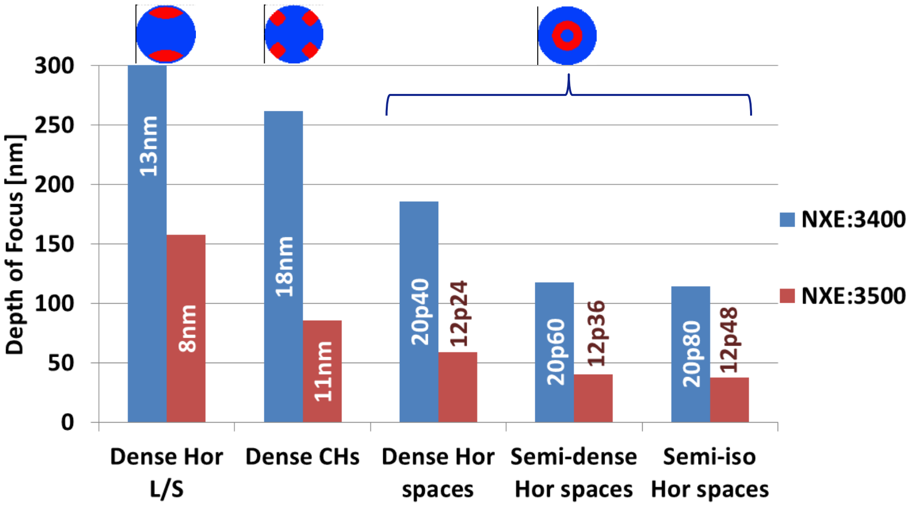


HF



Imaging evaluation of key lithographic structures: comparable performance as 0.33 NA at ~40% lower resolution





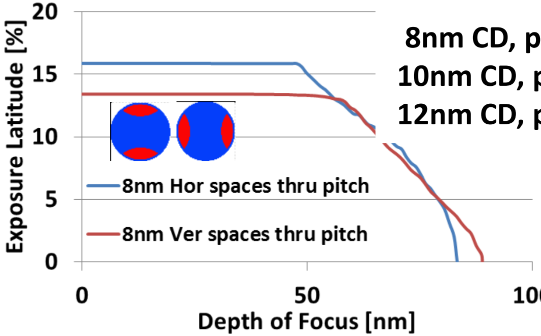
Comparable Exposure Latitude at 40% lower resolution

DOF at equivalent k_1 factor
Follows NA scaling → $\left(\frac{0.33}{0.55}\right)^2$

Simulations based on high-NA lens Jones pupil; mask 3D effects included

Good overlapping process window for customer relevant structures

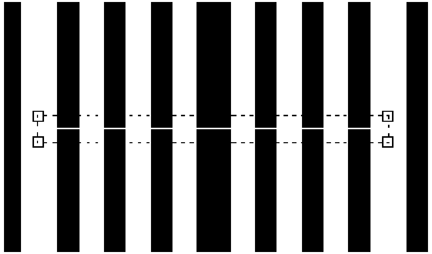
8nm spaces through pitch



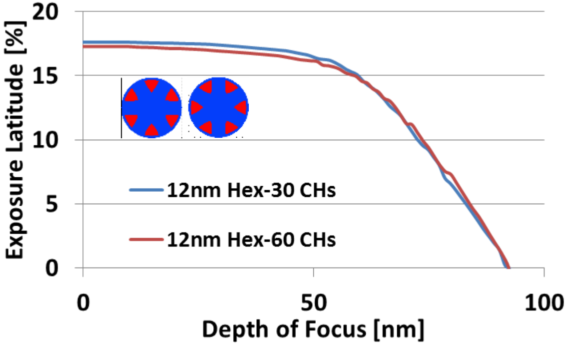
8nm CD, pitch 16nm
10nm CD, pitch 20nm
12nm CD, pitch 24nm

