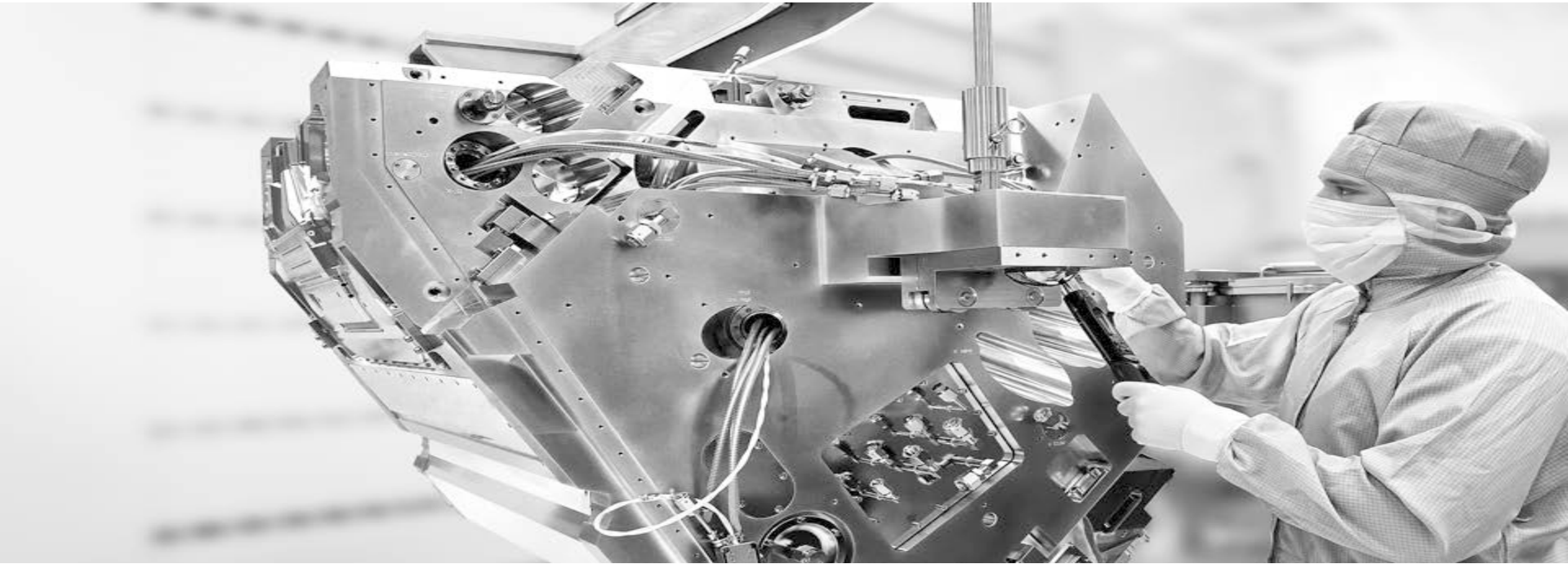


# Optics for EUV Lithography



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**2018 EUVL Workshop**

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# The resolution of the optical system determines the minimum feature size on a chip.



