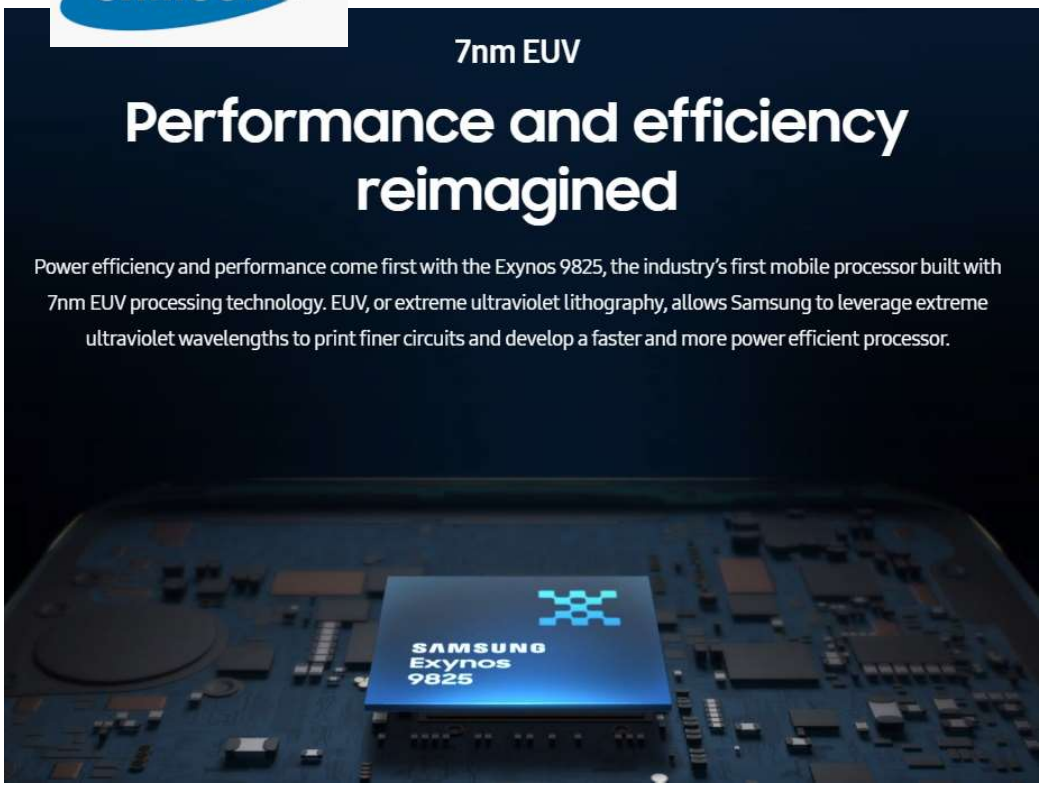
Progress in High NA EUV Optics Development for sub-10nm resolution