DoF @ 10% EL (H,V) = 68 / 56nm

Multi-pitch L/S pattern



12nm staggered CHs



DoF @ 10% EL = 73nm

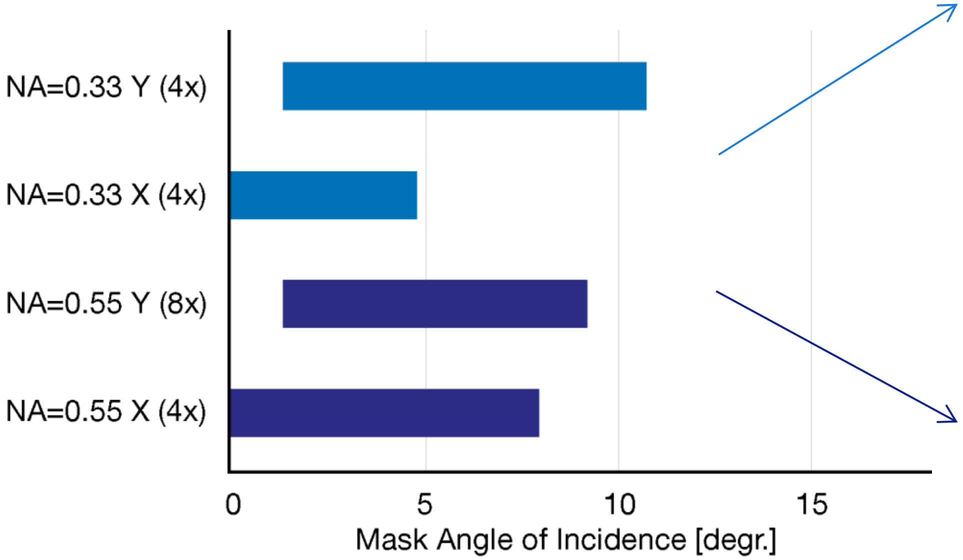
Logic cutmask

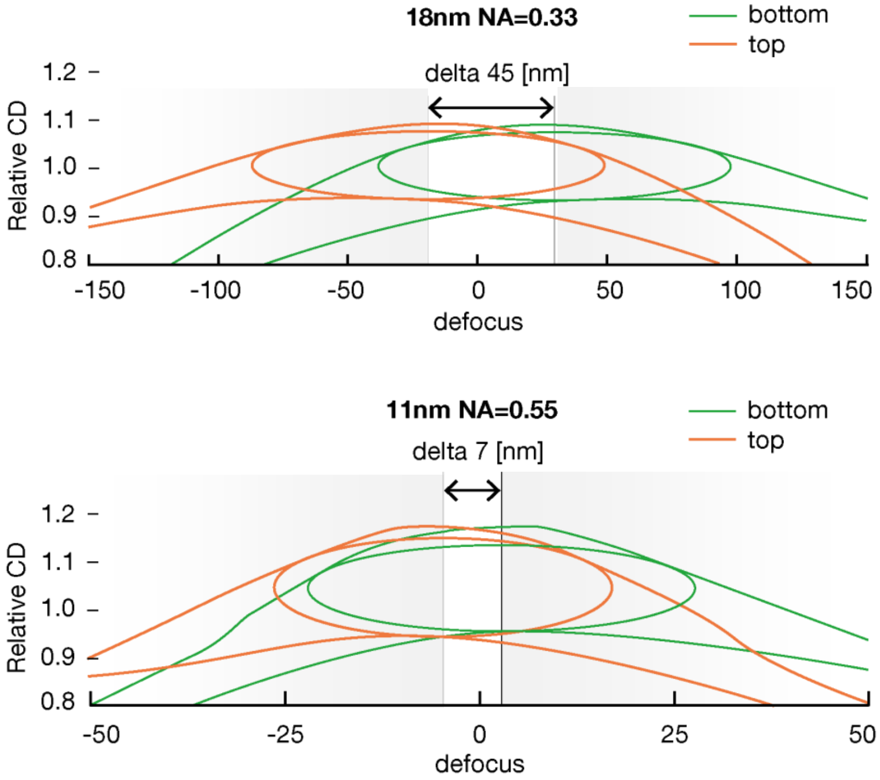
Simulations based on high-NA lens Jones pupil; mask 3D effects and curved exposure slit included