Ernst Abbe in 1873

$$\textit{resolution} = k_1 \frac{\lambda}{NA}$$

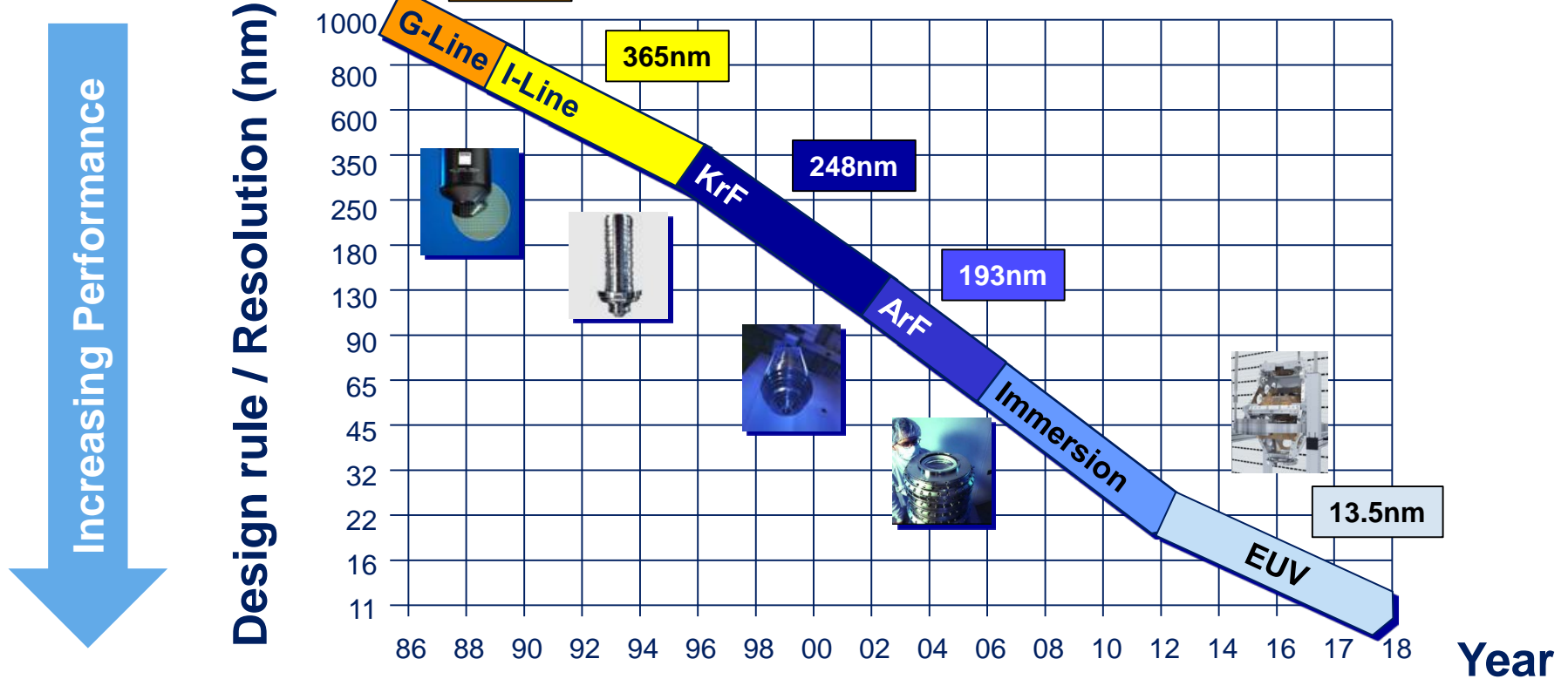
$k_1$  is process factor

$\lambda$  is wavelength

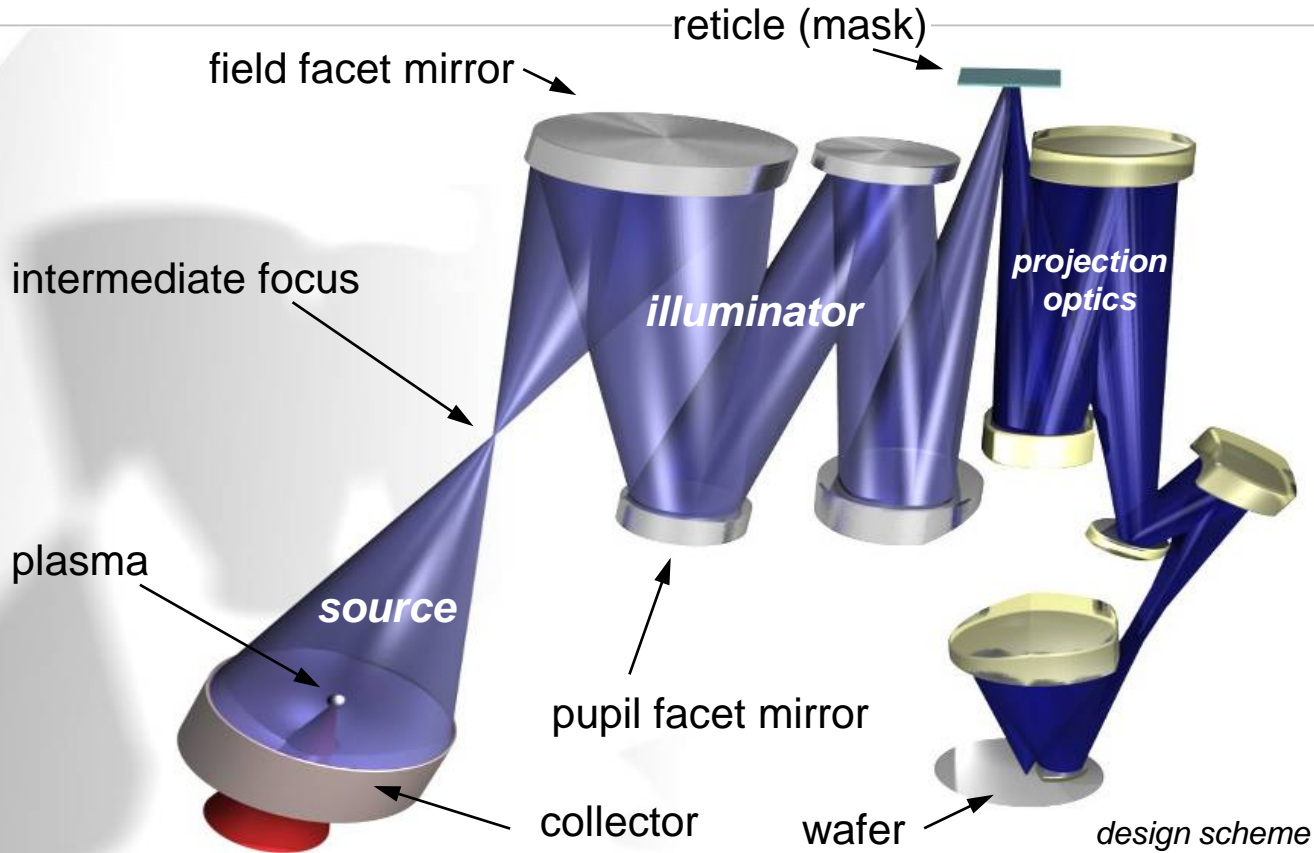
**NA** is numerical aperture

***Moore's Law drives the requirements on the optical system.***

The sequence  $\lambda$  down  $\rightarrow$  NA up  $\rightarrow$   $k_1$  down has been repeated several times during the last 25 years.



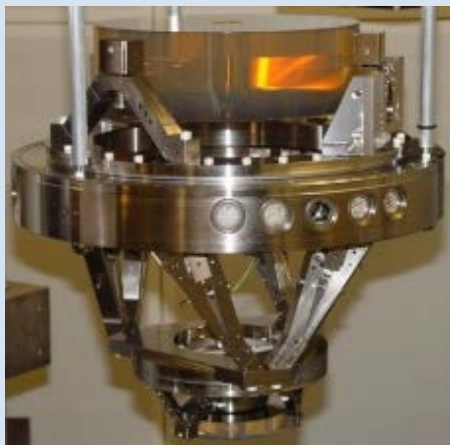
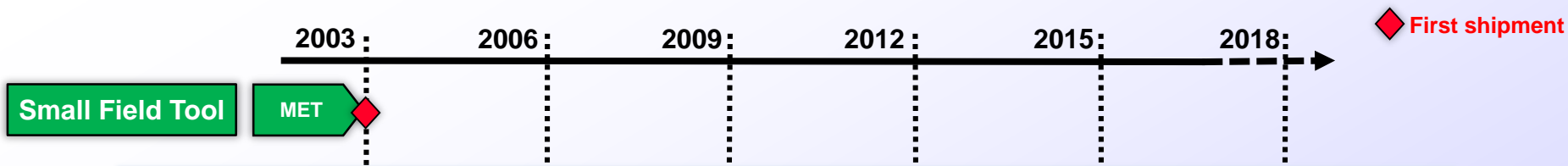
# EUV optical train (schematic).



**1 The EUV Program at ZEISS has enabled serial production.**

**2 High-NA EUV Lithography will provide further shrink.**

# EUV program at ZEISS: Continuously improving resolution.



## Micro Exposure Tool

NA *0.30*

Field *0.6 x 0.2 mm<sup>2</sup>*

MAG *5x*

Resolution *20 nm*

- Since mid-1999 developed in cooperation with Lawrence Livermore National Lab and Lawrence Berkeley National Laboratories.

# EUV program at ZEISS: Continuously improving resolution.



◆ First shipment

Small F

Proto

Pre-Pro



= 0.30  
0 nm

**Starlith<sup>®</sup> 3100**

NA **0.25**

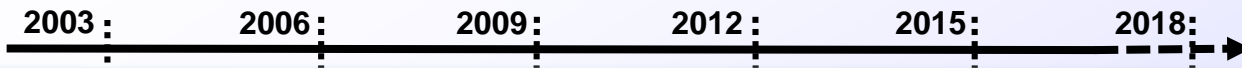
Field **26 x 33 mm<sup>2</sup>**

MAG **4x**

Resolution **27 nm**

- The 1st EUV full field system: Optics for ASML ADT / NXE:3100.

# EUV program at ZEISS: Continuously improving resolution.



◆ First shipment

Small F

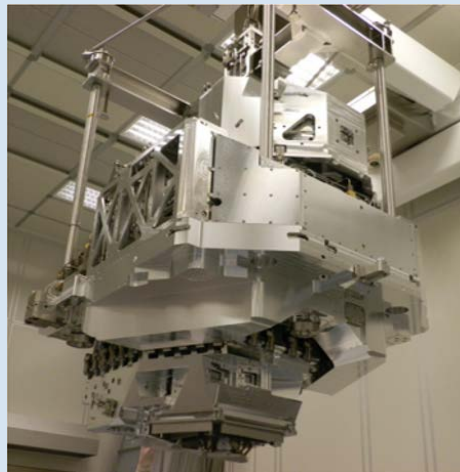
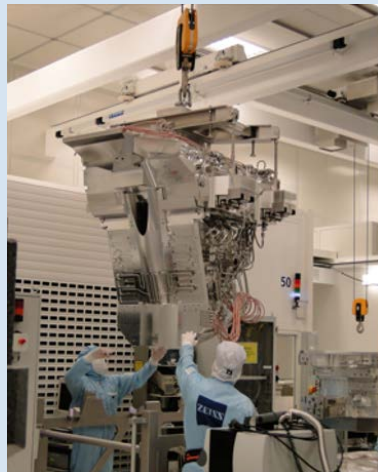
Proto

Pre-Pro

Serial Pr

= 0.30  
0 nm

= 0.25  
.27 nm



**Starlith<sup>®</sup> 3400**  
NA **0.33**  
Field **26 x 33 mm<sup>2</sup>**  
MAG **4x**  
Resolution **13 nm**

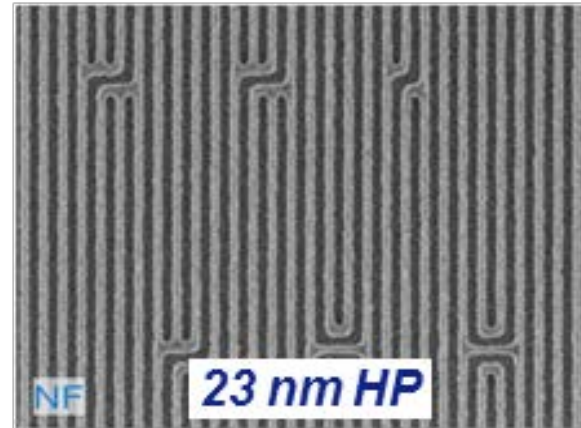
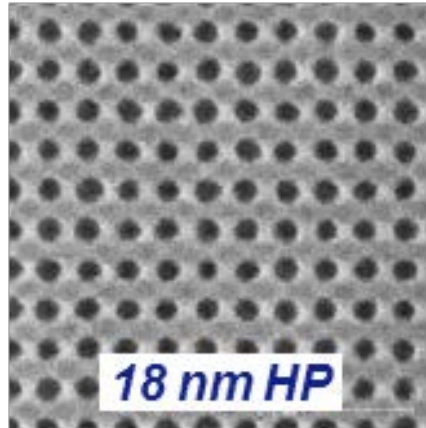
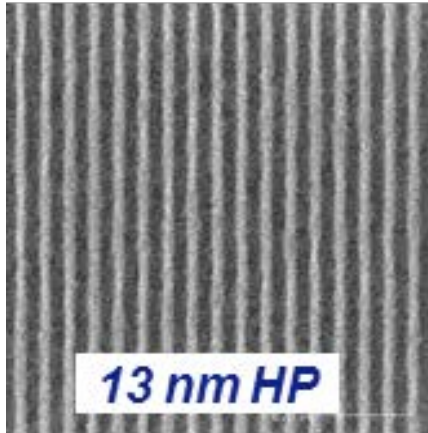
- The solution for serial production: Optics for ASML NXE:3400B.



The ZEISS Starlith<sup>®</sup> 3400 optics delivers excellent imaging...

