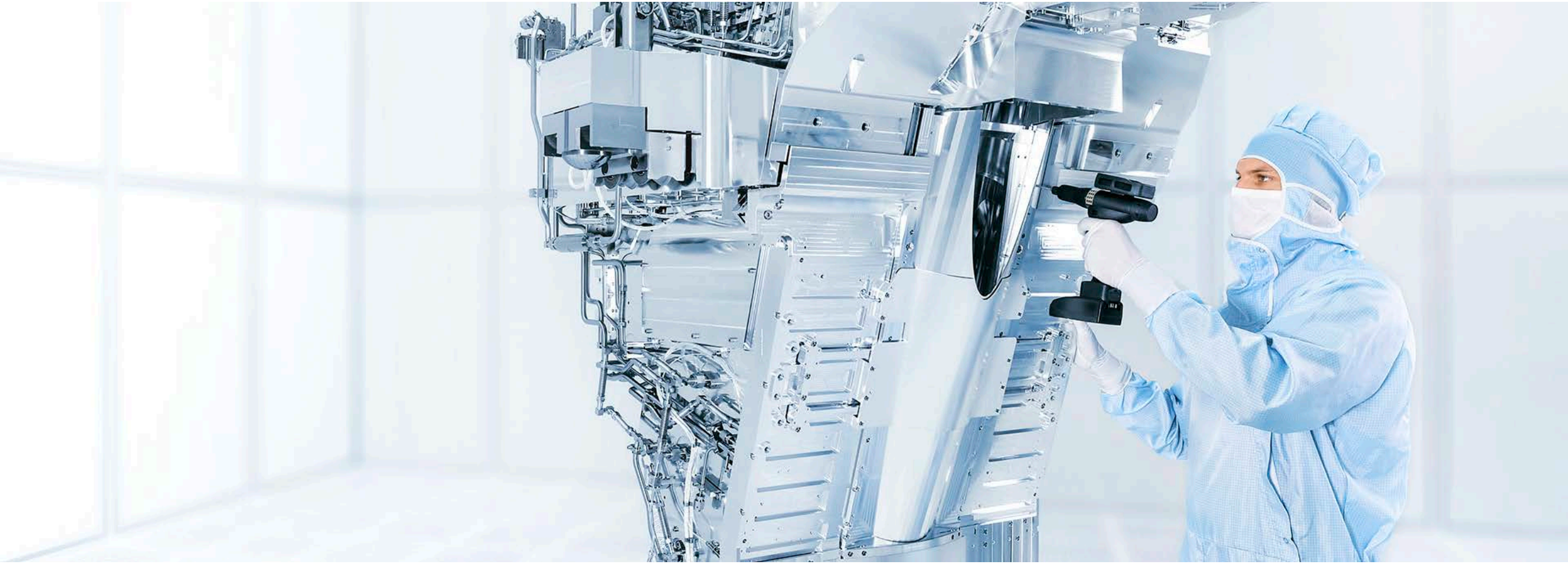
High NA EUV optics
preparing lithography for the next big step



Paul Gräupner[1], Peter Kürz[1], Judon Stoeldraijer[2], Jan van Schoot[2]

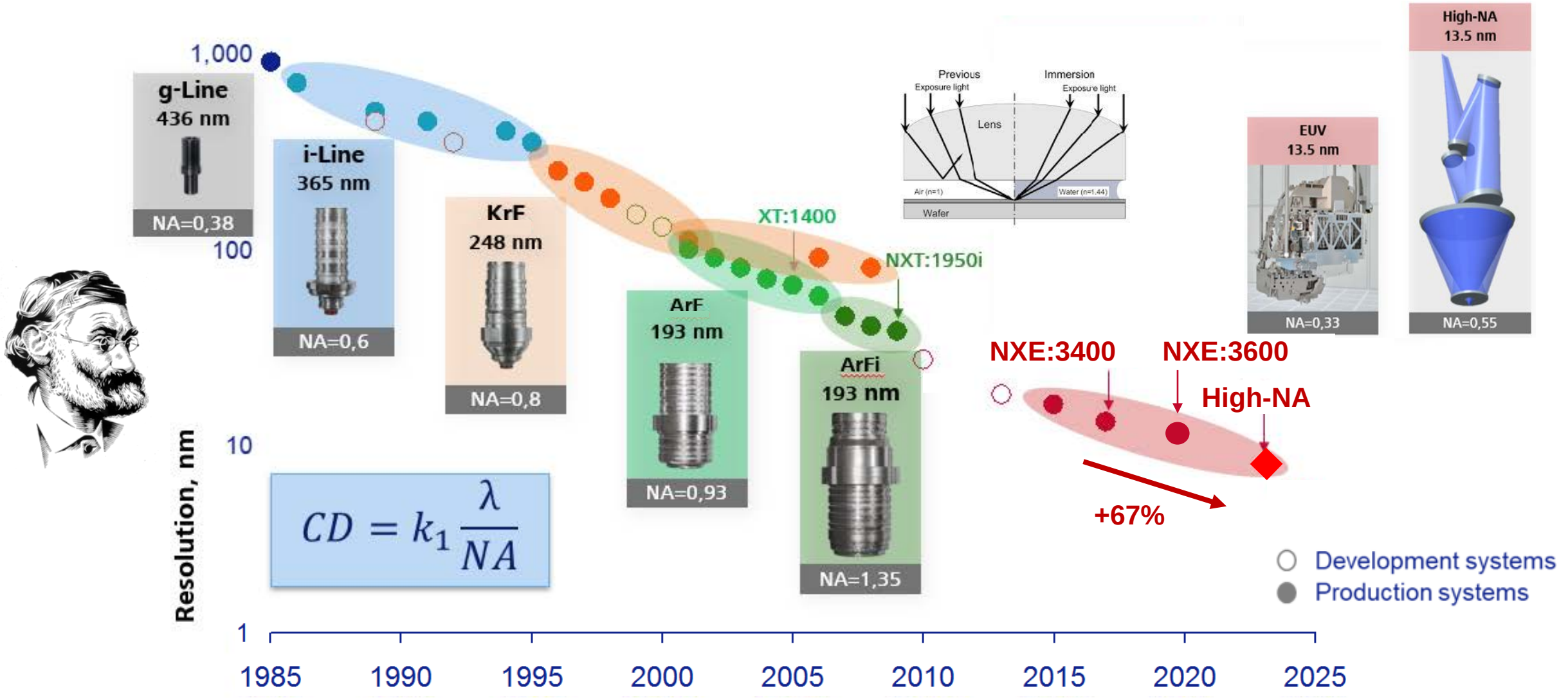
[1]ZEISS, [2]ASML

SPIE Photomask Technology + EUV Lithography 2021

Customer flagship products are powered with EUV

Source: https://www.samsung.com/semiconductor/minisite/exynos/products/mobileprocessor/exynos-9825/ , https://consumer.huawei.com/en/campaign/kirin-990-series/

Next logical step on lithography roadmap is a High-NA EUV system



Outline

1 New 0.33NA EUV optics

2 Design features of High-NA EUV optics

3 Manufacturing of High-NA EUV mirrors and frames

4 Outlook

Outline

1 New 0.33NA EUV optics

2 Design features of High-NA EUV optics

3 Manufacturing of High-NA EUV mirrors and frames

4 Outlook

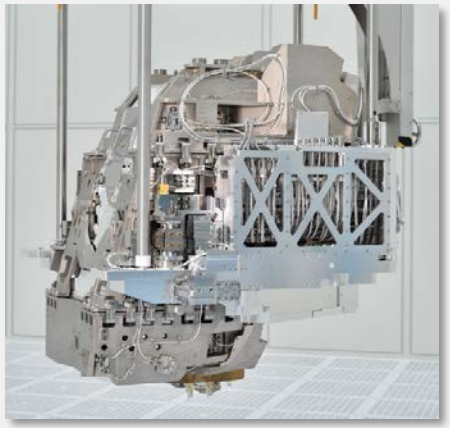
Starlith® 3600: Extending the Roadmap for 0.33NA

EUV aberration roadmap continues at higher source power

3600 Illuminator

Key features:

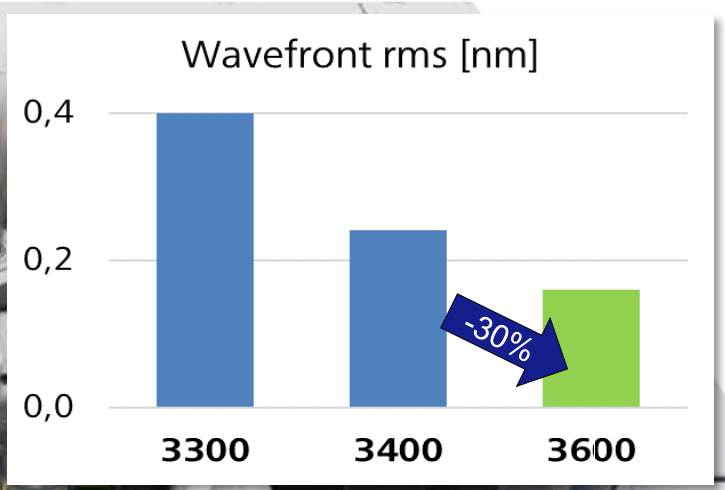
- Support of higher EUV power

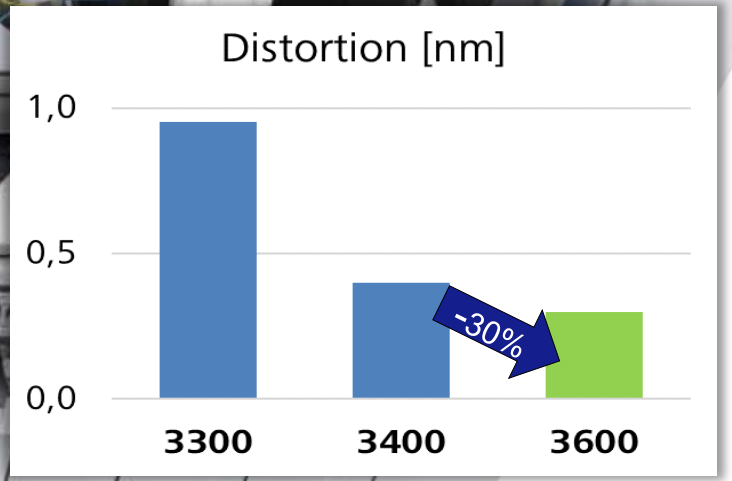


3600 Projection Optics

Key features:

- Support of higher EUV power
- Improved wavefront performance
- Improved distortion

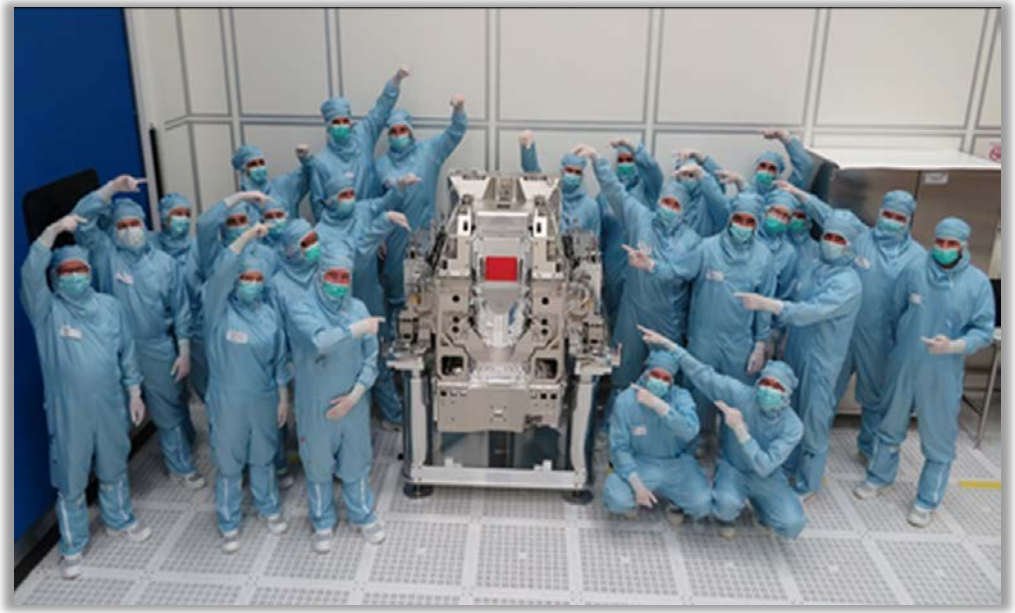




Starlith® 3600: more than 30 systems delivered

First Starlith® 3600 Illuminator delivery

First Starlith® 3600 POB delivery



- Delivery of more than 140 EUV systems with 0.33 NA at high and robust performance.
- More to come due to strong market pull.