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

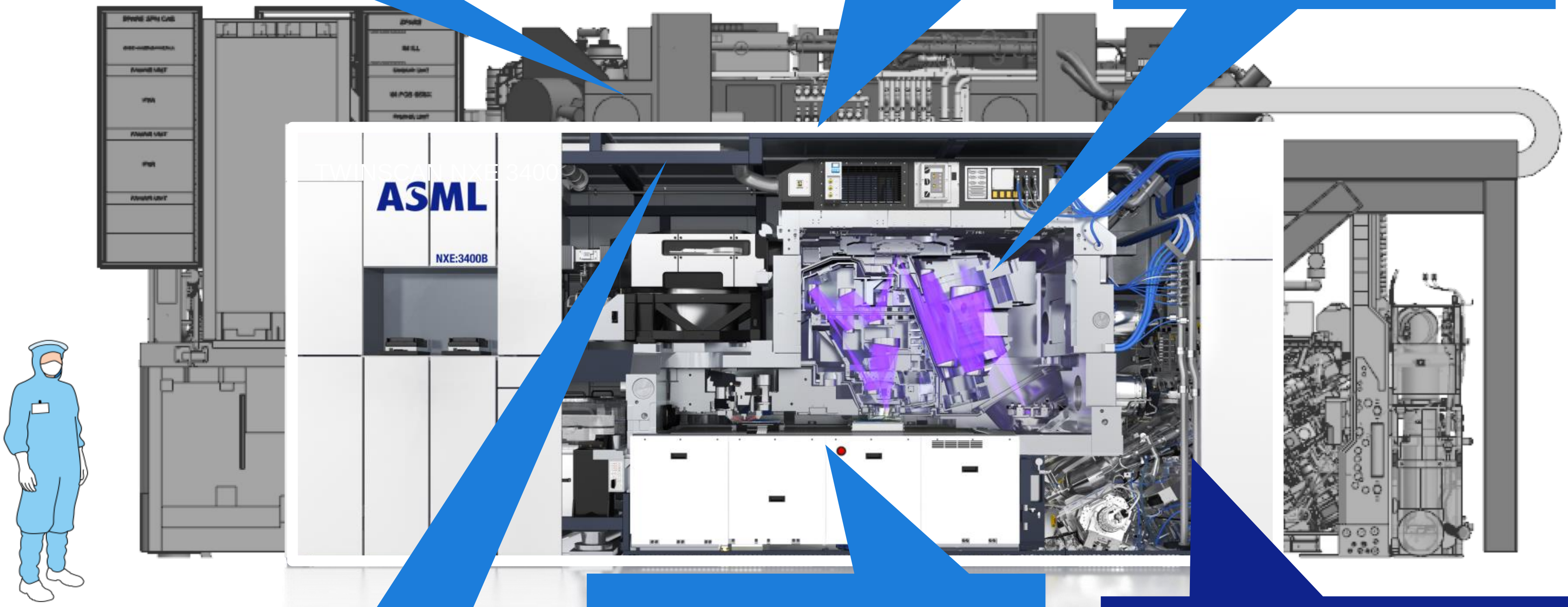




**L. de Winter, Understanding the Litho-impact of Phase due to 3D Mask-Effects when using off-axis illumination, EMLC 2015*