Wischmeier, Lars
Carl Zeiss SMT GmbH, Germany
lars.wischmeier@zeiss.com

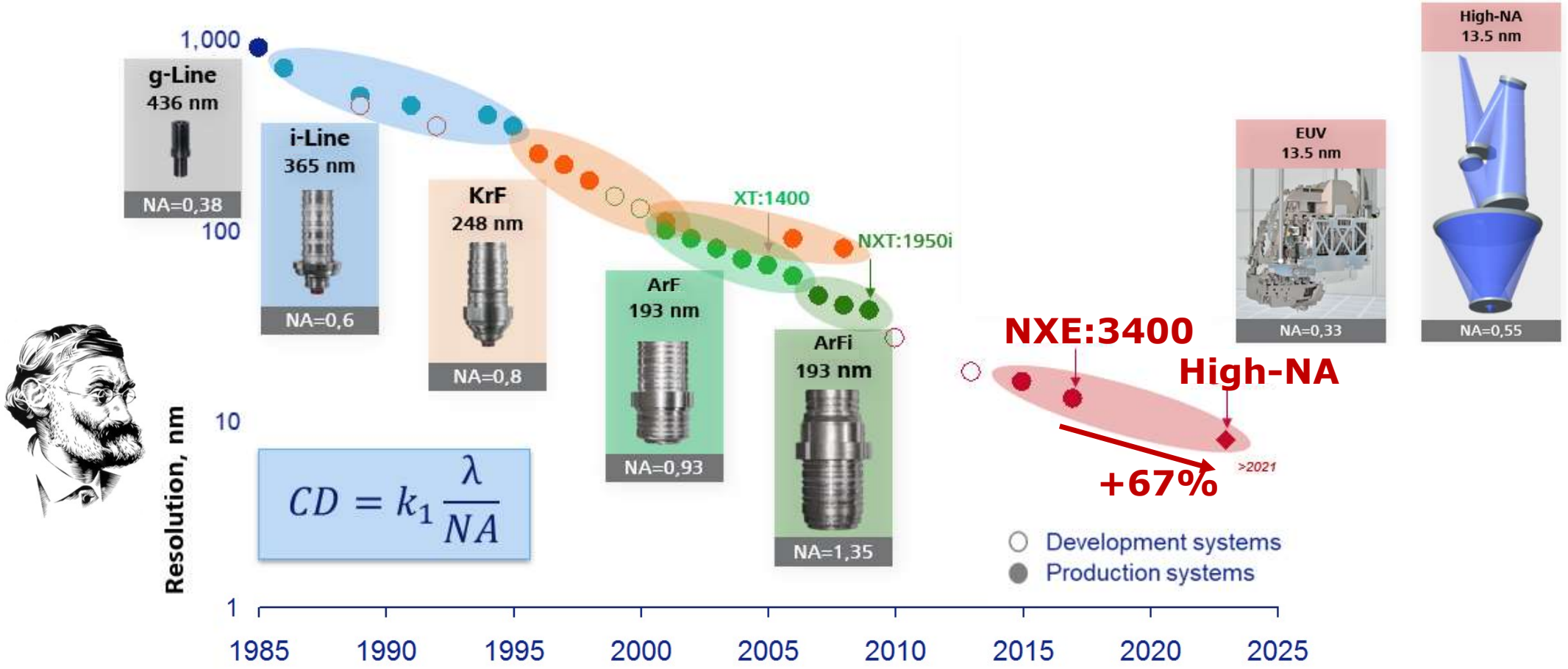
September 14-18, 2020

Customers flagship products are powered with 7nm+ EUV



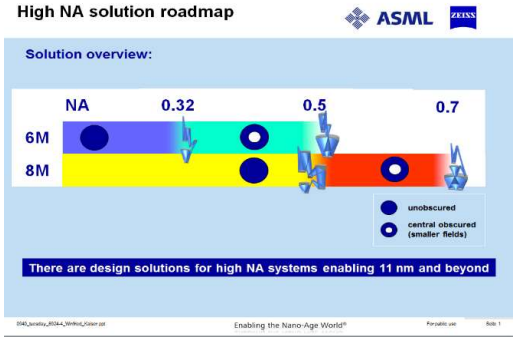
Source: https://www.samsung.com/semiconductor/minisite/exynos/products/mobileprocessor/exynos-9825/ , https://consumer.huawei.com/en/campaign/kirin-990-series/

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



History of high-NA EUV Lithography

SPIE 2008
Winfried Kaiser



SPIE 2015
Bernhard Kneer

EUV Lithography Optics for sub 9 nm Resolution ASML ZEISS

MICROLITHOGRAPHY www.lithoguru.com

SPIE Advanced Lithography 2015 – day 4

February 27, 2015 Leave a comment

On Thursday I was EUV focused. My first complaint is that there were too many ASML papers. Of course, this is not ASML's fault. They are doing most of the important work in this field. Still, some sessions started to feel like an ASML meeting rather than an SPIE meeting.

The first session was directed to high numerical aperture (NA) designs for EUV, and the ASML/Zeiss anamorphic imaging approach looks like a good idea. Current lens designs can't scale to NA > 0.5 because they result in angles hitting the mask on the order of 9° rather than the current 6°. These higher angles degrade imaging performance, removing most of the advantage of the higher NA. Higher magnification (8X) would fix this, but would result in either much larger mask sizes (an unlikely scenario) or much smaller field sizes (1/4 to be specific). The smaller field size would hit EUV where it hurts most: throughput.

The Zeiss/ASML solution is to have an 8X magnification in the direction needed to lower the incident angles on the mask (the scan direction), keeping the magnification 4X in the slit direction. This results in field sizes 1/2 of the current size, a more manageable problem. And by moving to a design with a central obscuration, the angles on the mirrors are reduced as well, increasing mirror reflectivity and overall optics transmission. To keep the projector at six mirrors, the higher NA will require extreme aspheres, a daunting manufacturing challenge. But as Bernhard Kneer of Zeiss said, in perfect Teutonic style, "Zeiss can do this." I love it.

SPIE 2020
Lars Wischmeier

Session 2:
The Future is High NA

Monday 24 February 2020
1:20 PM - 3:20 PM

Session Chairs: Kenneth A. Goldberg, Lawrence Berkeley National Lab. (United States) ; Ted Liang, Intel Corp. (United States)

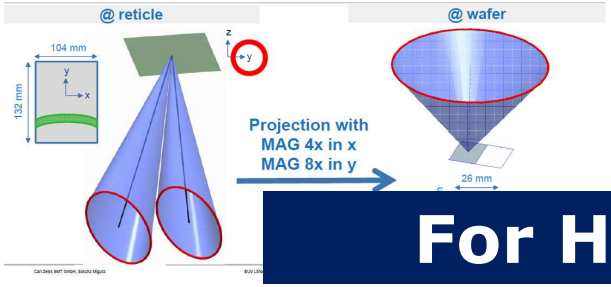
High-NA EUV lithography optics becomes reality ASML ZEISS

L. Wischmeier, P. Gräupner, P. Kürz, W. Kaiser (ZEISS) , J. v. Schoot, J. Mallmann, J. d. Pee, J. Stoeldraijer (ASML)

SPIE Advanced Lithography 2020 - Extreme Ultraviolet (EUV) Lithography XI
February 24th, 2020 - San Jose, CA, USA

EUVL Symposium 2014
Sascha Migura

…which enables a High-NA EUVL optical system with 26mm slit. ZEISS



For High-NA optics, the future is now!