Outline

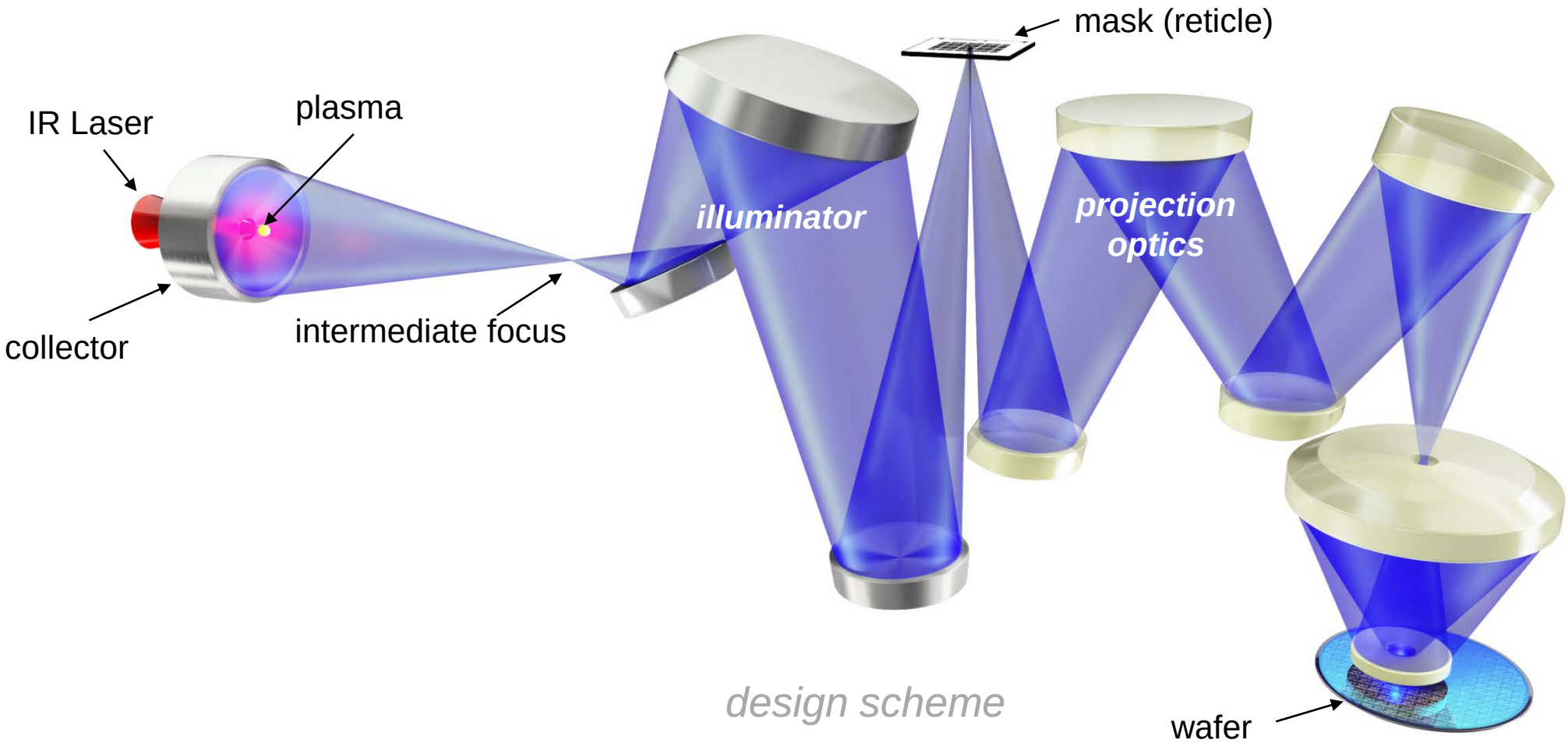
1 New 0.33NA EUV optics

2 Design features of High-NA EUV optics

3 Manufacturing of High-NA EUV mirrors and frames

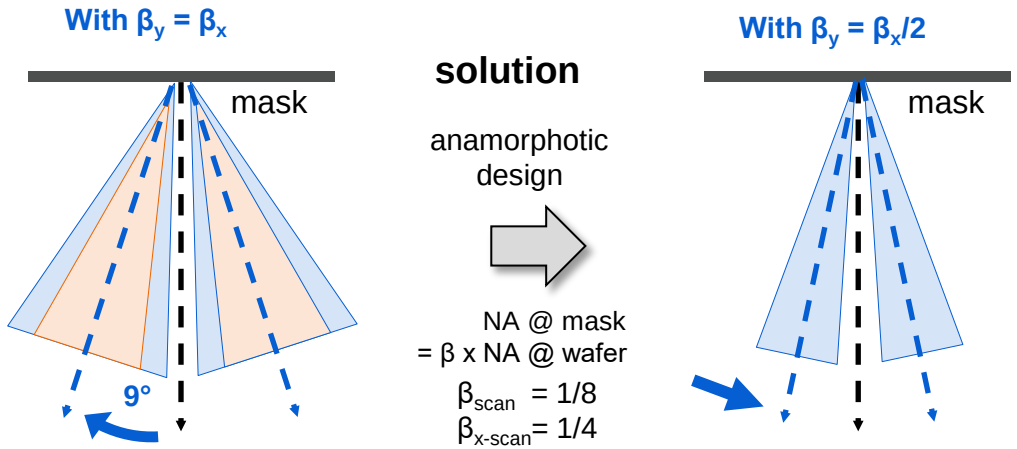
4 Outlook

High-NA EUV:
The optical system for the ultimate printing machine with NA = 0.55



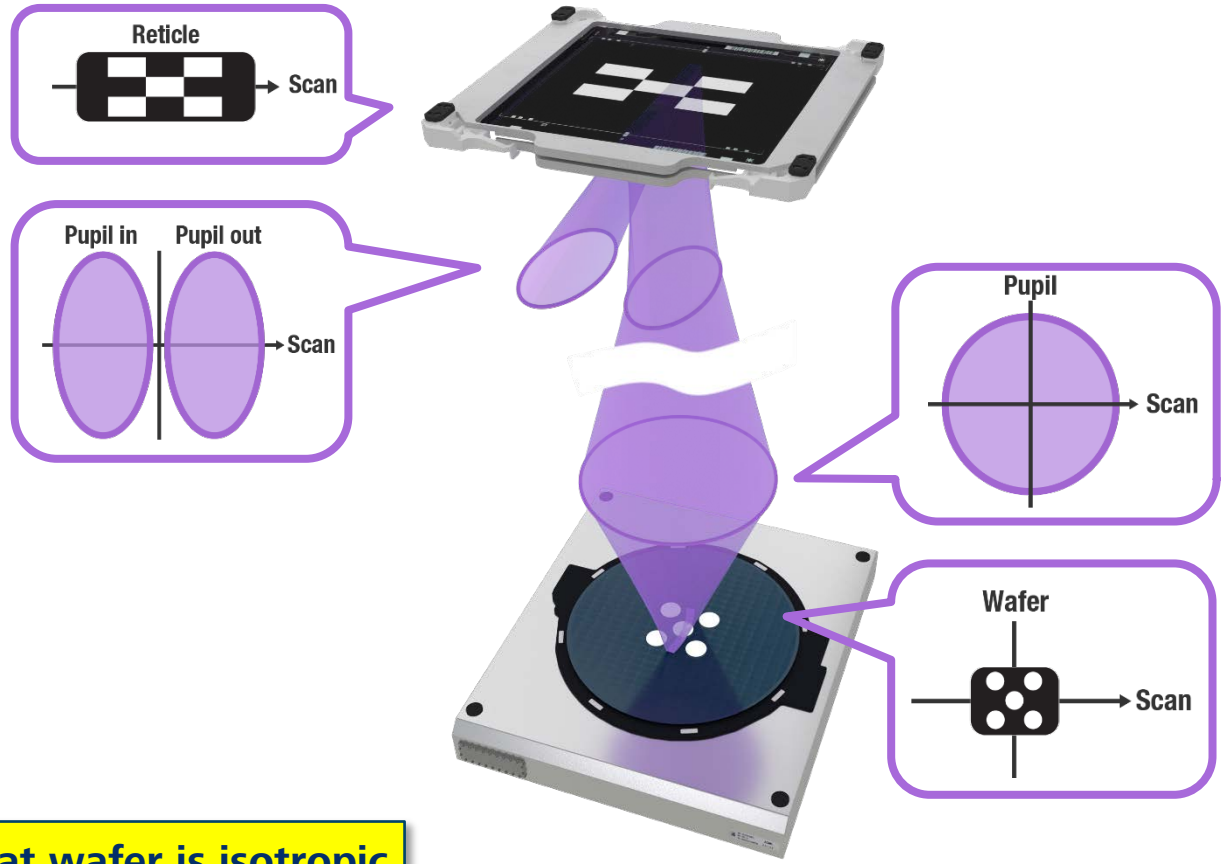
design scheme

Crash course angles at reticle and anamorphic design



- absorber shadowing at mask is angular dependent
- Inacceptable contrast loss for system with β_{scan}= 1/4

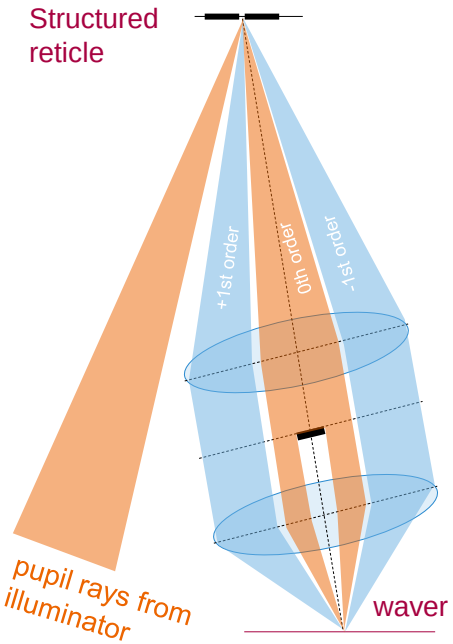
mask design needs to be stretched by 2x in scan direction

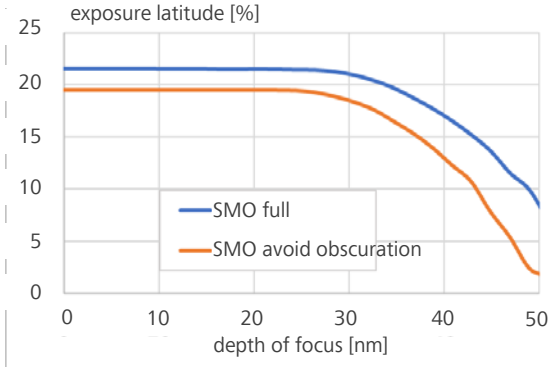


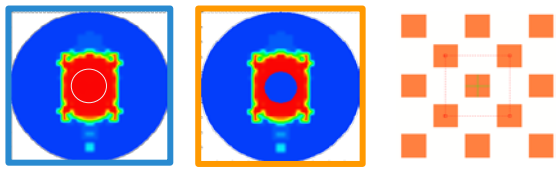
Resolving power at wafer is isotropic
resolution$_x$ = resolution$_y$

Crash-course / reminder on High-NA design features

Obscuration can be used for new illumination feature that can improve process window

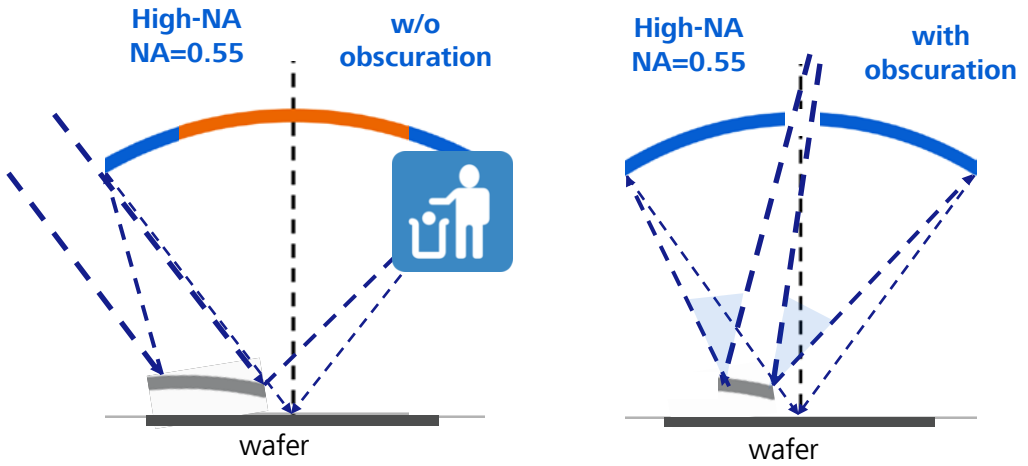






pitch = 28 nm
CD = 14 nm

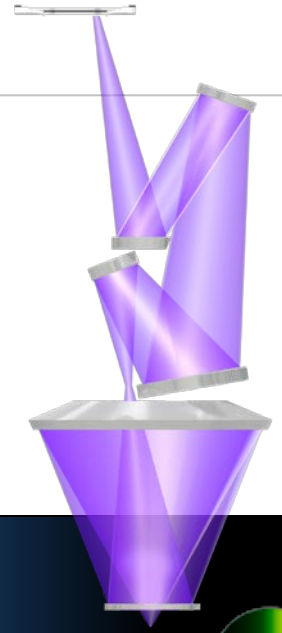
[1] van Setten et al, Proc. SPIE 1095709



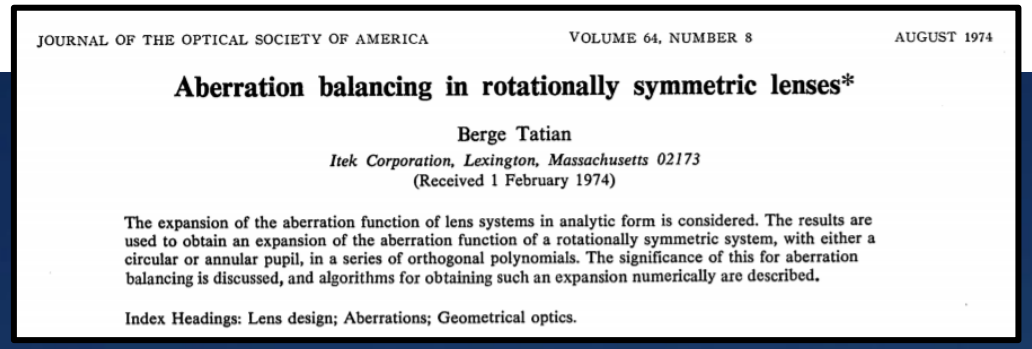
- Obscuration reduces angular load and angle variation
- High-transmission design solution.