System Architecture

High-NA system architecture available



Improved metrology
2~3x improvement in overlay/focus

Mask Stage
4x increase in acceleration

Lens & illuminator
- NA 0.55 for sub-10nm resolution
- High transmission

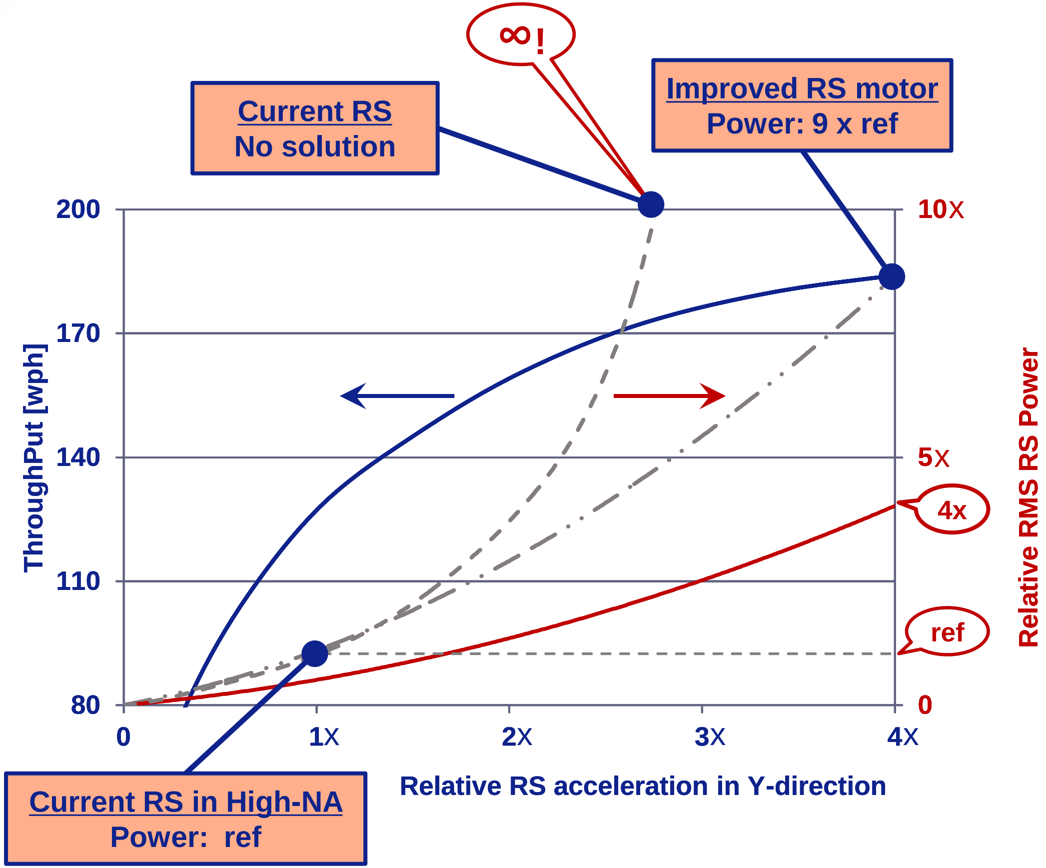
New Frames
Improved thermal and dynamic control with larger optics

Wafer Stage
2x increase in acceleration

Source
Compatible with 0.33 NA sources, power improvements opportunities over time

High-NA Mask Stage solution for increased acceleration

Improved motor technology & different -light weight- 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

Reticle stage acceleration

4 x 3400 acceleration

3400 reticle stage

High-NA reticle stage

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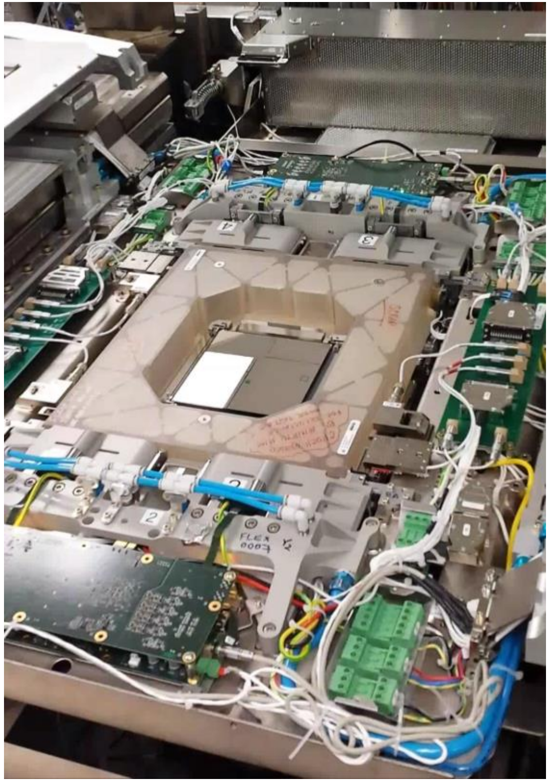
Mask stage short-stroke motor: demonstrated improved accuracy at high acceleration

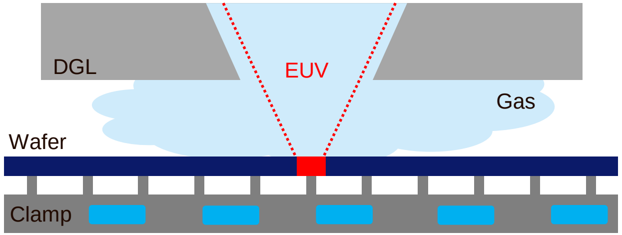


	Measured	Required
Actuators force (N)	**ref**	**1.2x**
Positioning accuracy (MA-Y, nm)	**0.37**	**$\leq$1.1**