Outline

1. Design features of High-NA EUV optics
2. Manufacturing of mirrors and frames
3. Mirror metrology for High-NA EUV

Outline

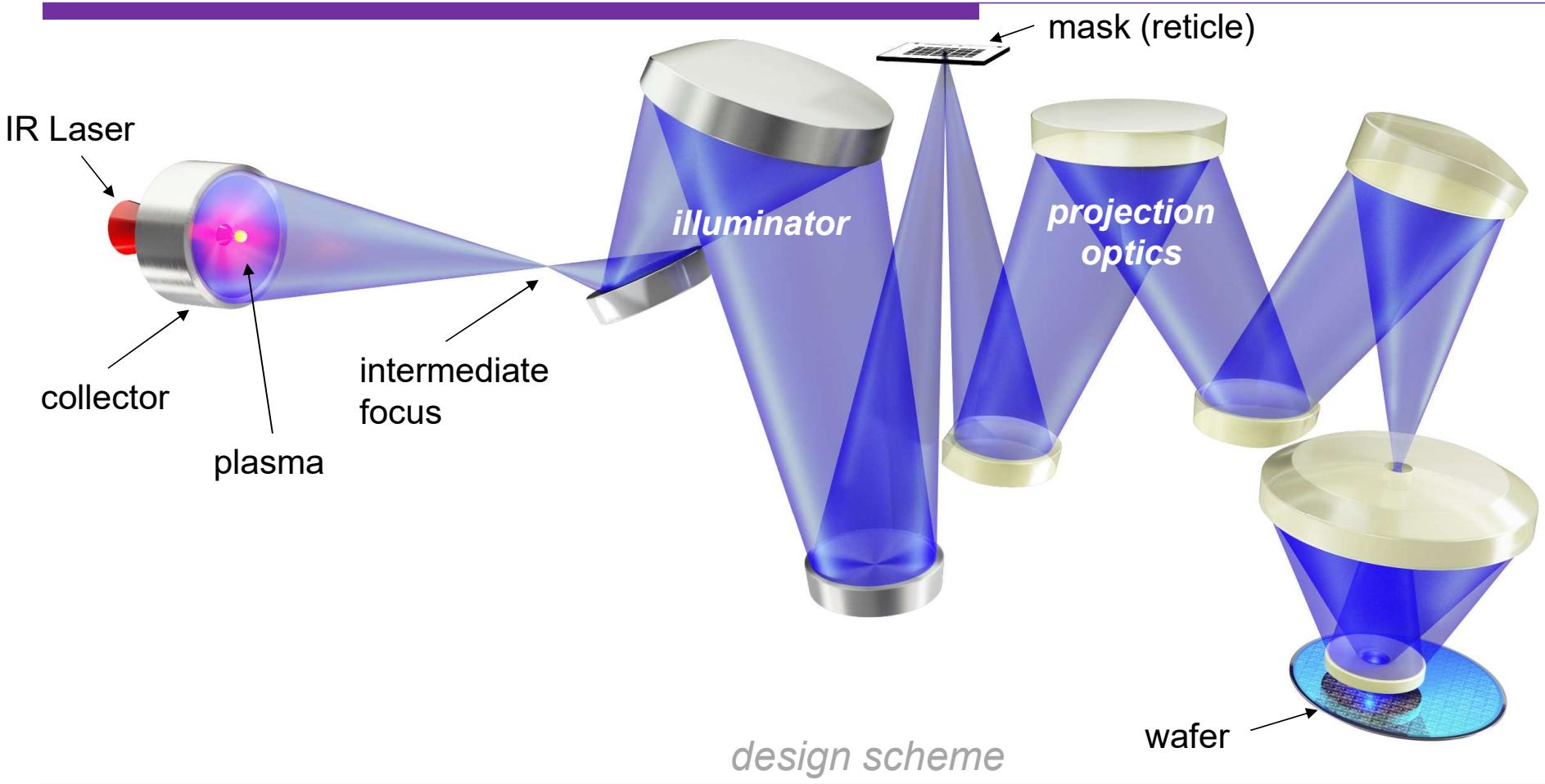
1 **Design features of High-NA EUV optics**

2 Manufacturing of mirrors and frames

3 Mirror metrology for High-NA EUV

High-NA EUV

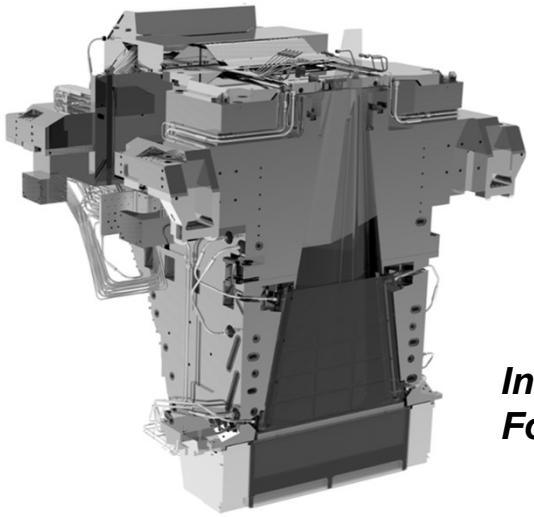
The optical system for the ultimate printing machine with NA=0.55