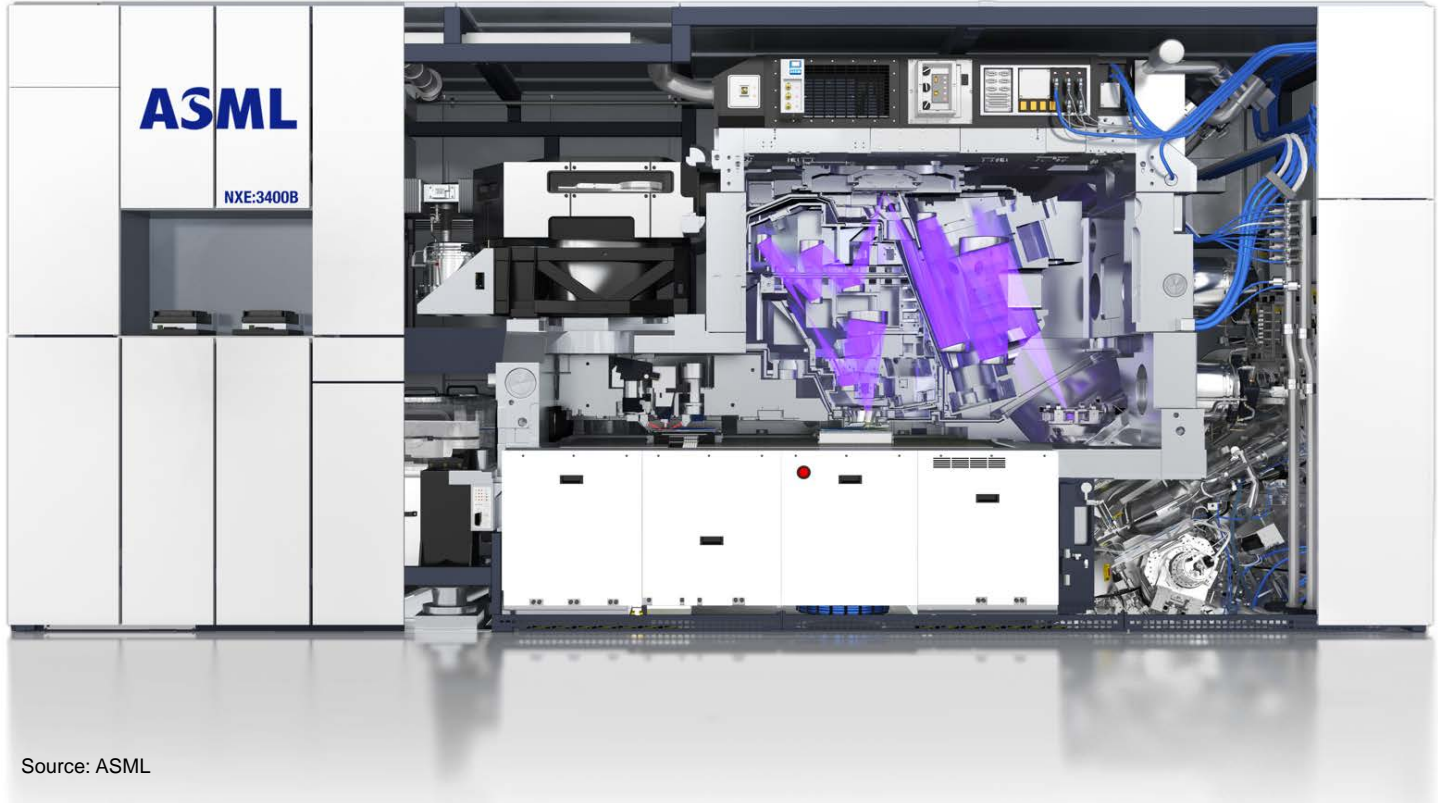
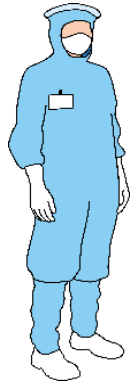


**Scanner capability**  
**HP = Half Pitch**



Source: ASML

...for the ASML NXE:3400B scanner.



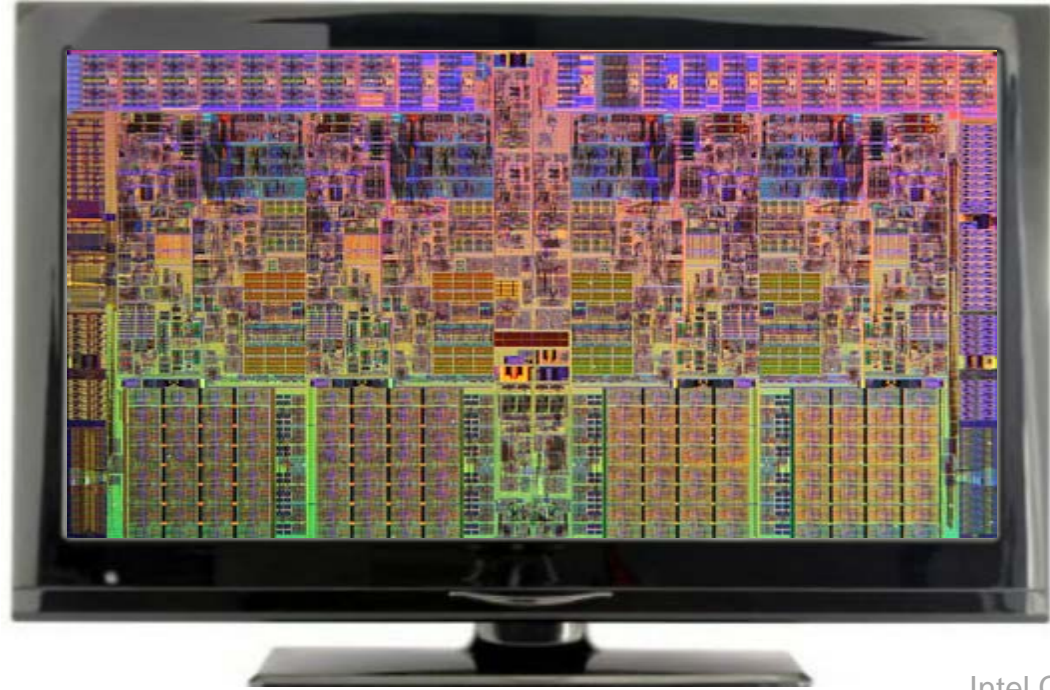
Source: ASML

# Displaying the information of one NXE:3400B field, requires a TV screen of 780m x 1370m.

One World Trade Center

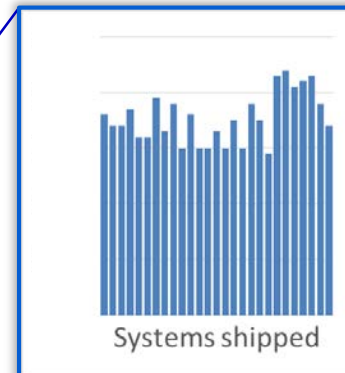
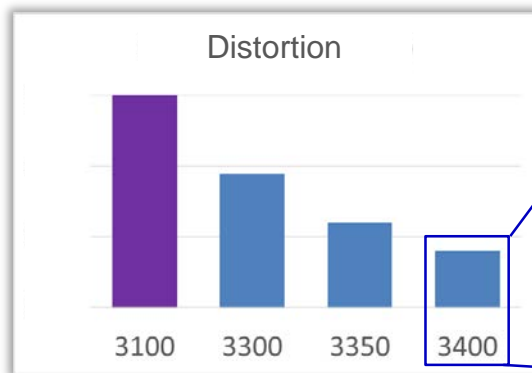
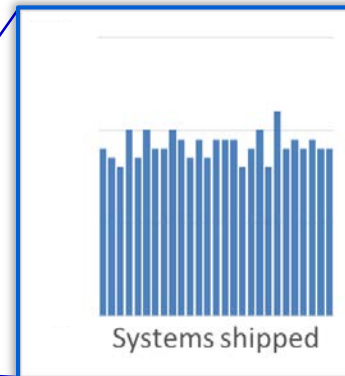
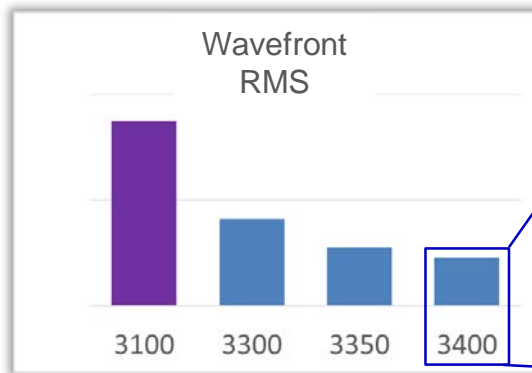
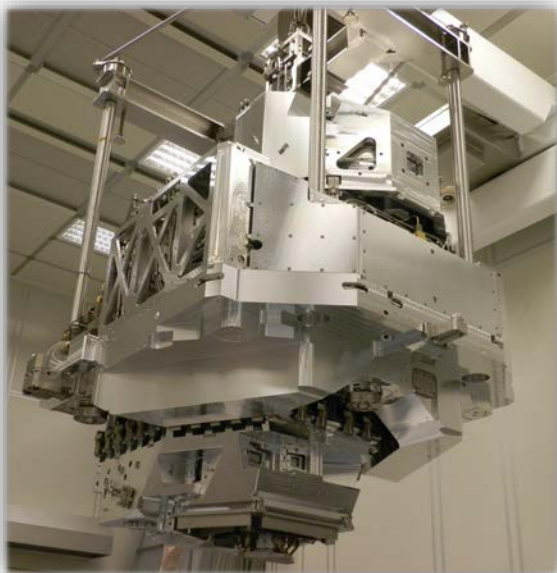
541 m