Zernike wave front description replaced by Tatians

To account for central obscuration in High-NA



- Zernike is a well-known basis to expand wavefronts
- For high-NA machines, projection lens has a central obscuration
- Tatian (or annular-Zernike) is a basis that ASML & ZEISS use to express aberration with central obscuration



JOURNAL OF THE OPTICAL SOCIETY OF AMERICA VOLUME 64, NUMBER 8 AUGUST 1974

Aberration balancing in rotationally symmetric lenses*

Berge Tatian

Itek Corporation, Lexington, Massachusetts 02173

(Received 1 February 1974)

The expansion of the aberration function of lens systems in analytic form is considered. The results are used to obtain an expansion of the aberration function of a rotationally symmetric system, with either a circular or annular pupil, in a series of orthogonal polynomials. The significance of this for aberration balancing is discussed, and algorithms for obtaining such an expansion numerically are described.

Index Headings: Lens design; Aberrations; Geometrical optics.

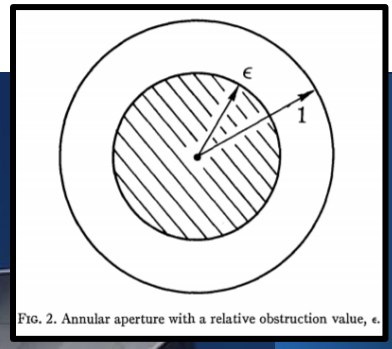
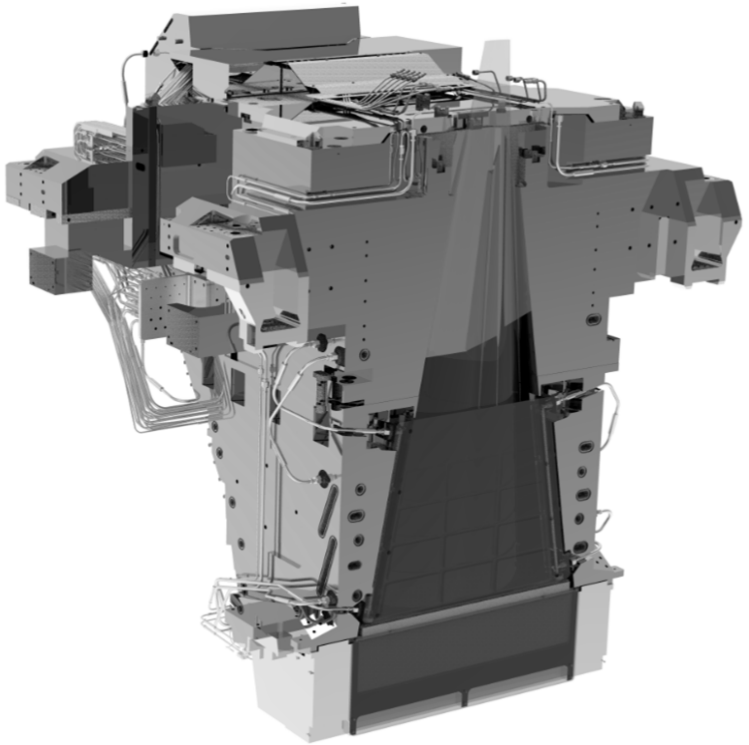
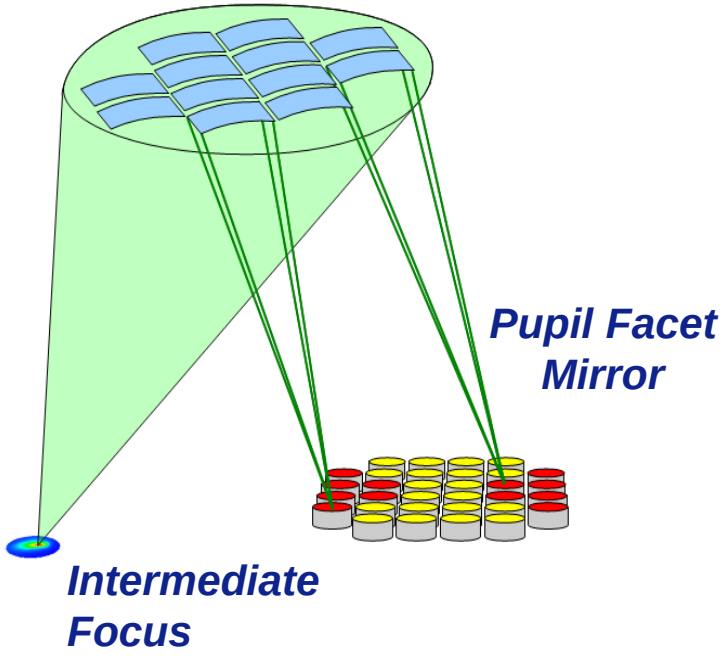


FIG. 2. Annular aperture with a relative obstruction value, ϵ.

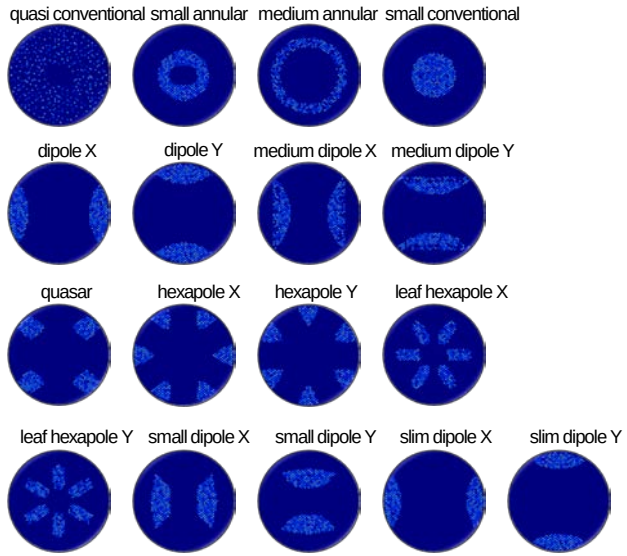
Reference: High NA EUV scanner: obscuration and wave front description, Laurens de Winter, EUVL 2020, 11517-38

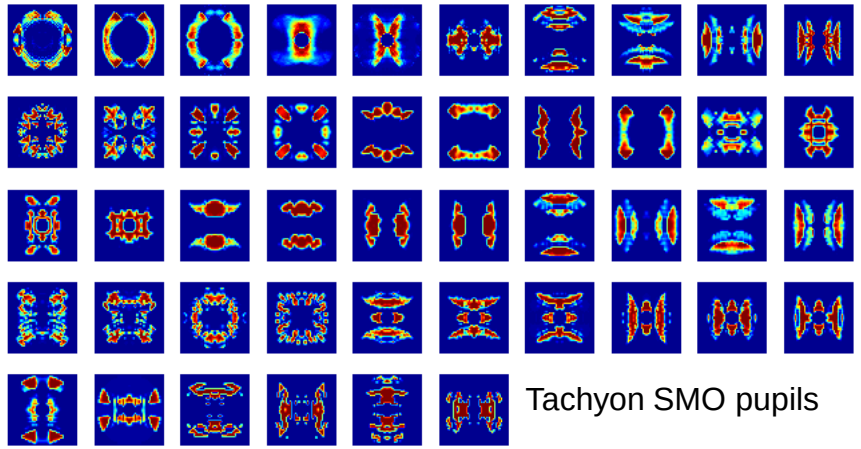
High-NA illuminator will utilize 0.33NA technology with actuated facet mirrors