Cooling Hood as Wafer Heating Solution

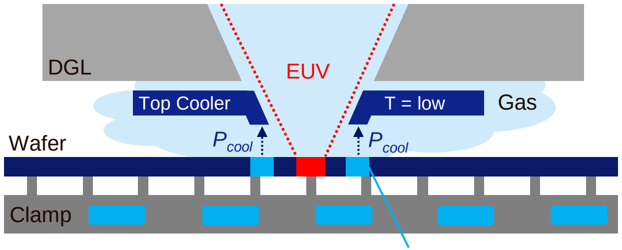
Extract heat from wafer using a cold body & gas pressure outside exposed area

NXE:3500 without Top Cooler



Include Wafer Top Cooling

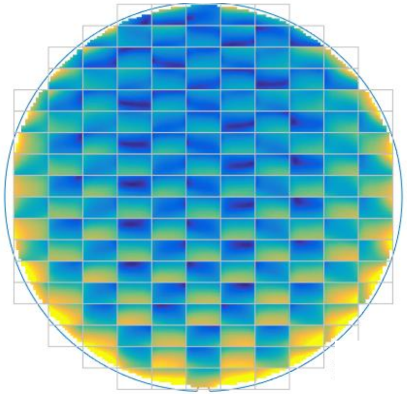
NXE:3500 with Top Cooler (“Cooling Hood”)



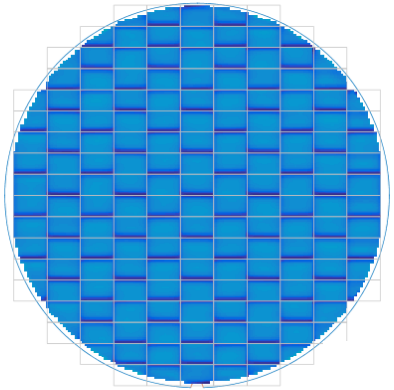
$$P_{cool} = HTC(p,z) \cdot A \cdot dT$$

P_{cool} = Cooling power [W]
A = Top cooler area [m^2]
dT = $T_{wafer} - T_{hood}$ [K]
HTC = heat transfer coefficient [W/($m^2 \cdot K$)]