From Wikipedia



Intel Core i7 layout

# The Starlith® 3400 projection optics performs with improved aberrations – consistent for shipped systems.

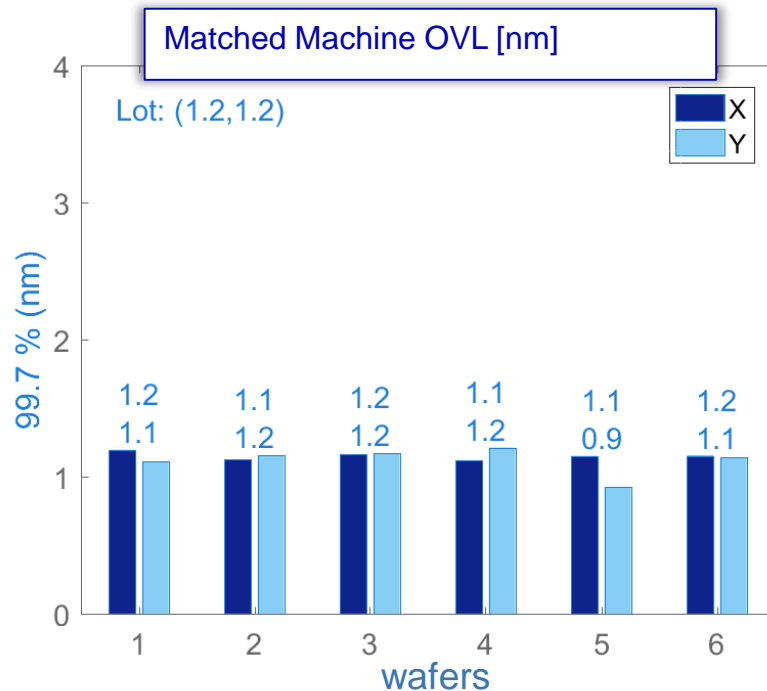
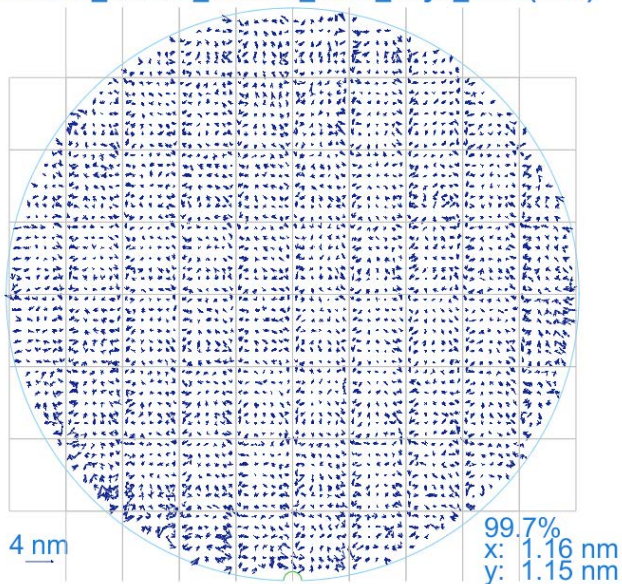


ZEISS inhouse EUV qualification

# The optical performance translates into world record breaking Matched Machine Overlay of 1.2nm for NXE:3400B.



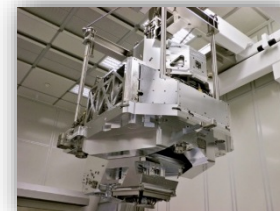
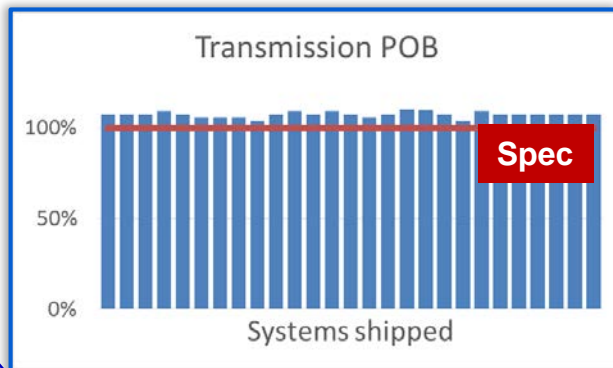
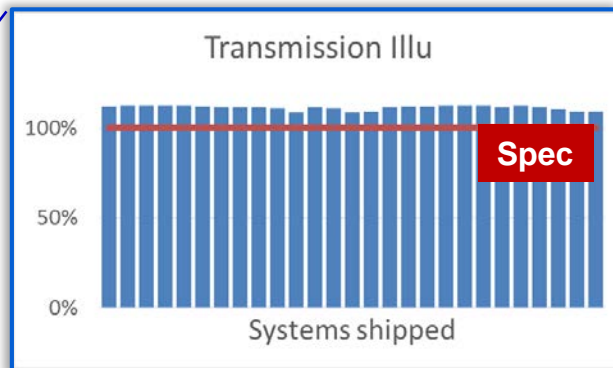
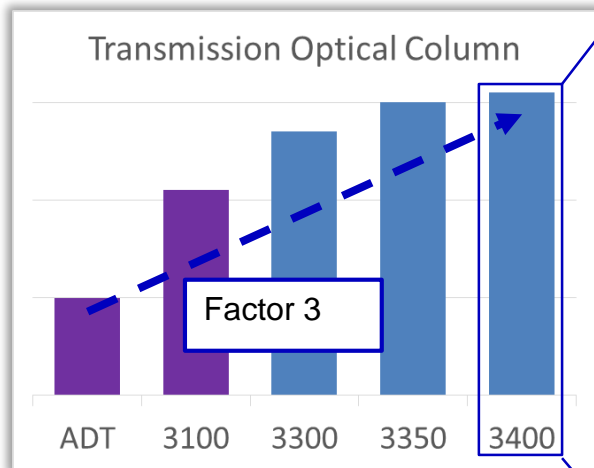
XYMMO\_BMMO\_170809\_0349\_day2\_wec (S2F)



6 wafers (BMMO v4.2), 76 fields (full wafer, 3 mm edge clearance),  
7x7 points per field, WEC, REC corrections, ATP model applied

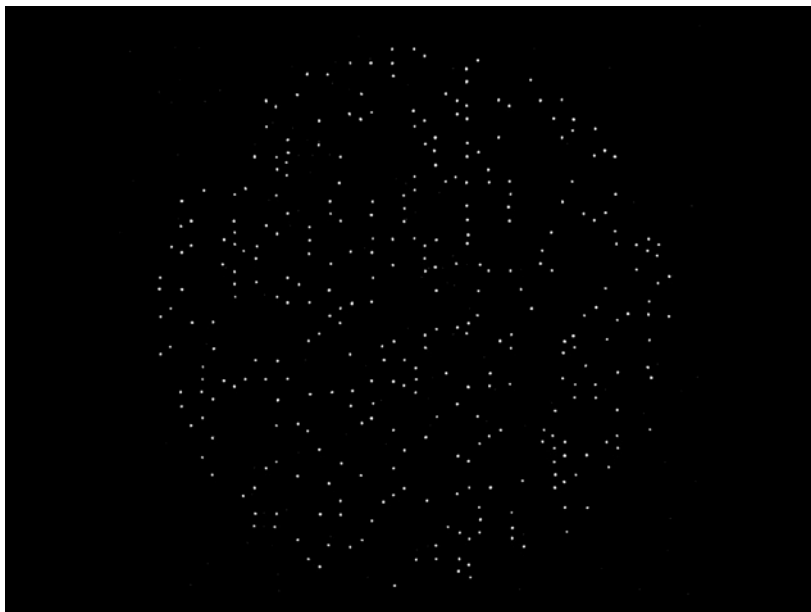


# A robust transmission trend for the Starlith® 3400 optics supports increased throughput.

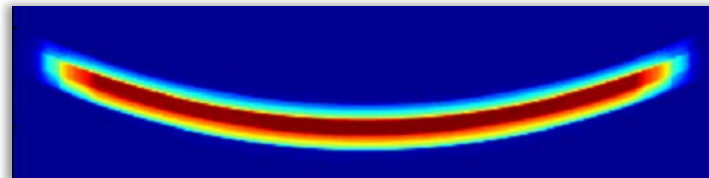


ZEISS inhouse EUV qualification

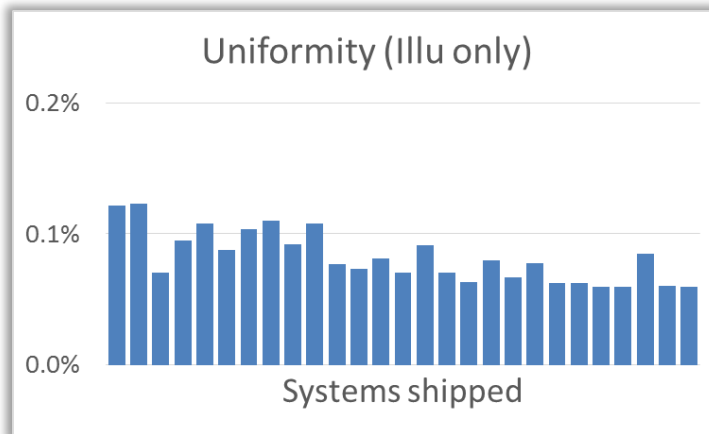
# The Starlith® 3400 illuminator is fully qualified @EUV and consistently meets specification for shipped systems.