Standard Illumination Settings





Tachyon SMO pupils

- High-NA illuminator provides 20% pupil fill ratio

Outline

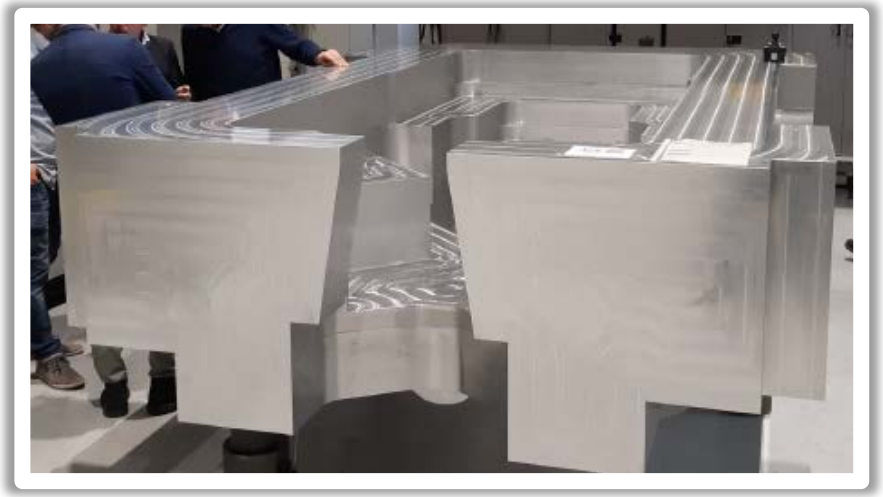
1 New 0.33NA EUV optics

2 Design features of High-NA EUV optics

3 Manufacturing of High-NA EUV mirrors and frames

4 Outlook

Frames for illuminator and POB in production



Build up of system integration tooling is progressing

assembly & qualification on module level

mirror glueing

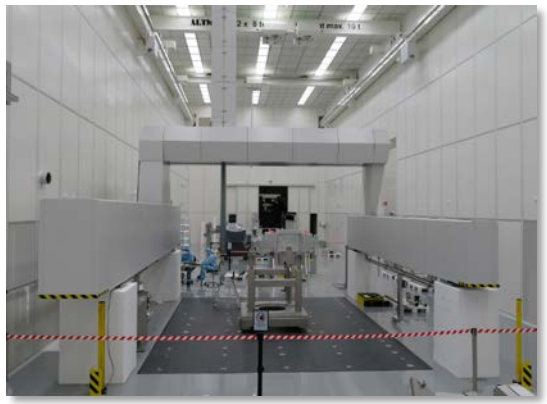
mirror module assembly

dynamic qualification

assembly & qualification on sensor frame level

sensor frame & interferometer assembly

alignment & qualification



transports

module transport

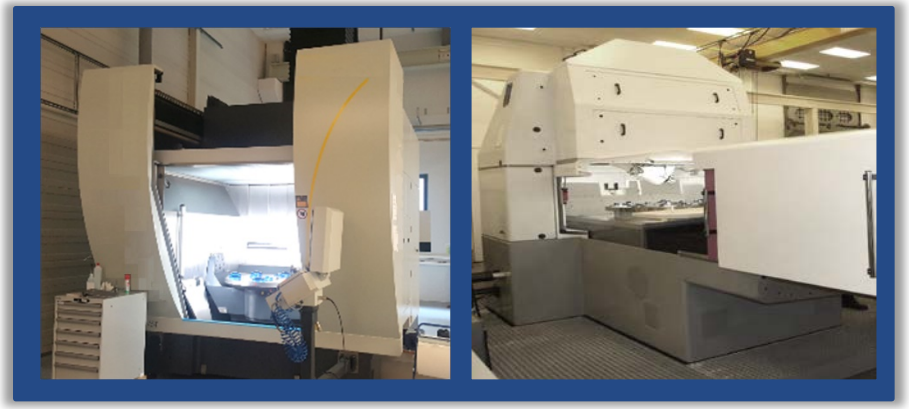
frame transport

assembly & cleaning

force frame & module integration

cleaning & leak check

Optics manufacturing process



Roughness metrology

Grinding

Polishing

Ion beam Figuring

Coating

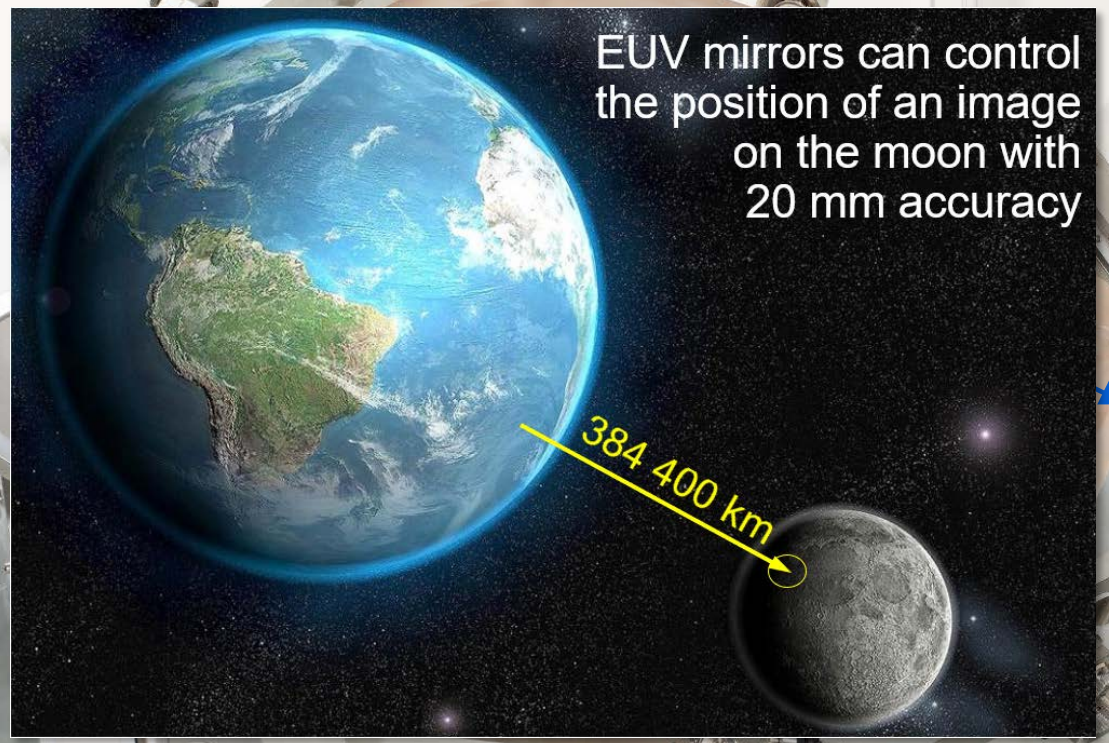
Surface Figure Metrology

Reflectivity metrology

High-NA Mirror Challenge

Extremely tight control of position and non rotational symmetric surfaces of large and heavy mirrors