Modelled raw distortions



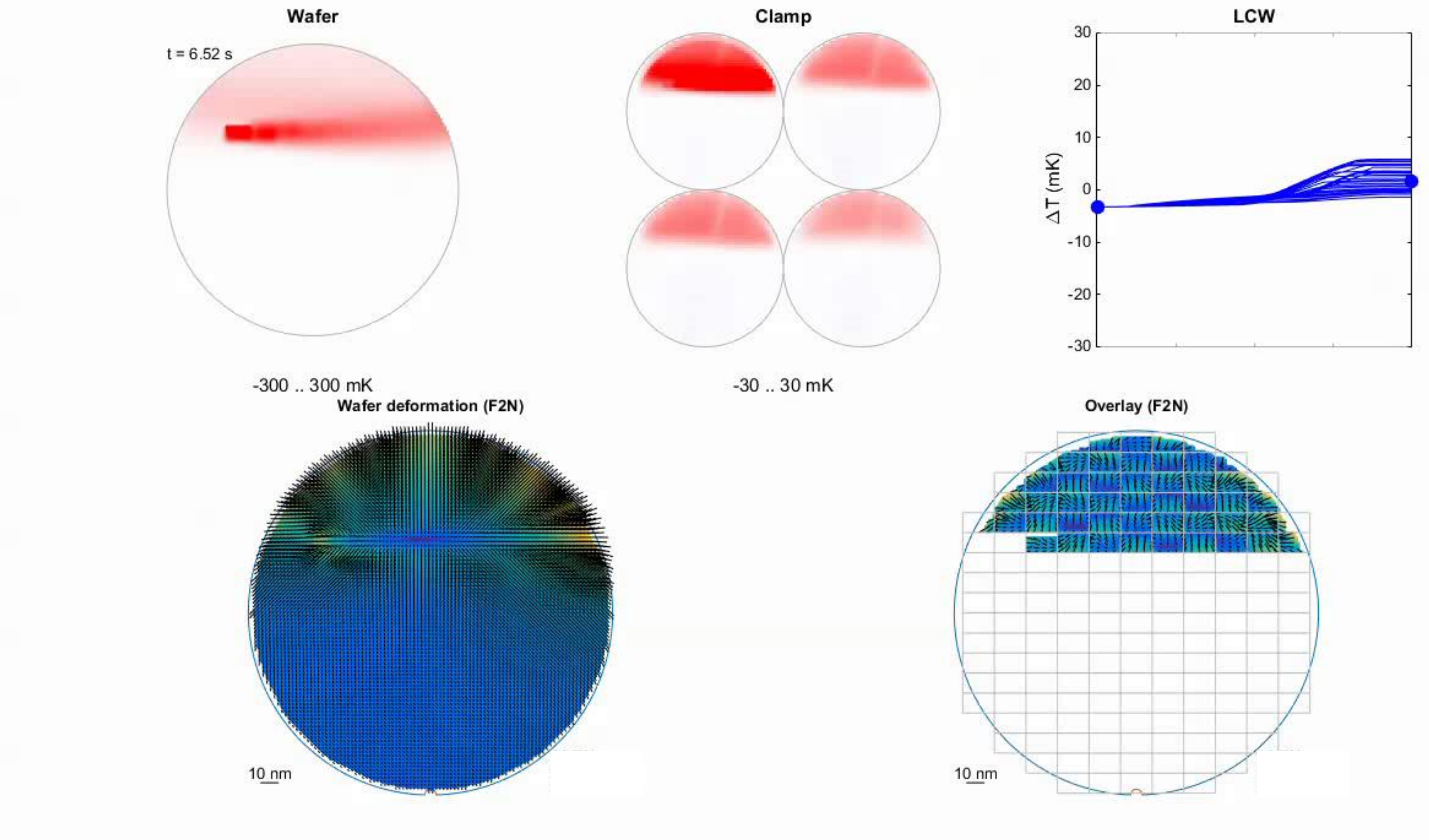
Modelled raw distortions