**Actual EUV measurement of 22 illumination settings during system qualification**



slit intensity @reticle for dipole setting

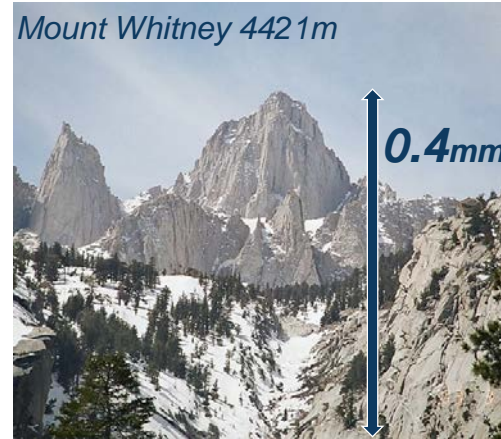
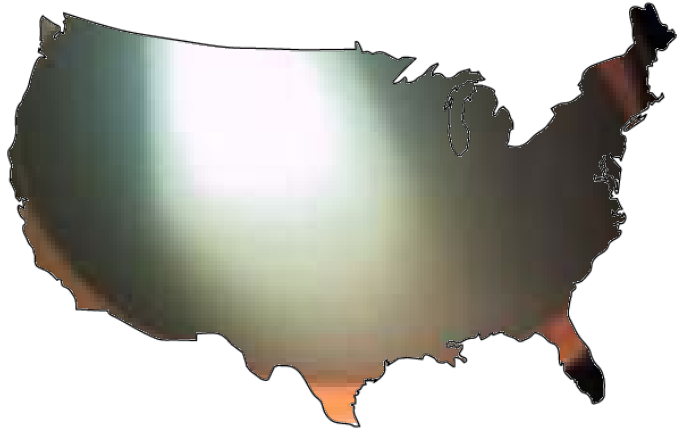


ideal UNICOM correction applied

A mirror surface is polished down to  $\sim 50\text{pm}$  rms.



*Inflated to the size of the contiguous United States...*

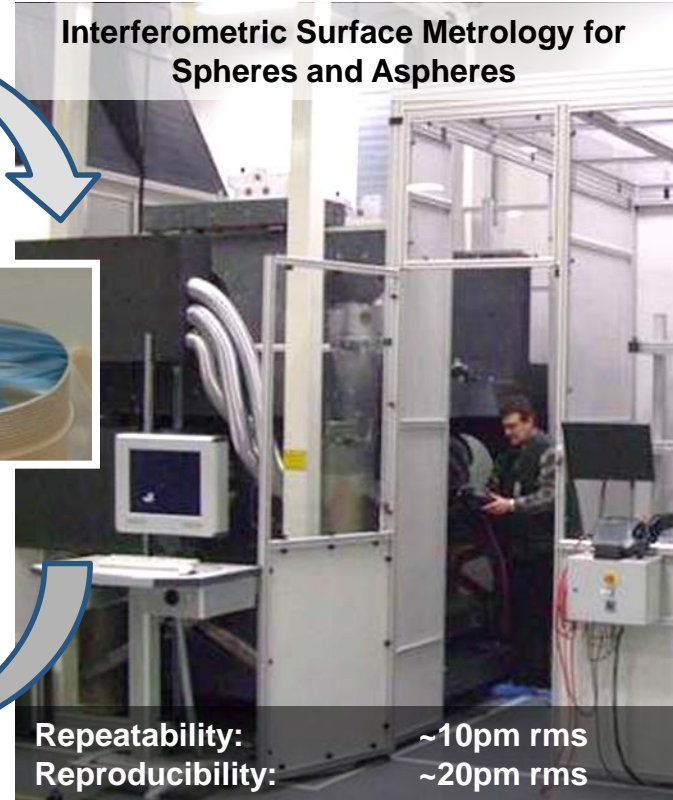
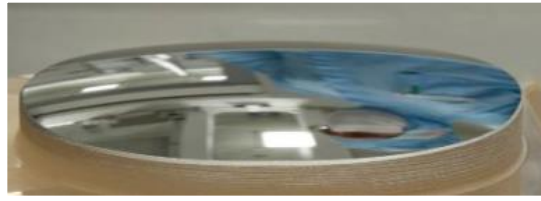