Tilt control < 0.1 nrad

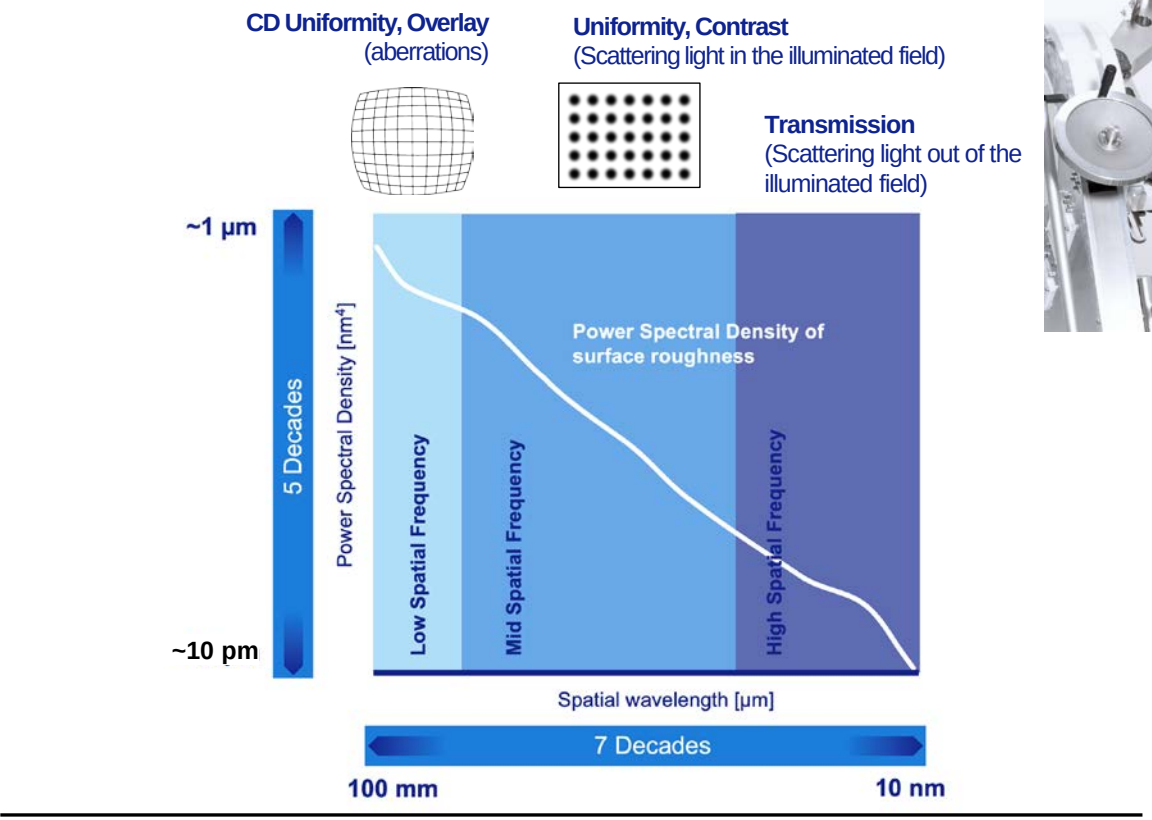


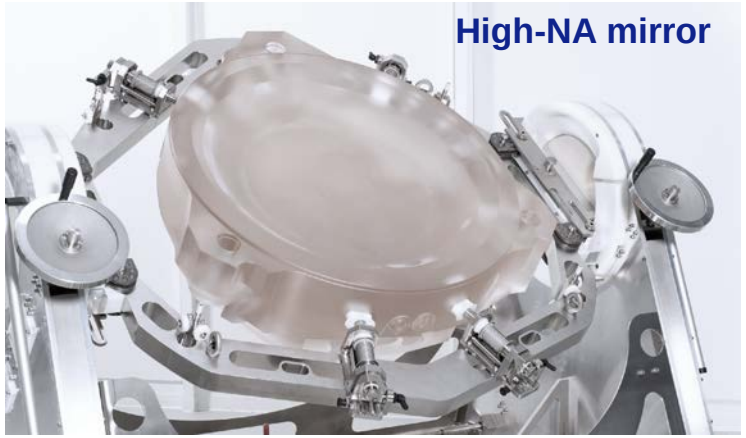
Surface control < 30 pm

Scaling mirror size
to France:
No mountain higher
than **15 µm**

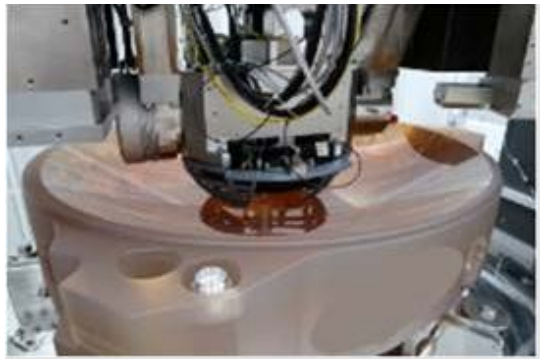
Mirror Metrology results

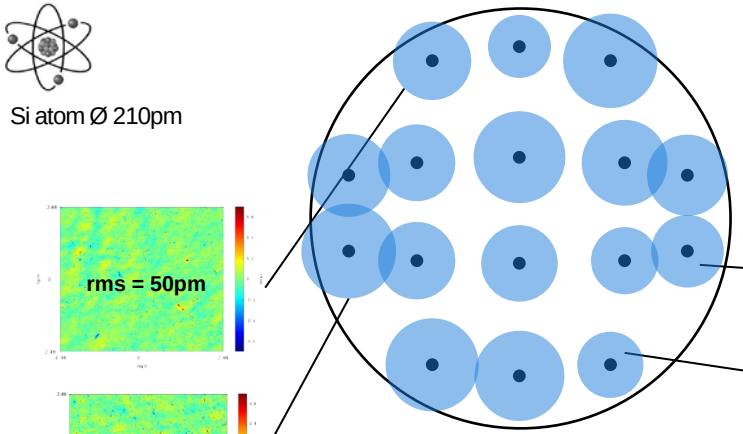
Mirror roughness close to final targets



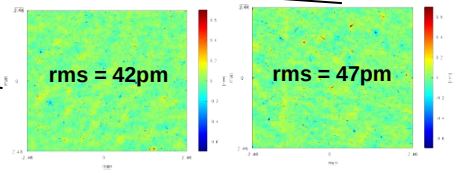


Micro Interferometer



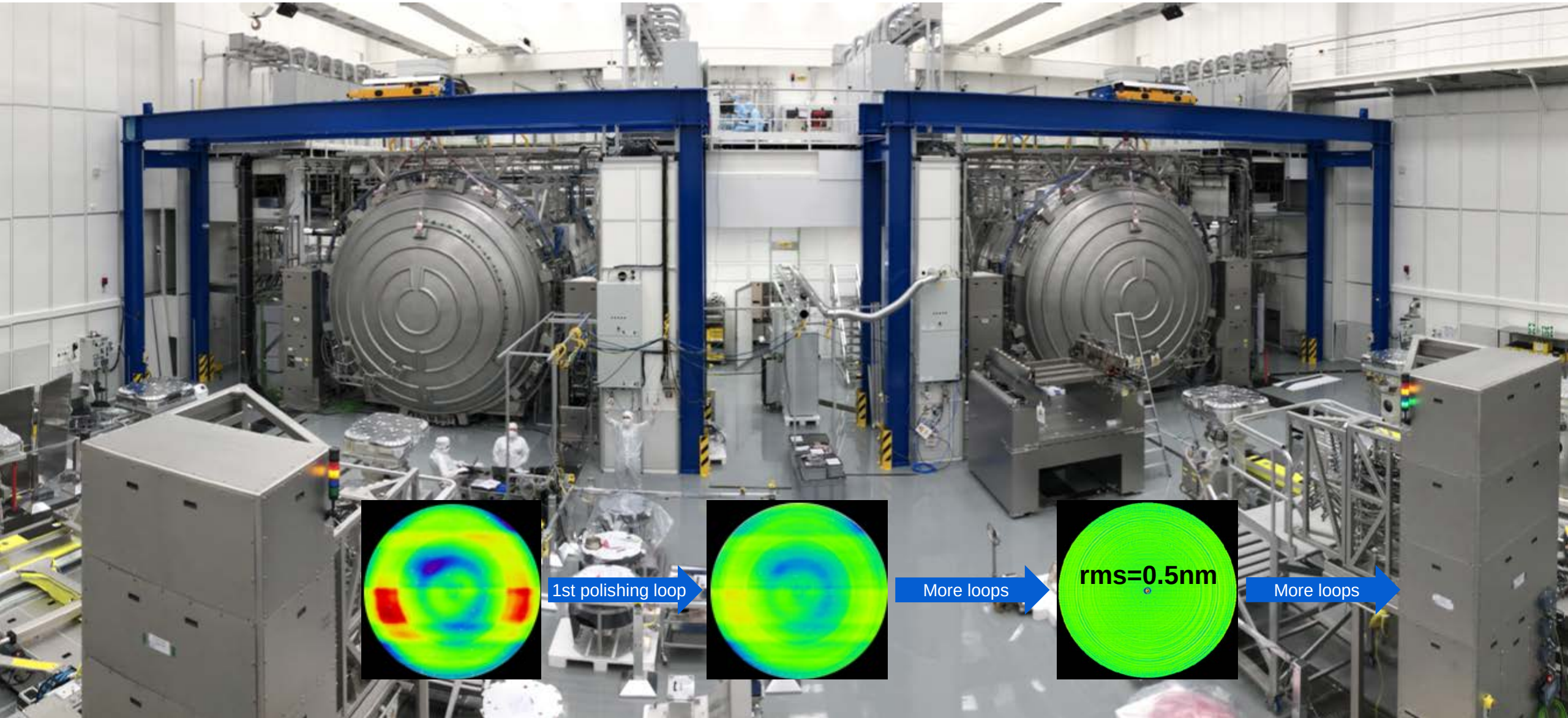


Si atom Ø 210pm



Mirror roughness after polishing <61pm rms for all measurement points.
Measured on Micro Interferometer (Field of View ~5mm)
Measurement data taken on sample positions (no full surface coverage)