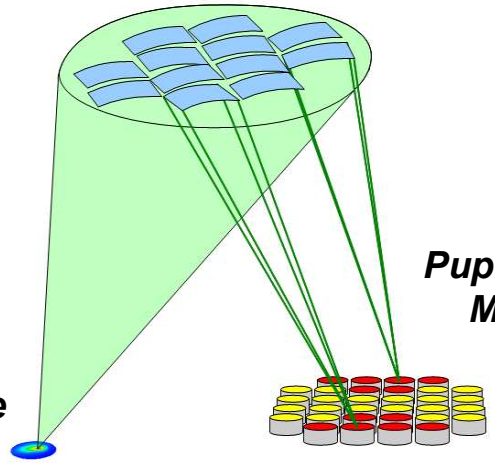


design scheme

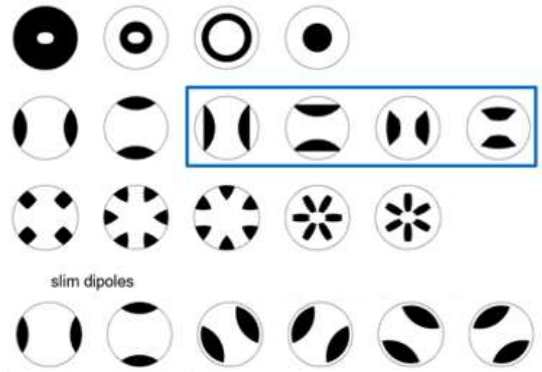
High-NA illuminator will utilize medium-NA technology with actuated facet mirrors