From Wikipedia

*...roughness defects must not be taller than 0.4mm.*


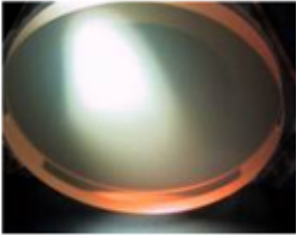



# Manufacturing technologies and metrology are closing the loop for figure control on sub-atomic level.

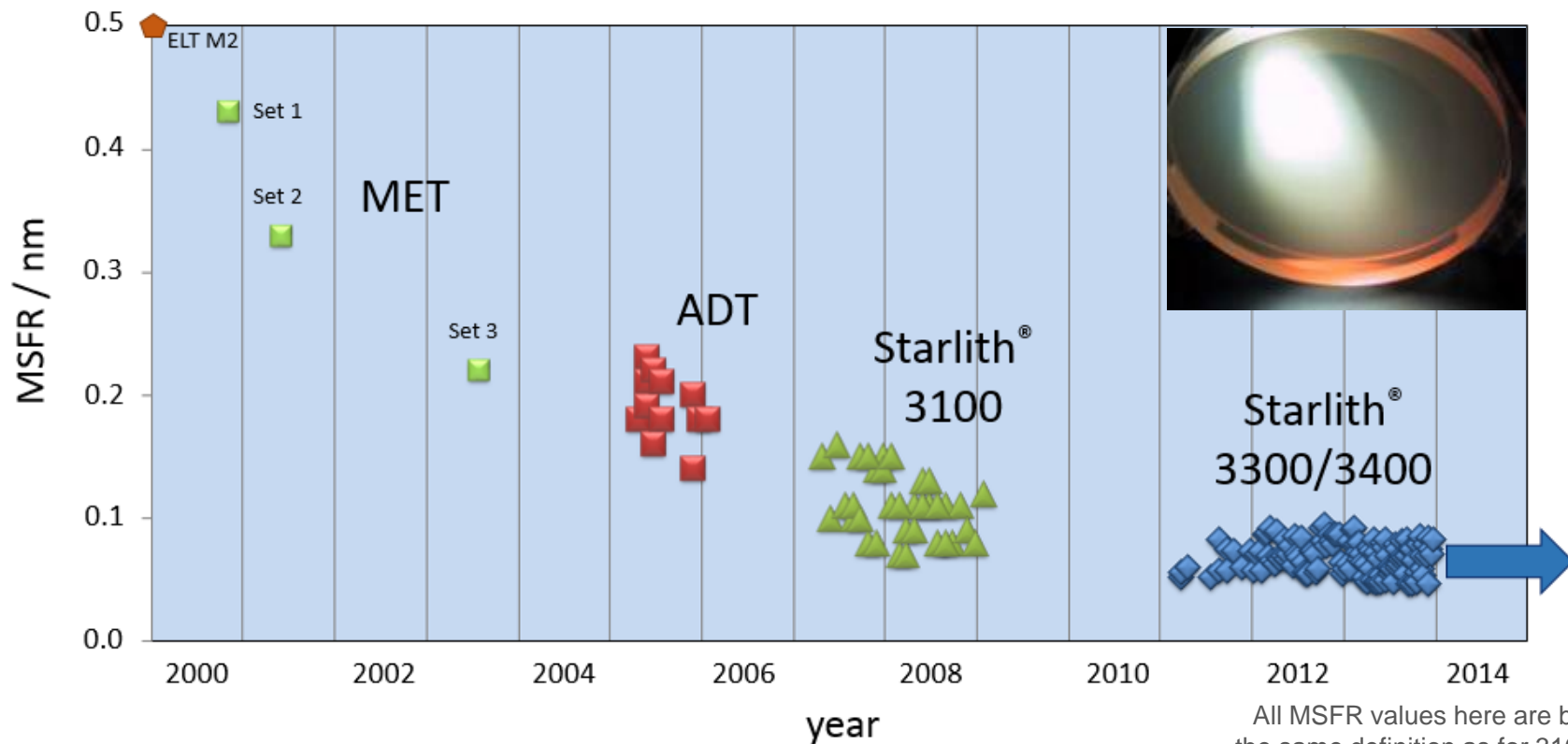


# Polishing: Key performance parameters have improved significantly over time.



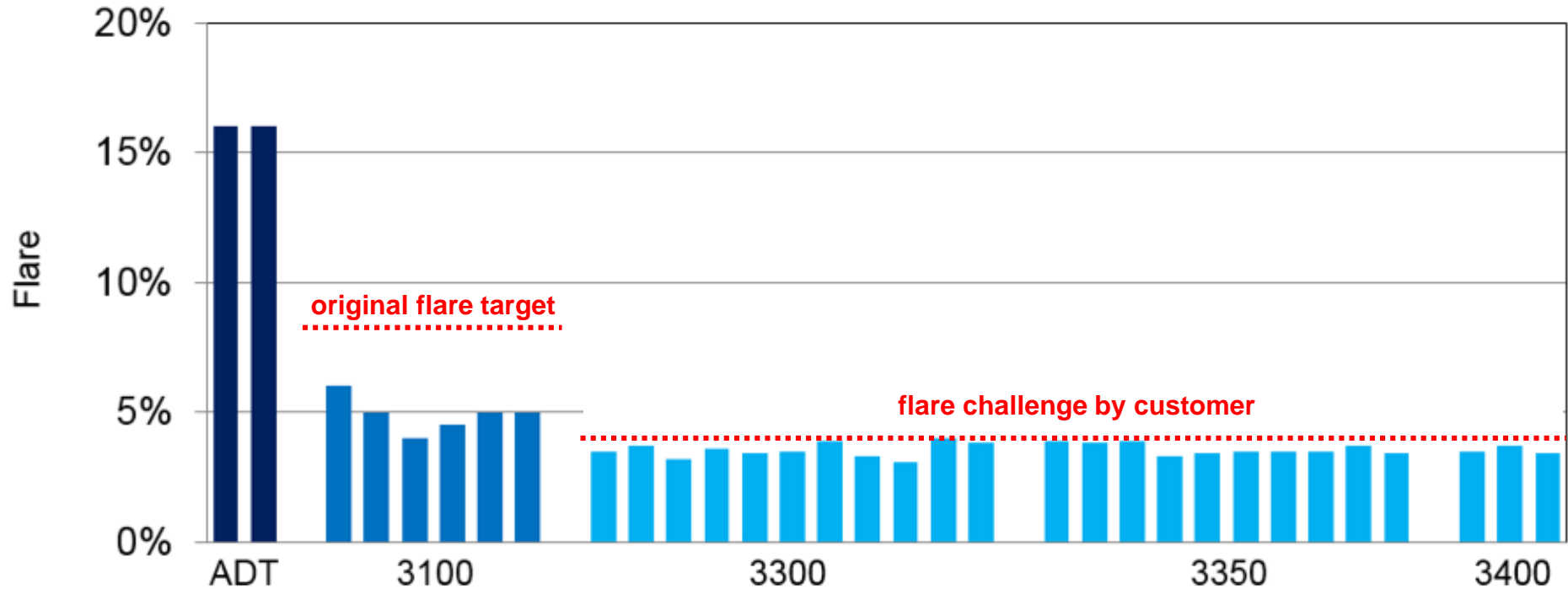
Optics	MET	ADT	3100	3300 / 3400
Photos show relative mirror size				
Figure [pm rms] → aberrations	350	250	140	< 75
MSFR [pm rms] → flare	250	200	130	< 80
HSFR [pm rms] → light loss	300	250	150	< 100

# Mid Spatial Frequency Roughness (MSFR) improved significantly...

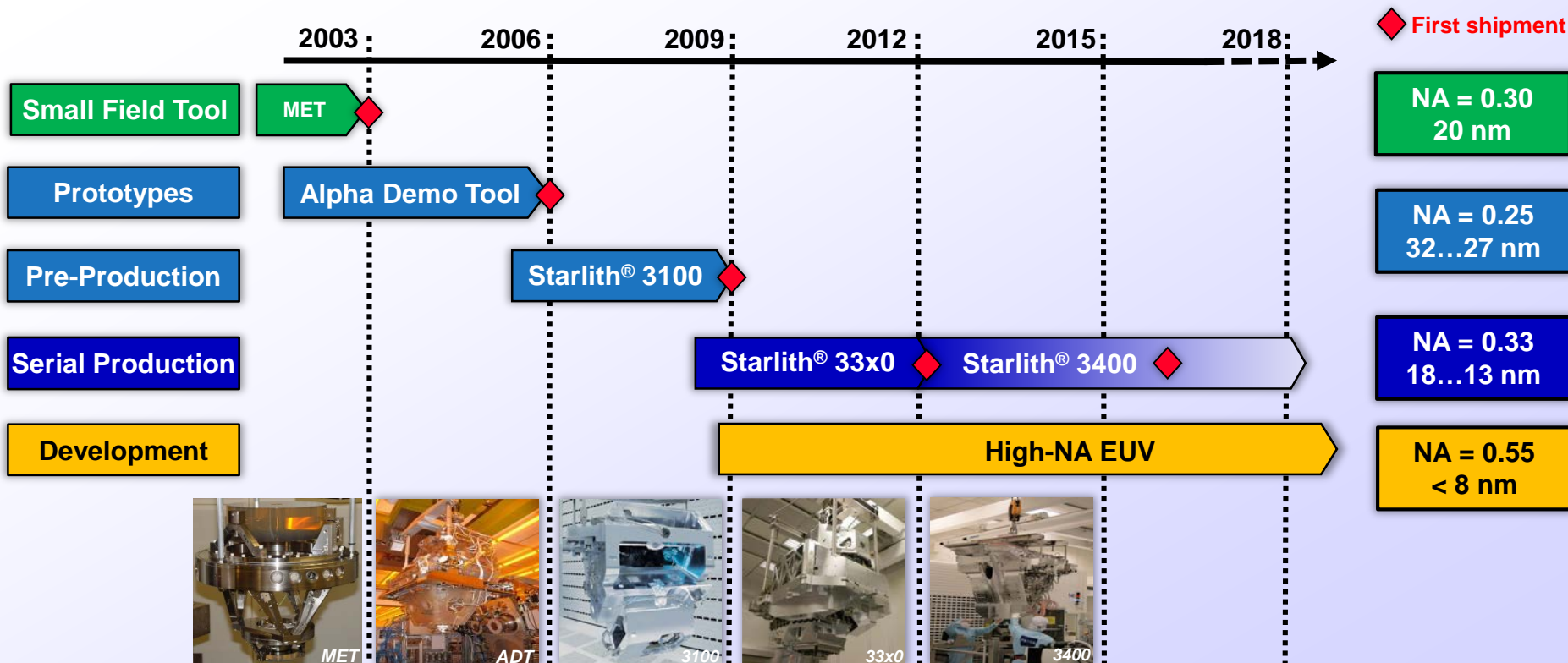


All MSFR values here are based on the same definition as for 3100/3300.