Mirror metrology is operational and supports mirror manufacturing requirements



First test mirror coated

Outline

1 New 0.33NA EUV optics

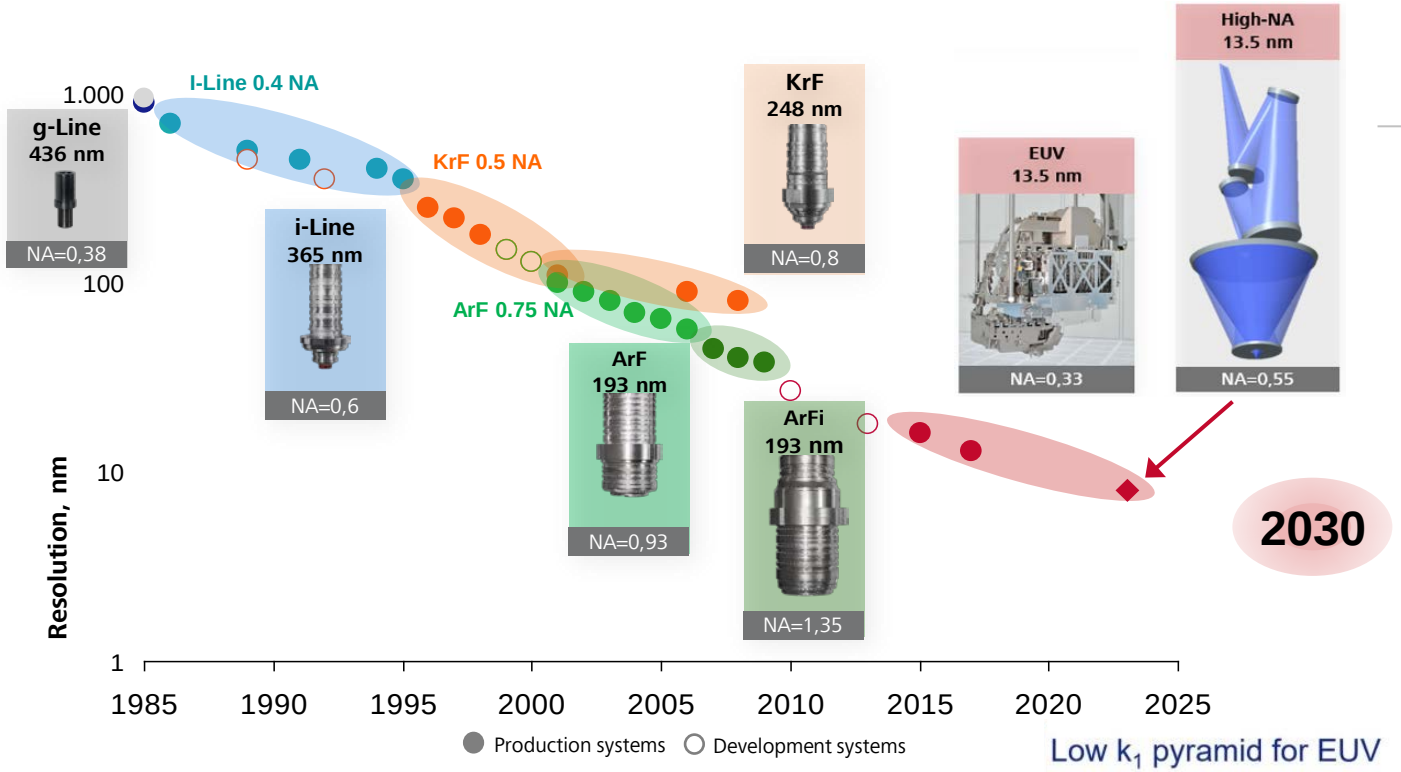
2 Design features of High-NA EUV optics

3 Manufacturing of High-NA EUV mirrors and frames

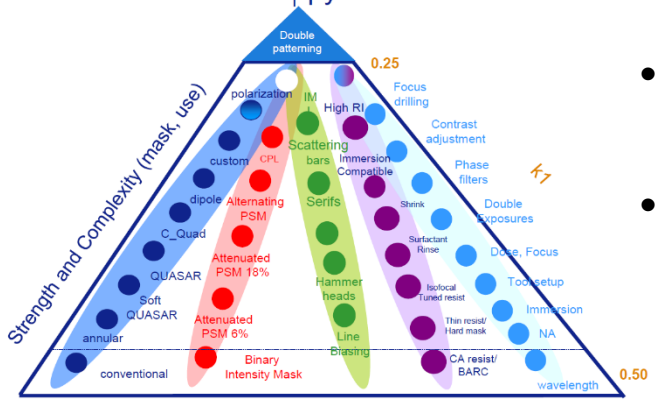
4 Outlook

EUV Litho in 2030

$$CD = k_1 \frac{\lambda}{NA}$$



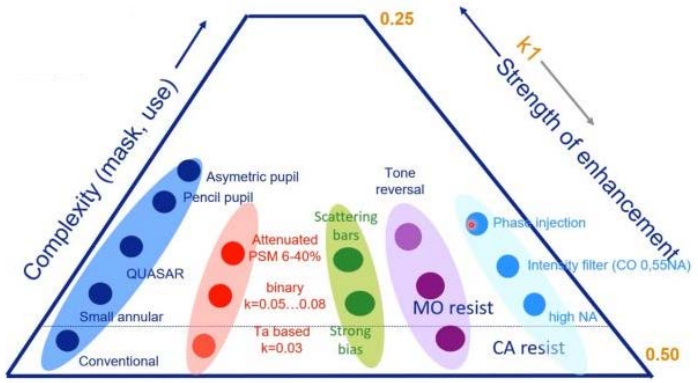
Immersion: RET and Low k_1 pyramid



- We keep climbing the low k1 pyramid on many legs following ArF
- New challenges are M3D, stochastics

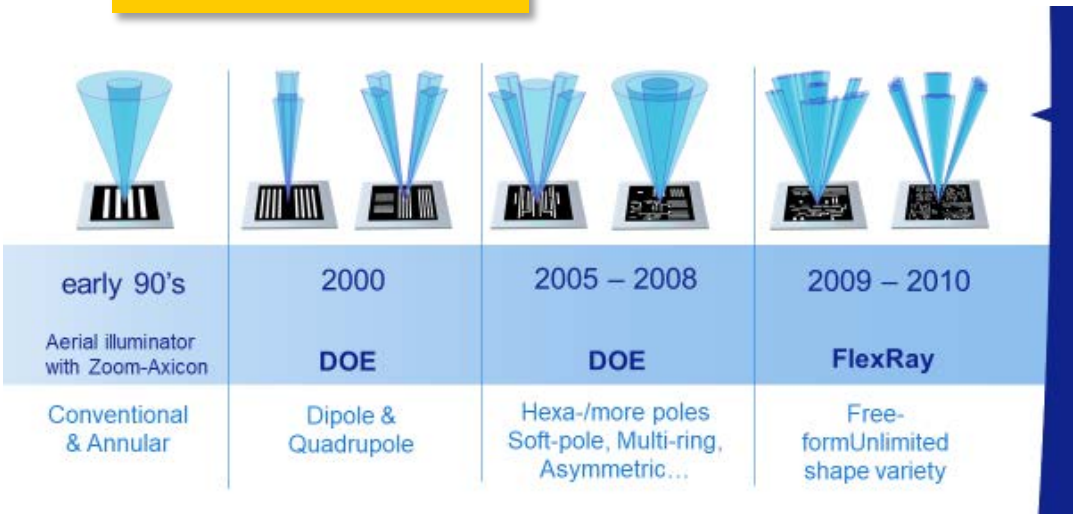
Pyramids by Jo Finders, ASML

Low k_1 pyramid for EUV



Illumination Roadmap towards 2030
Following Immersion in Flexibility and Pupil Fill Ratio

DUV Immersion

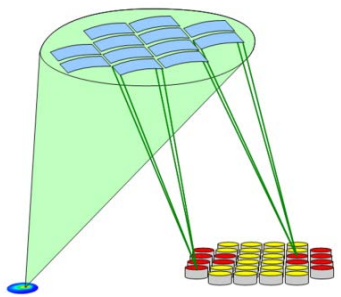


Maximum flexibility in the pupil

- enables low k1 imaging and
- helps to mitigate EUV specific challenges like M3D effects and stochastics

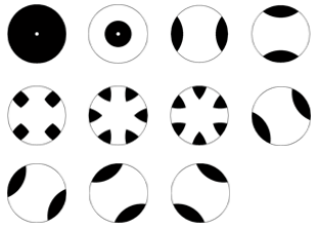
EUV

2009
NXE 3100
develoment system
Conventional / annular settings

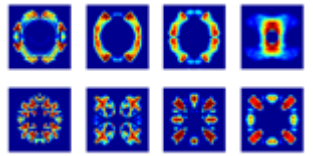


2012
NXE 3300
Flexible
PFR 40%

2016
NXE 3400
Higher flexibility
PFR 20%

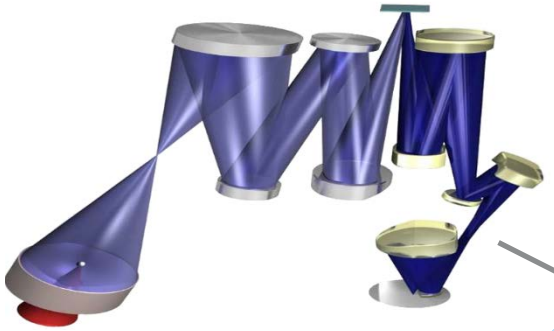


High-NA
Higher flexibility
PFR 20%
Dark field illumination

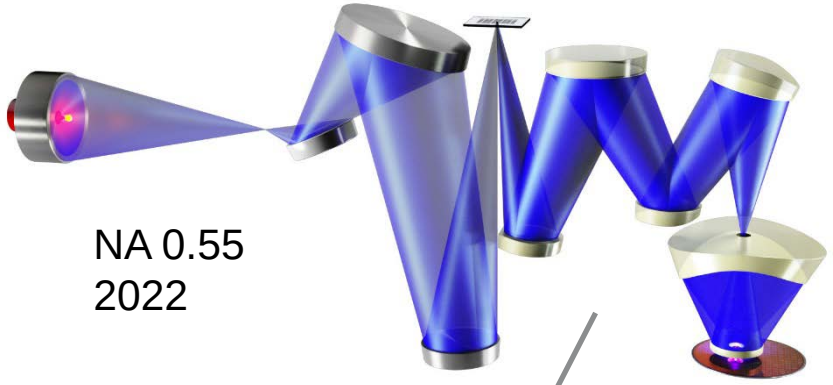


Future
Lower PFR will enable lower k1 at higher contrast

Projection Optics Roadmap towards 2030
DUV Immersion is at physical limits – where is the limit for EUV?