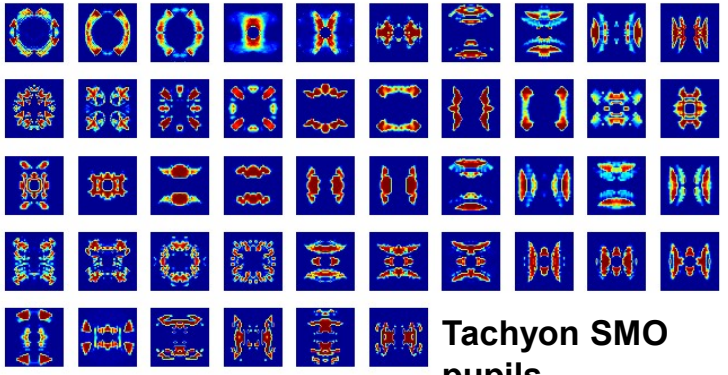
High-NA illuminator





Standard Illumination Settings



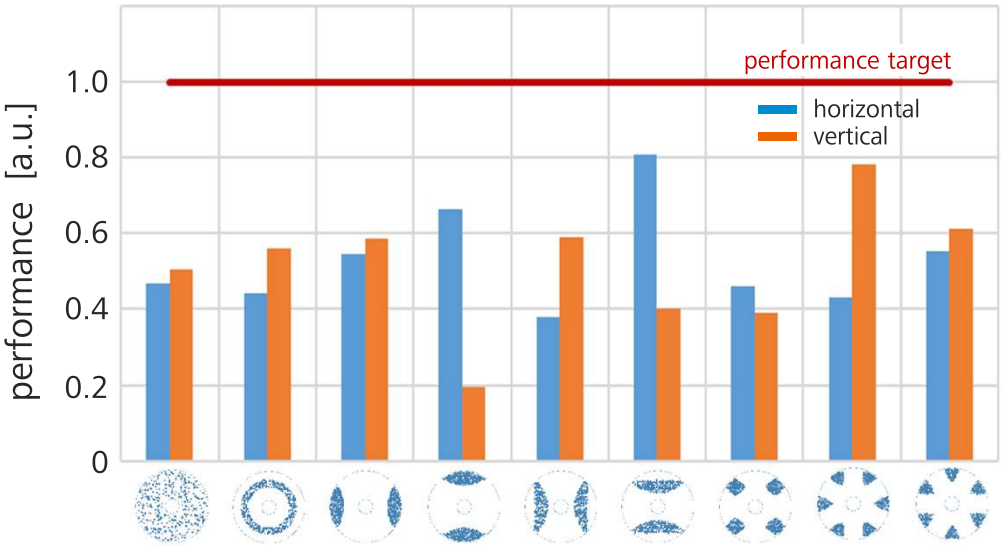


Tachyon SMO pupils

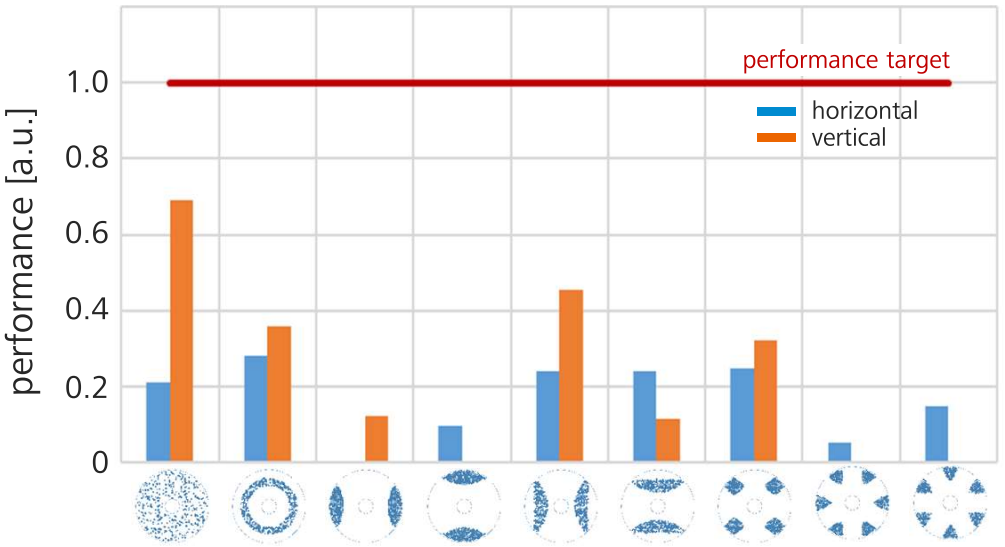
- High-NA illuminator provides 20% pupil fill ratio
- More focus on medium sigma dipoles (→ mask 3D effects)

Predicted imaging performance of the new illuminator shows a good outcome of the design process