# ... and reduced system flare to satisfying levels – meeting a challenging target.



# EUV program at ZEISS: Continuously improving resolution.



**1 The EUV Program at ZEISS has enabled serial production.**

**2 High-NA EUV Lithography will provide further shrink.**

# NA>0.5 is needed to achieve sub 8 nanometer resolution.

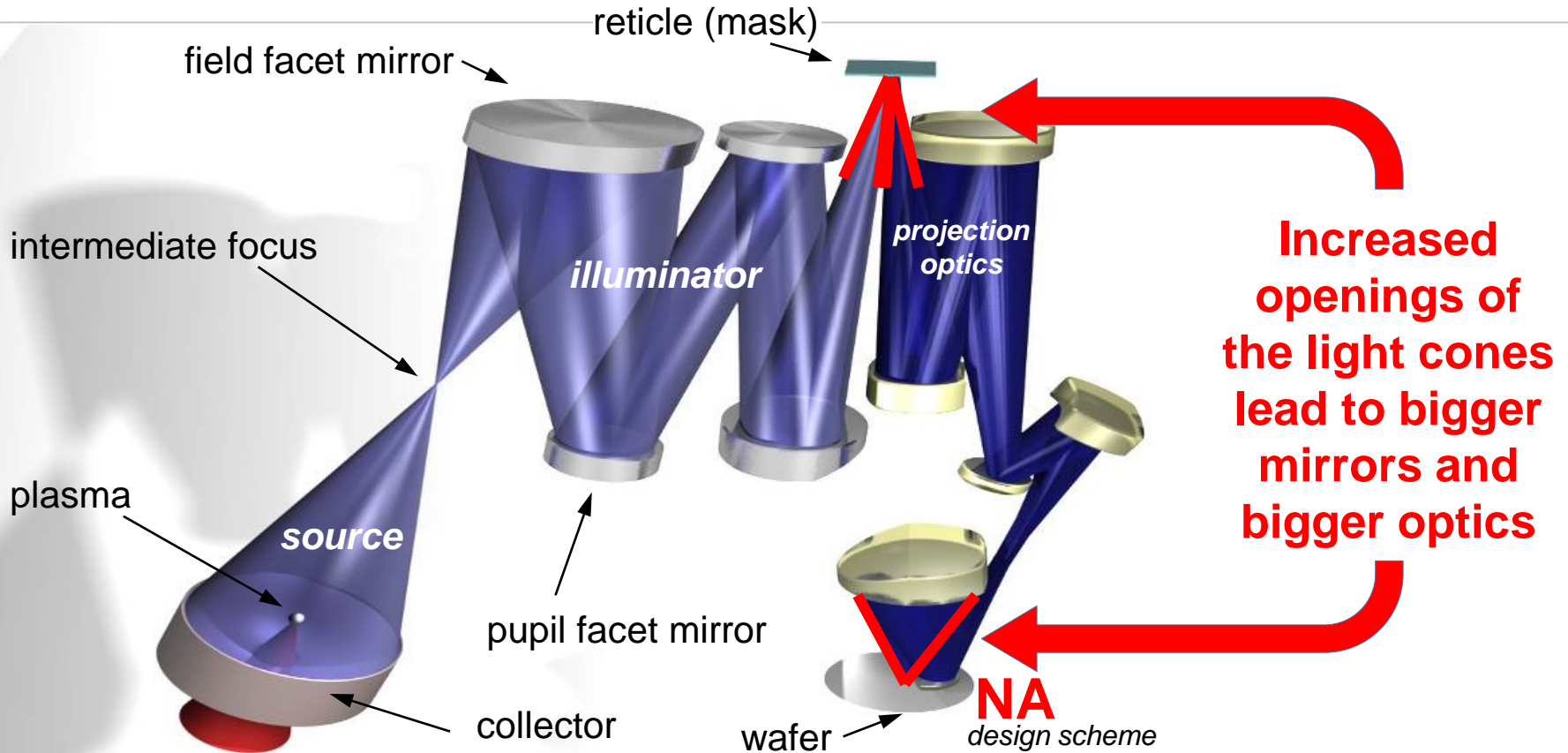


Ernst Abbe in 1873

$$\text{resolution} = k_1 \frac{\lambda}{NA} \text{ High-NA}$$

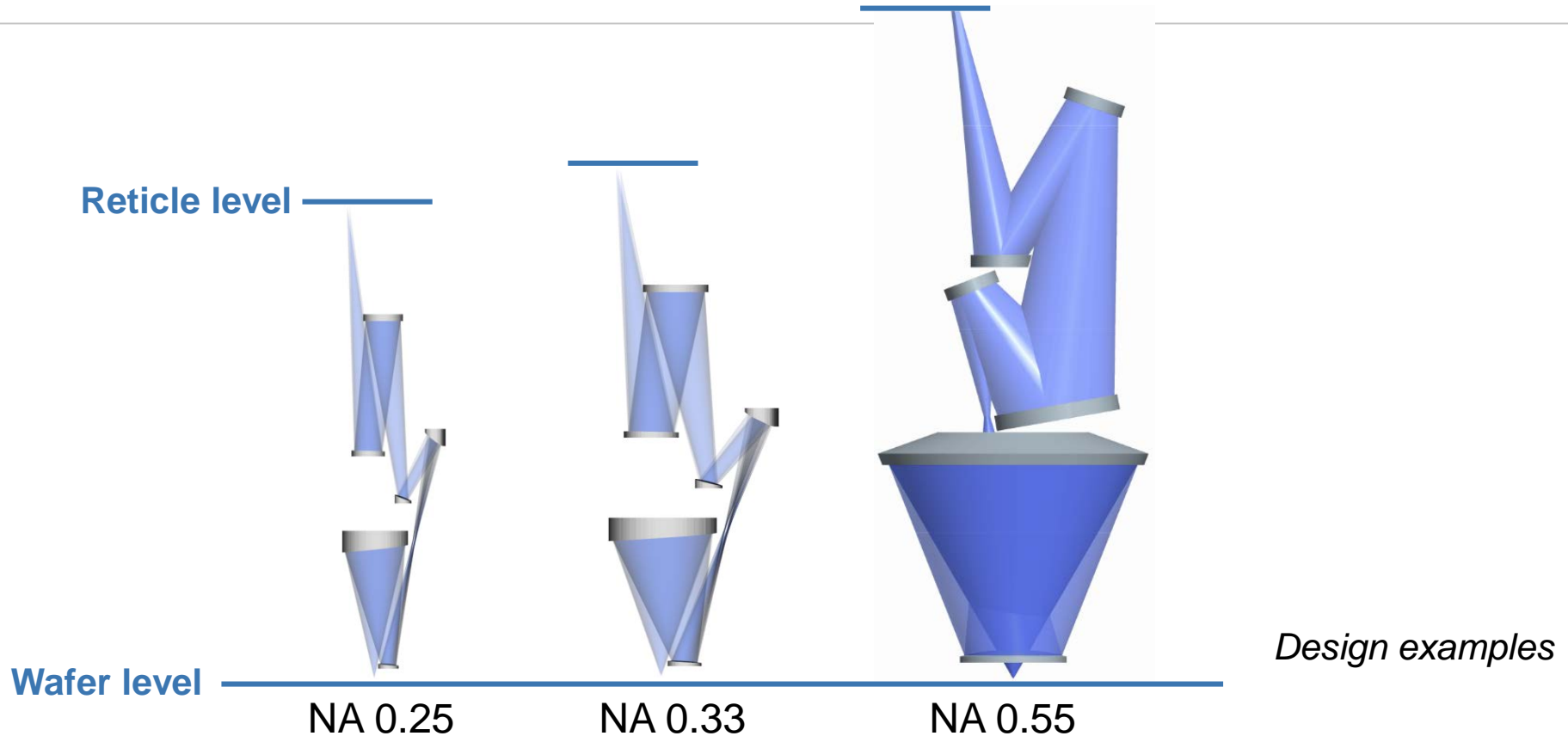
NA	0.25	0.33	...	0.45	0.50	0.55
Resolution @ $k_1=0.3$ single exposure / nm	16.2	12.3	...	9.0	8.1	7.4

# EUV optical train (schematic).





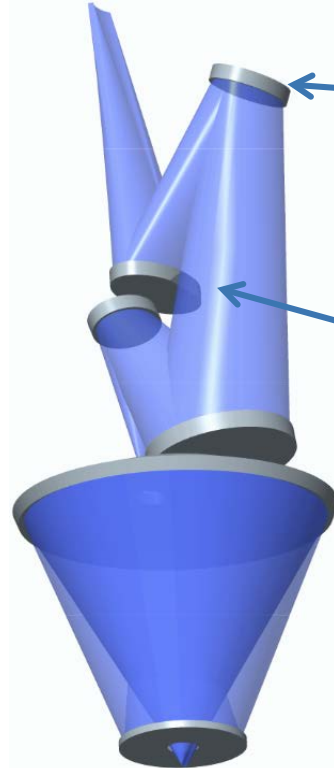
# We have designs for such High-NA optics available.



# These are big optical systems with very large mirrors and extreme aspheres at increased accuracy requirements.



Large overall size of optical system



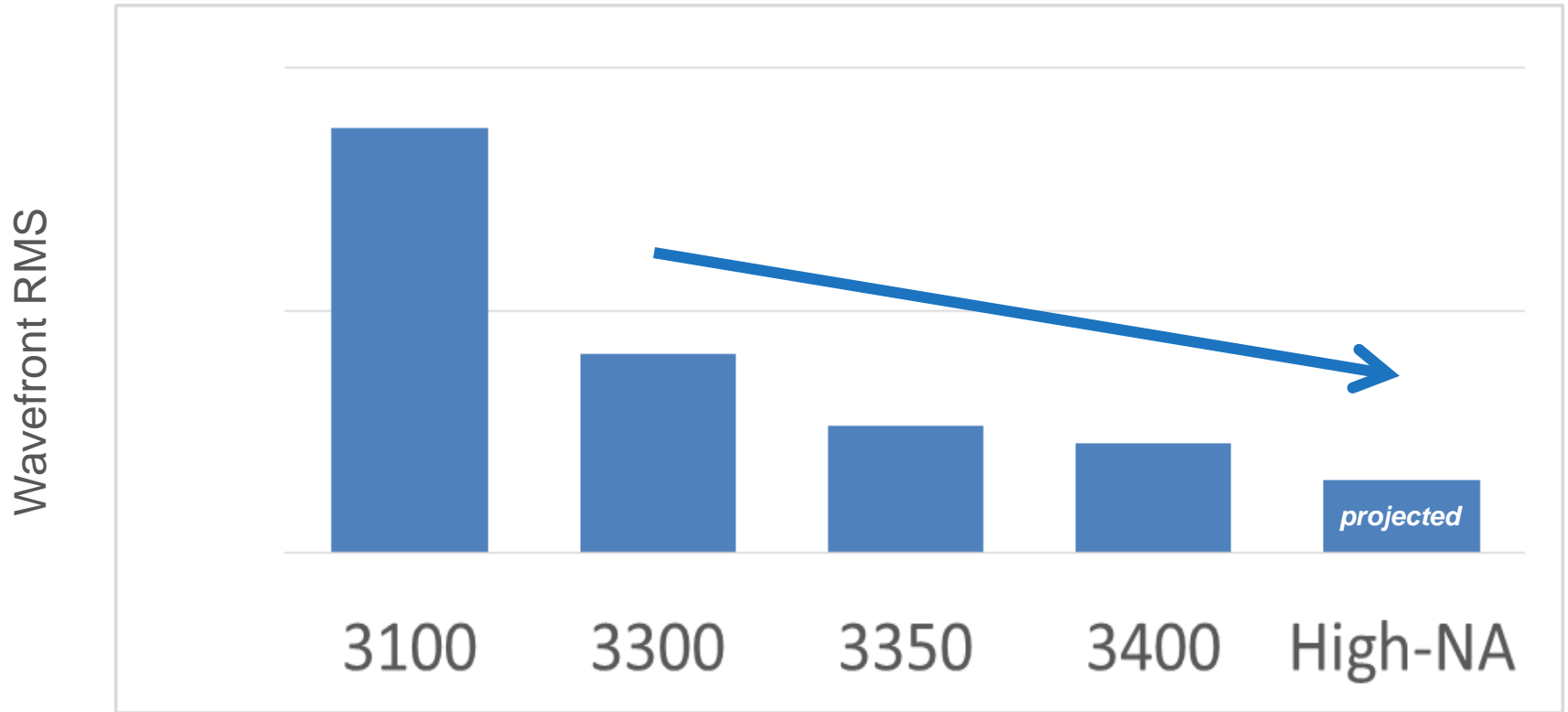
Extreme aspheres enabling further improved wavefront / imaging performance