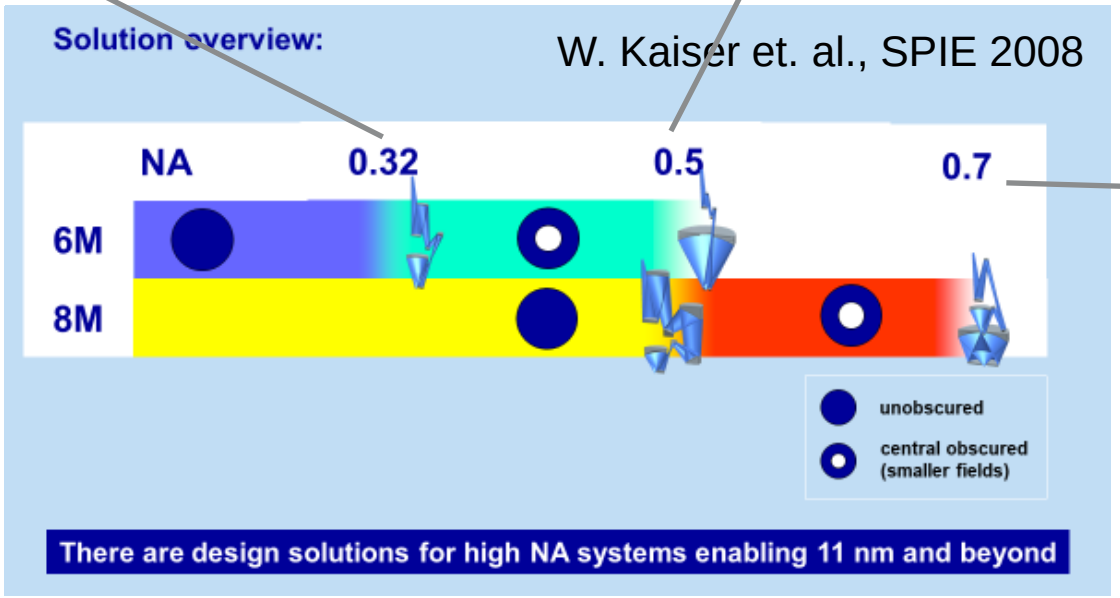


NA 0.33
2012 / 2016



NA 0.55
2022

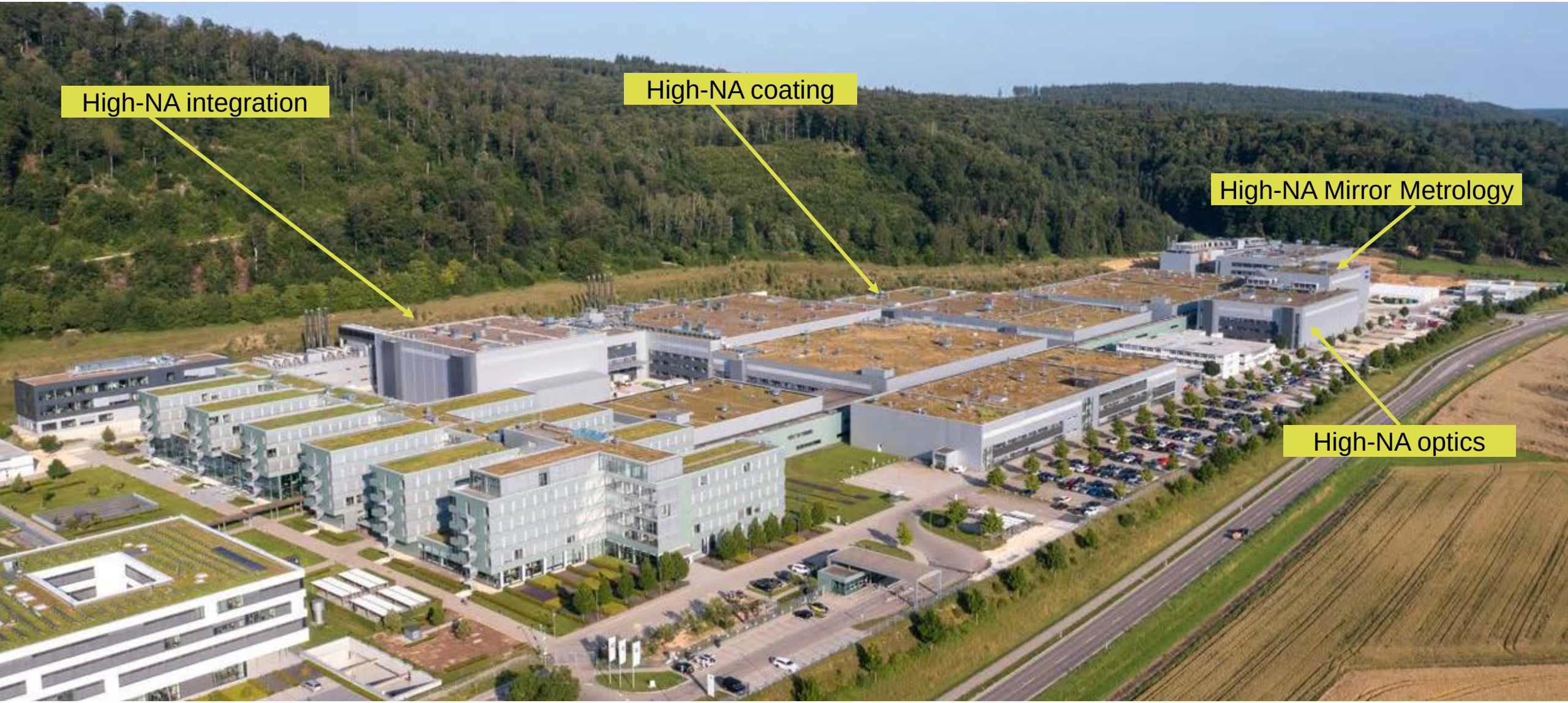
W. Kaiser et. al., SPIE 2008



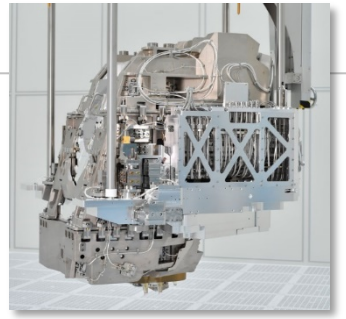
What about even higher NA?

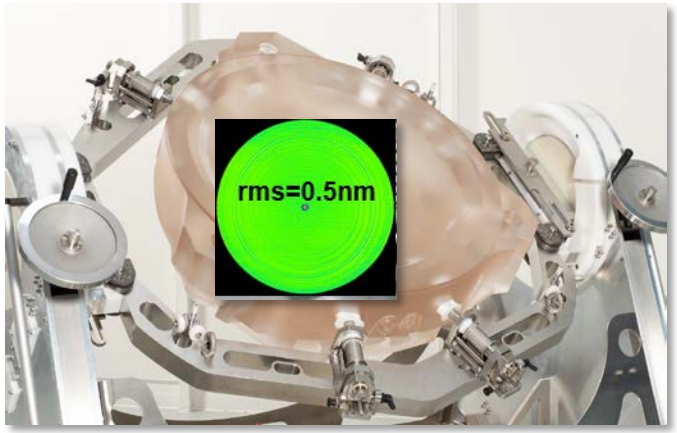
- Basic ideas exist
- Many problems still to be solved
- In 2030 we will know...

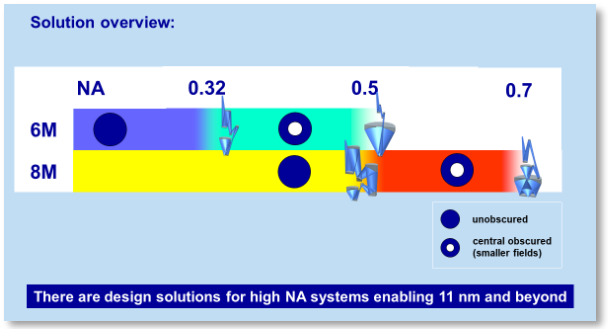
ZEISS SMT Campus Oberkochen



Summary







- We are shipping 0.33NA optics in high volume to the customers.
- We are producing mirrors and frames for High-NA EUV optics at full speed.
- Mirror performance approaches specification level in sub-nanometer regime
- Build up of system integration tools is progressing.
- EUV roadmap extensions are visible.

Acknowledgements

Special thanks goes to:

Many, many people, too numerous to mention all by name

The high-NA teams at ASML and ZEISS

Our suppliers, customers, and project partners around the globe

This work has received funding form the ECSEL Joint Undertaking (JU) under grant agreements No. 662338, 698522, 737479, and 783247. The JU receives support from the European Union‘s Horizon 2020 research and innovation program and the member states.

The projects on which this publication is based were funded by the Federal Ministry of Education and Research under the funding codes 16ESE0036K, 16ESE0072K, and 16ESE0287K, and by the Federal Ministry for Economic Affairs and Energy under the funding codes 16IPCEI605 / 16IPCEI630.

Gefördert durch:
Bundesministerium für Bildung und Forschung
aufgrund eines Beschlusses des Deutschen Bundestages

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

Responsibility for the content lies solely with the authors and neither the ECSEL JU nor the German Federal Ministries may be made responsible for information it contains.


Thank you!