Telecentricity

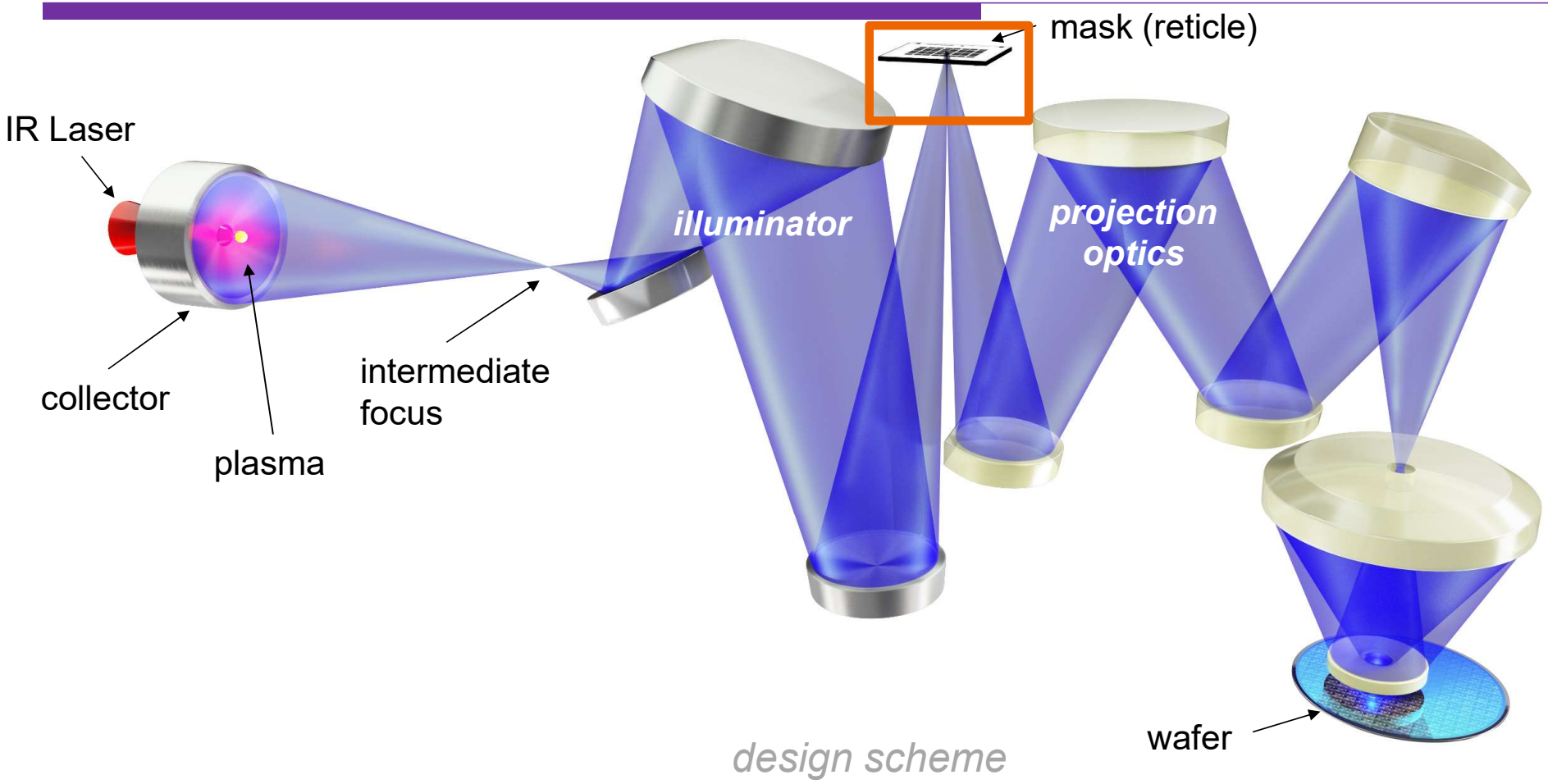


CD uniformity



High-NA EUV

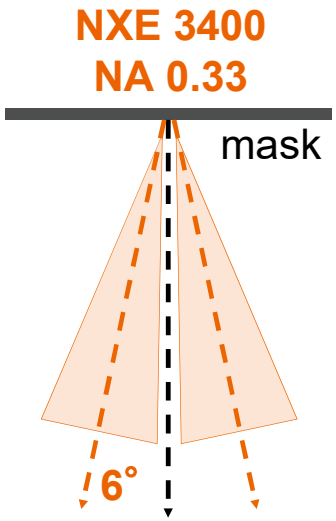
The optical system for the ultimate printing machine with NA=0.55

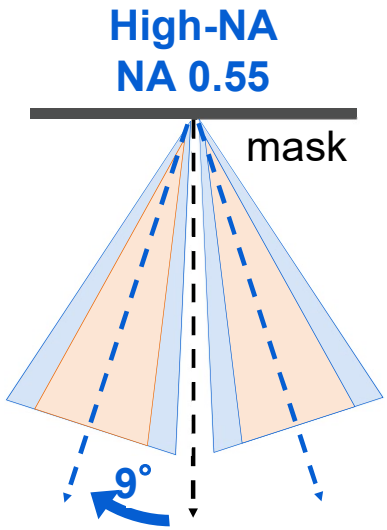


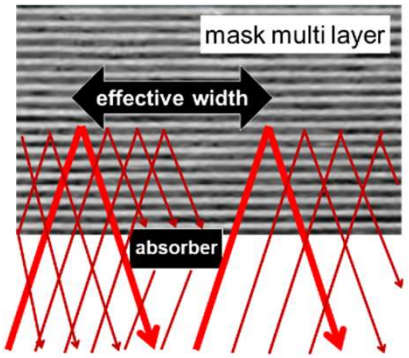
design scheme

Angle limits at mask

„Anamorphic“ design allows 6“ masks and full 26mm scan width







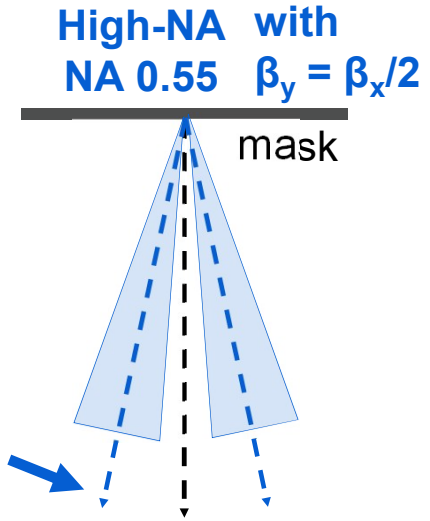
- absorber shadowing at mask is angular dependent
- **inacceptable contrast loss**