Tight surface specifications enabling low straylight / high contrast imaging

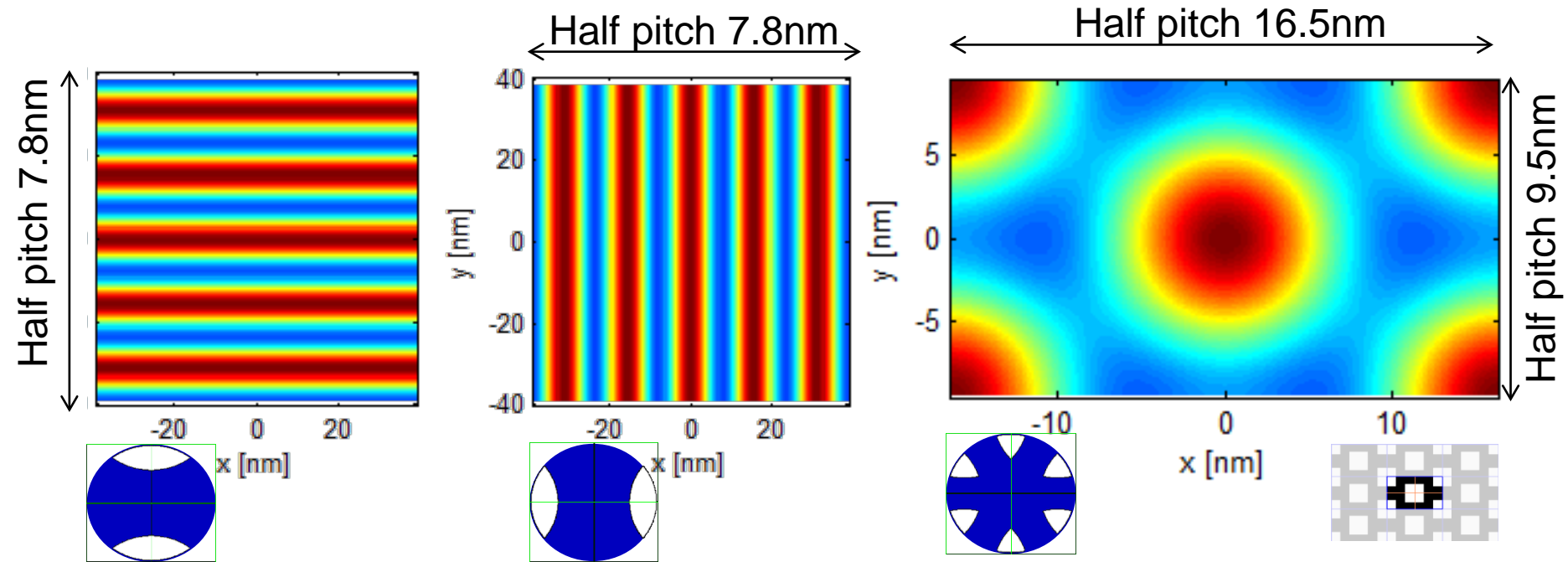
Big last mirror driven by High NA

→ Challenge to optics technology and manufacturing  
→ No fundamental limits

# The High-NA optics design supports a considerable reduction of the wavefront aberrations.

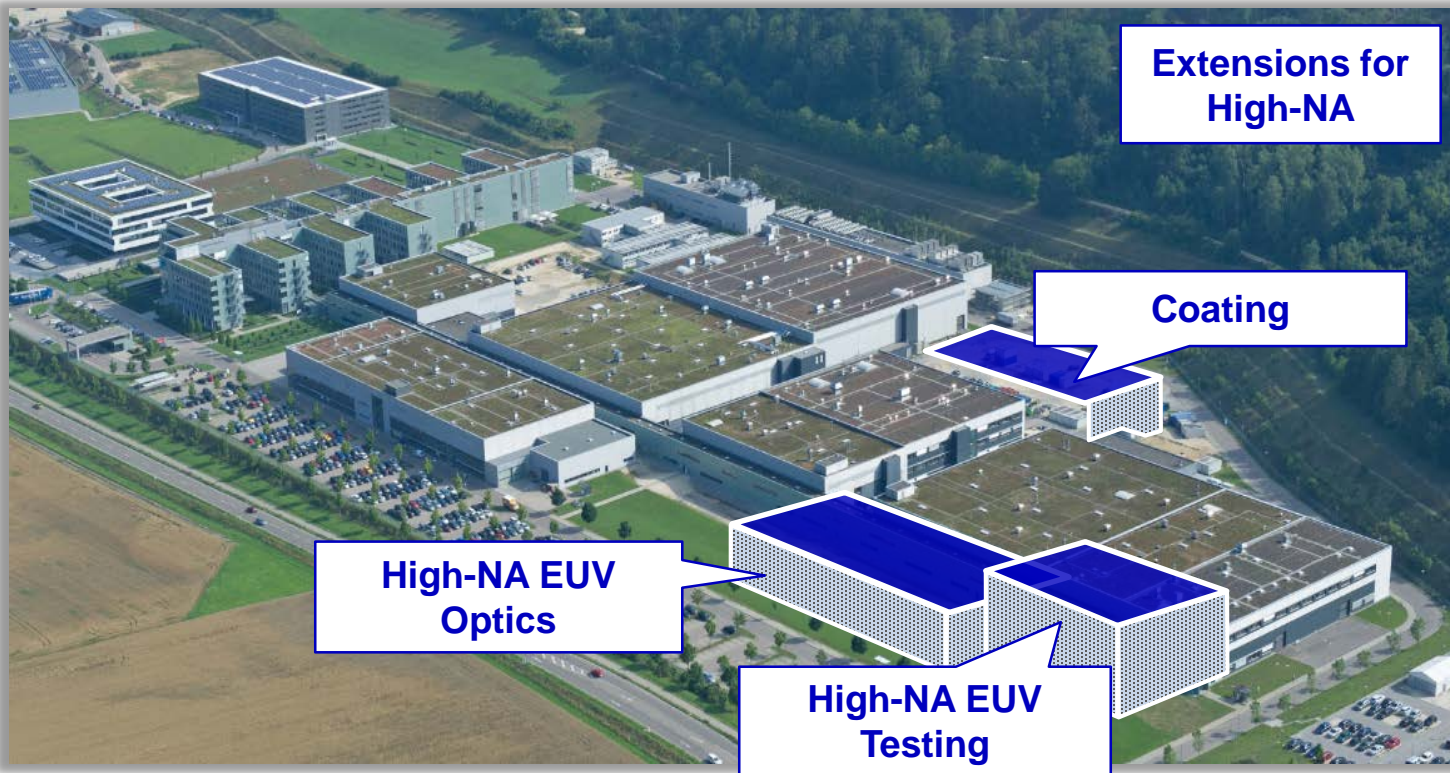


# High-NA EUV: Ultimate resolution power.



**With its superior resolution and highest productivity potential the High-NA EUV system offers the chance to be the ultimate lowest cost/pixel printing machine!**

# Extensions for High-NA EUV optics manufacturing are under construction.



# Extensions for High-NA EUV optics manufacturing are under construction.



***Construction  
status***

***October 2017***



# Conclusions.



- Optics for EUV Lithography have evolved over three decades to a level where excellent imaging is demonstrated.
- Right now, the Starlith<sup>®</sup> 3400 Optics extends EUV Lithography to 13nm single-shot resolution with high productivity for serial production.
- High-NA EUV Lithography enables further shrink for the semiconductor industry to continue Moore's Law.

# Acknowledgements.



## **EUVL Teams at ASML & ZEISS and at our partners**

**Federal Ministry of Education and Research (Germany)**

**DG Connect of the European Commission**

*for funding of the BMBF project „ETIK“ (16N12256K)  
and the projects „E450LMDAP“ (621280), “SeNaTe” (662338),  
“TAKE5” (692522) and “TAKEMI5” (737479)  
within the framework of the ENIAC and ECSEL programs.*