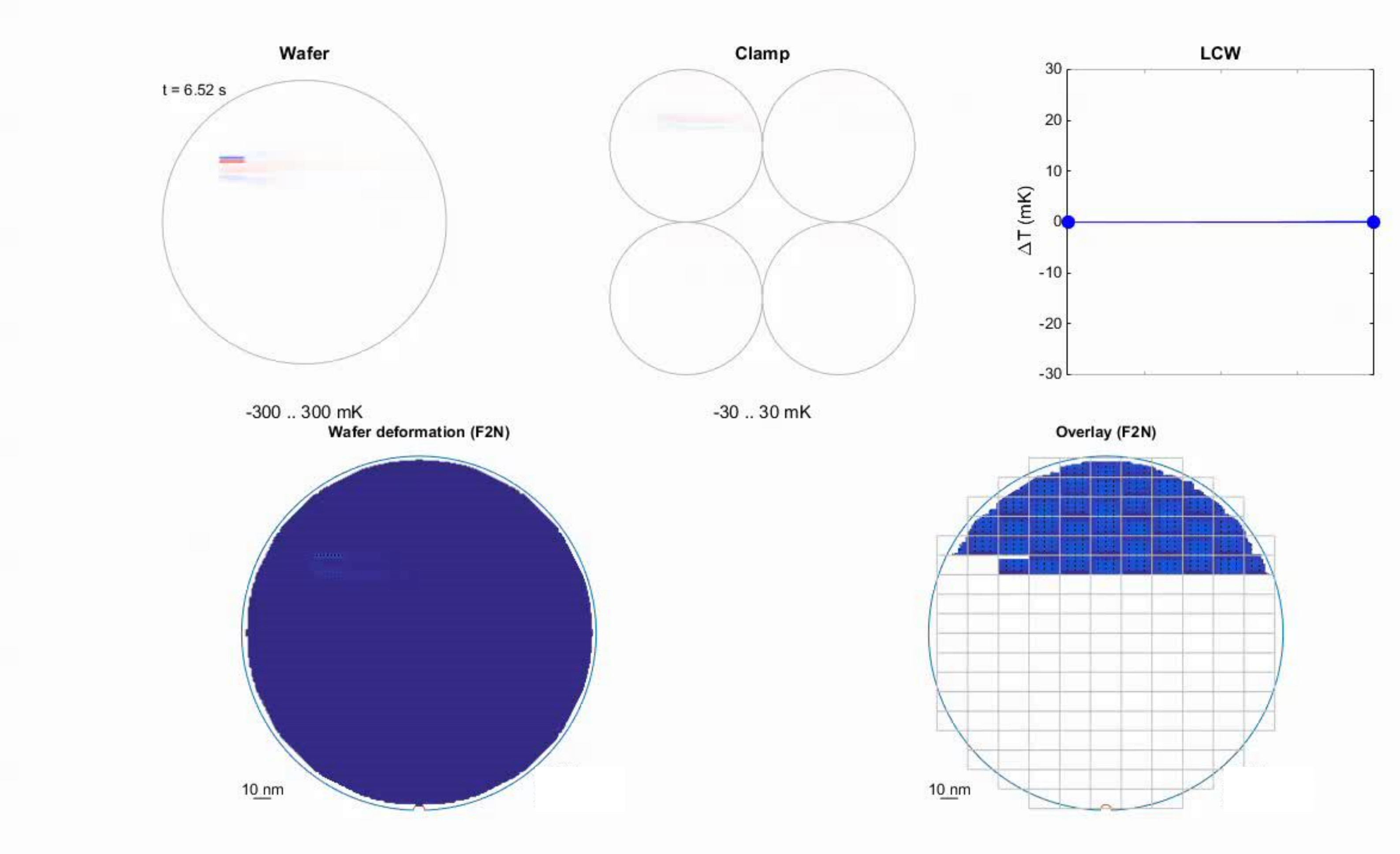
Top Cooler working principle:

- Heat from wafer to cold body via gas
- Match P_{cool} with exposure load,
- Switch cooling on/off between scans → gas pressure switching

Wafer Heating NXE:3500 without cooler

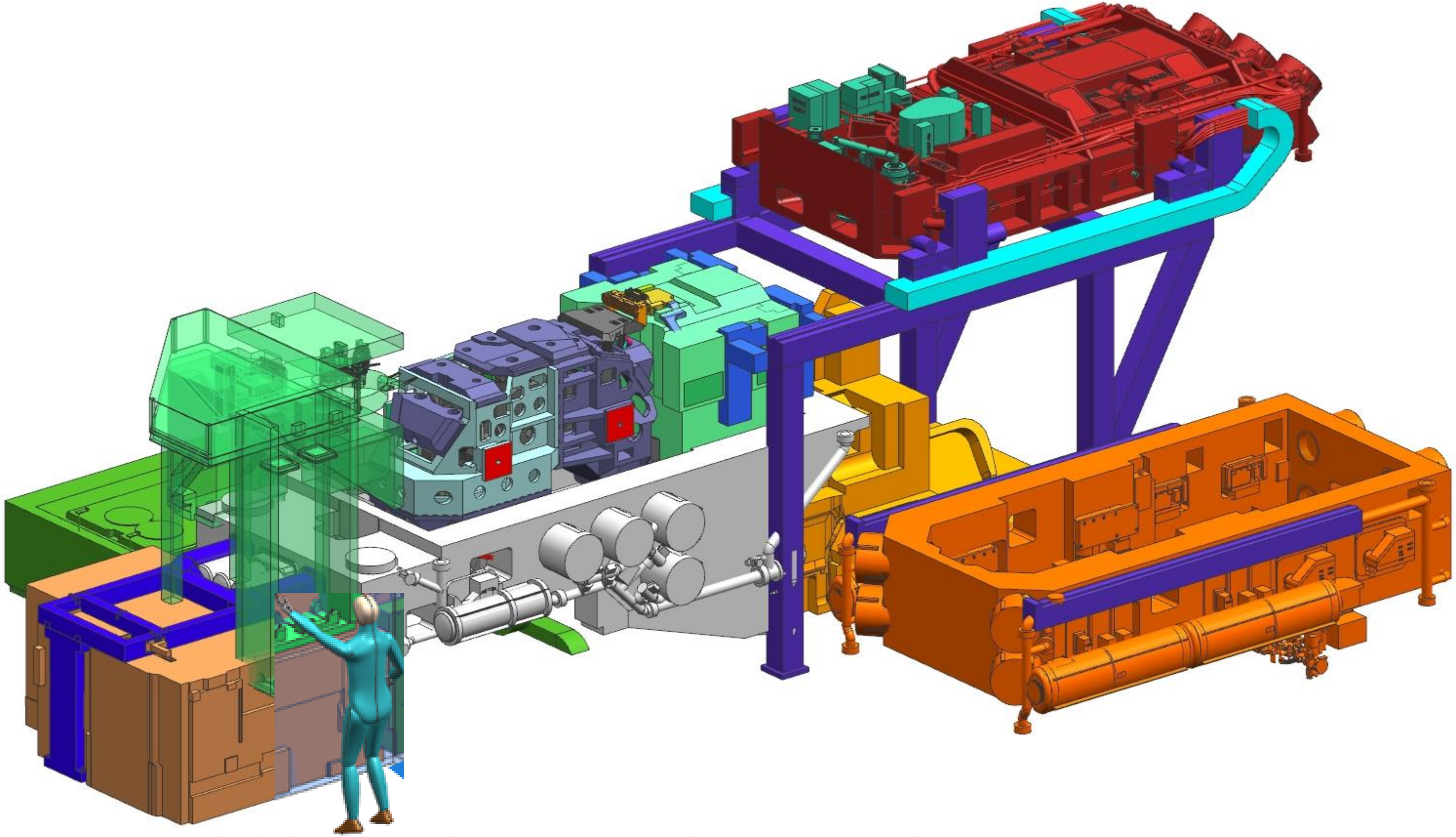


Wafer Heating NXE:3500 with cooler



Mechanical layout

Modularity key for manufacturing, shipment and service



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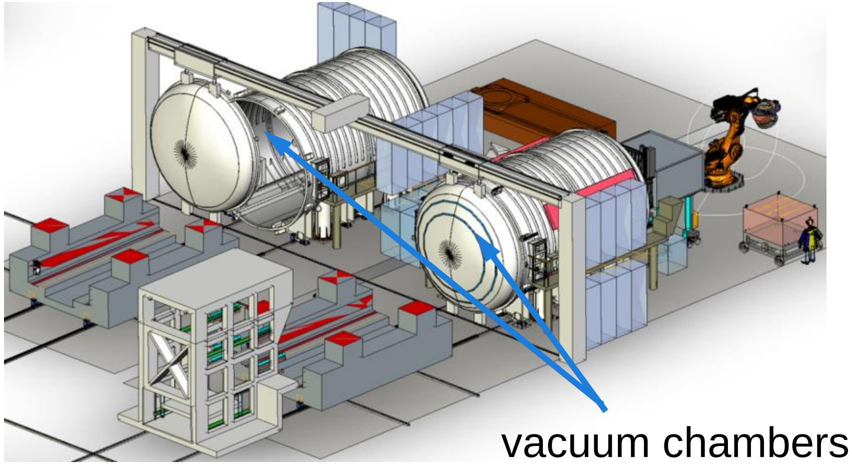
High-NA surface metrology

- ☐ Accuracy of mirror surface metrology is key for imaging quality
- ☐ High-NA wavefront needs improvement of factor ~2x compared to 3300 → 2x better measurement accuracy required
- ☐ For larger mirrors: Diameter of mirrors about doubled



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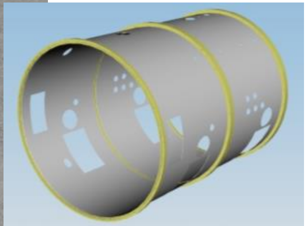
Courtesy Carl Zeiss SMT GmbH, 2016-09-20

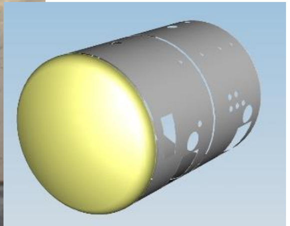
Non-design but leadtime critical components ordered Chamber flanges



Jan van Schoot et al, EUV roadmap extension by higher Numerical Aperture, EUVL conference 2016, Hiroshima, Japan

Courtesy Carl Zeiss SMT GmbH, 2016-09-20

Non-design but leadtime critical components ordered Chamber doors



Jan van Schoot et al, EUV roadmap extension by higher Numerical Aperture, EUVL conference 2016, Hiroshima, Japan

Courtesy Carl Zeiss SMT GmbH, 2016-09-20

New grinding technology and machinery

Courtesy Carl Zeiss SMT GmbH, 2016-09-20

Facility construction Zeiss in Oberkochen started

Courtesy Carl Zeiss SMT GmbH, 2016-09-20

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 are closing the feasibility, optics in design phase, first HW in place

Public

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- Oberkochen
- Wilton
- Veldhoven

Thank you for your attention

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