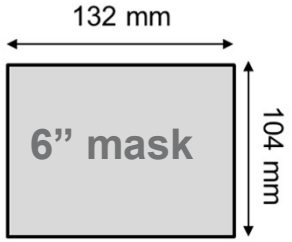
solution

anamorphotic design

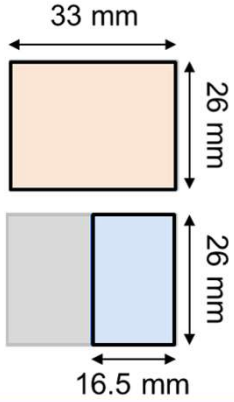
NA @ mask
= β x NA @ wafer

β_{scan} = 1/8
$\beta_{x\text{-}scan}$ = 1/4



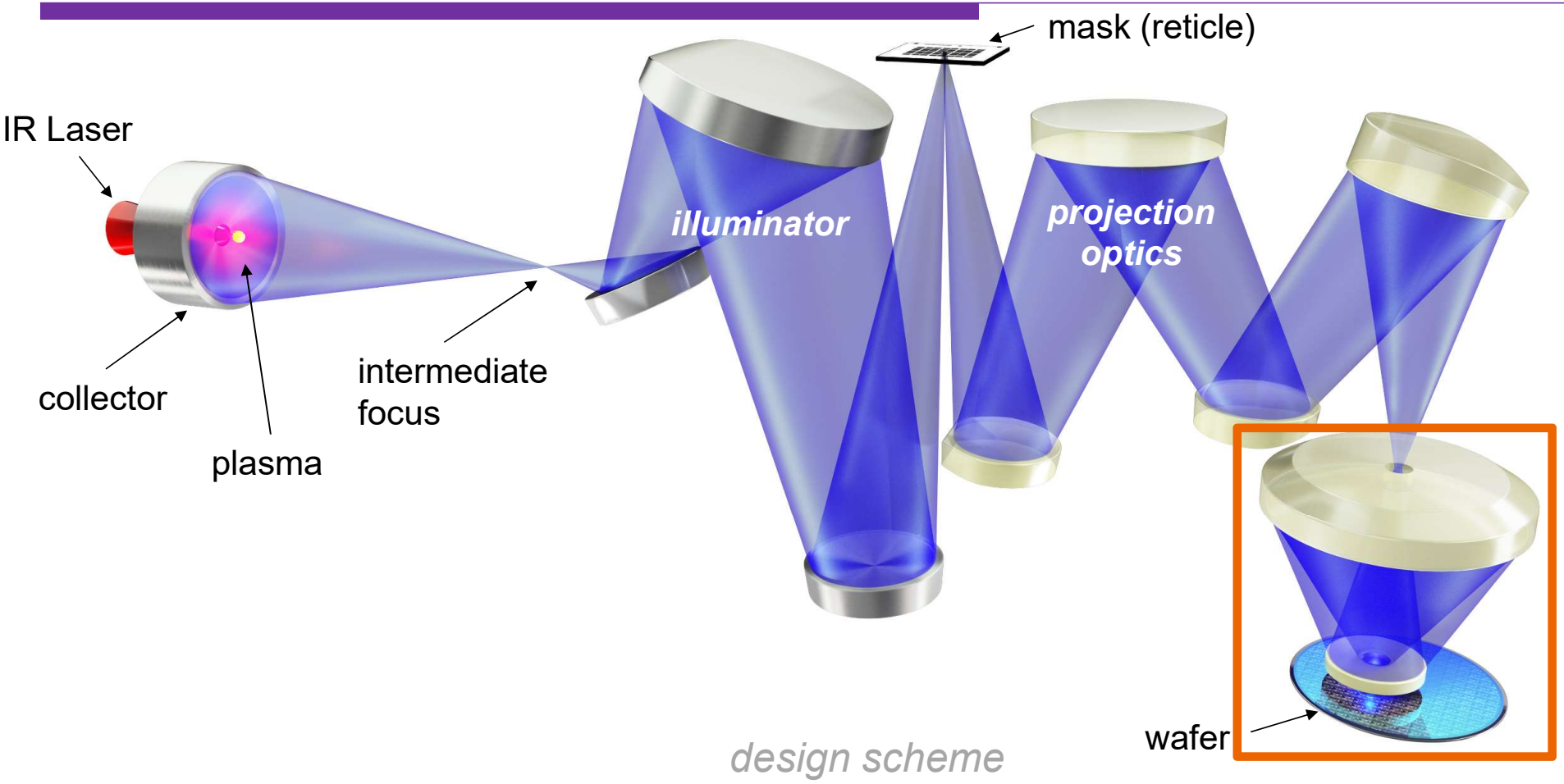


wafer



High-NA EUV

The optical system for the ultimate printing machine with NA=0.55

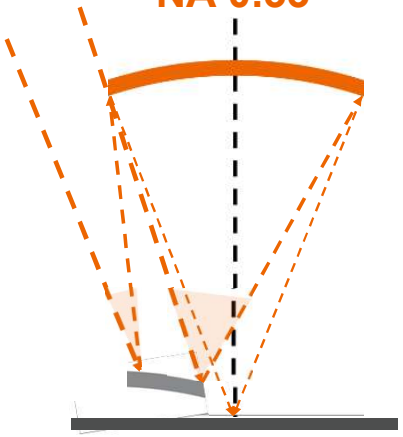


design scheme

Angles inside the optics

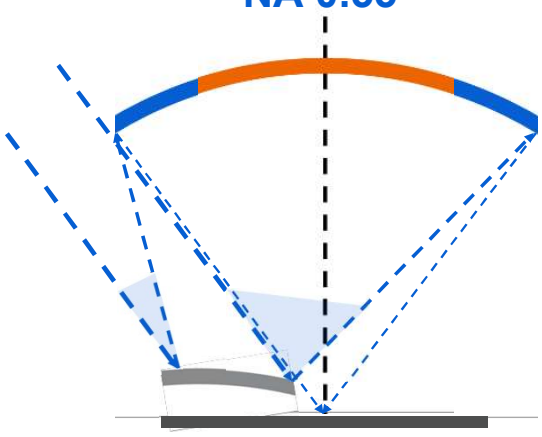
Obscuration needed to limit the angular spread

NXE 3400
NA 0.33



wafer

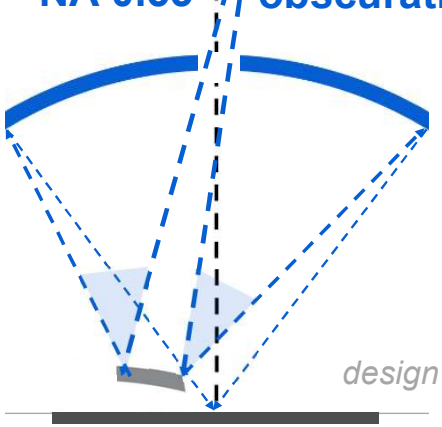
High-NA
NA 0.55



wafer

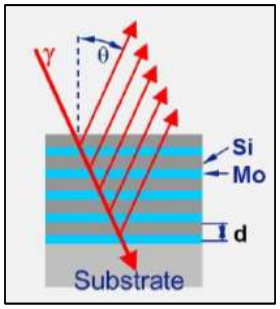
solution

High-NA **with**
NA 0.55 **obscuration**



design example

wafer



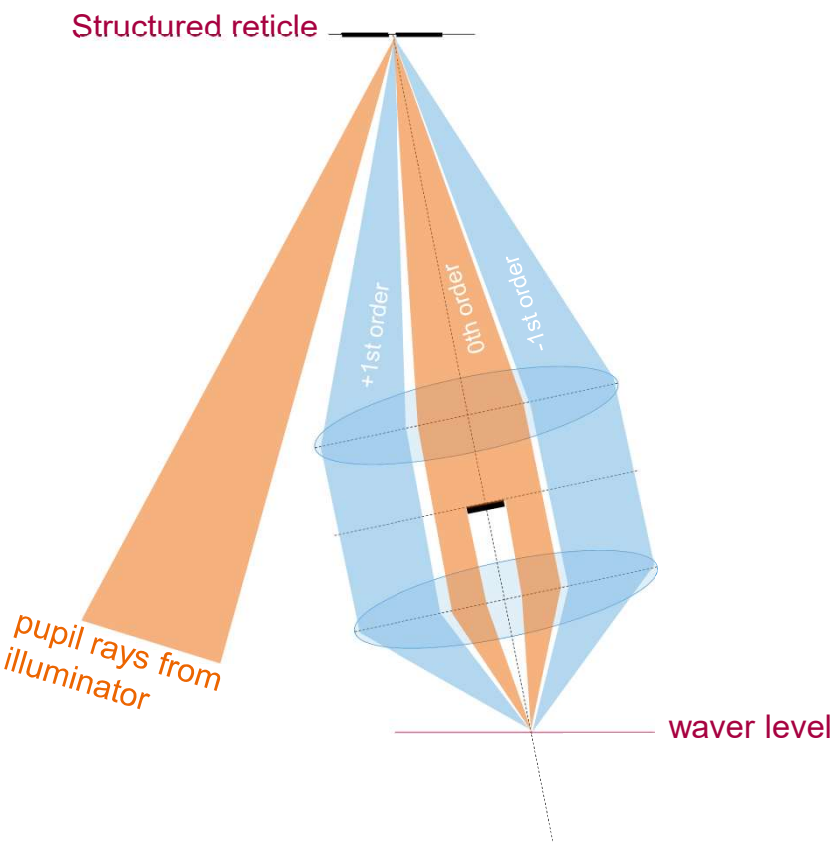
- larger deflection angle
- **larger angle variation over mirror**

costs transmission of multilayer coating

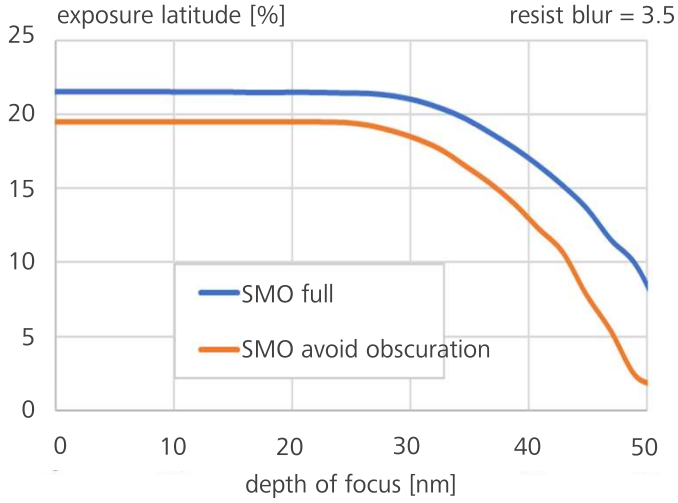
obscuration significantly reduces deflection angle & angle variation

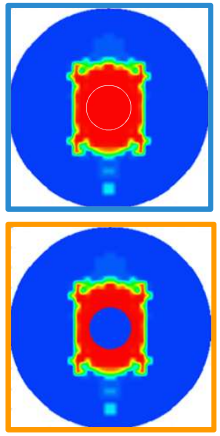
high transmission

POB central obscuration can be used for new illumination feature that can improve process window

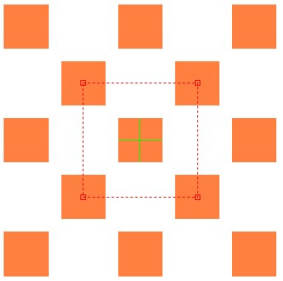


One possible example (1)





pitch = 28 nm
CD = 14 nm



Contrast and Depth of Focus can be improved exploiting partial dark-field illumination

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

Outline

1 Design features of High-NA EUV optics

2 Manufacturing of mirrors and frames

3 Mirror metrology for High-NA EUV

Status manufacturing of illuminator frame

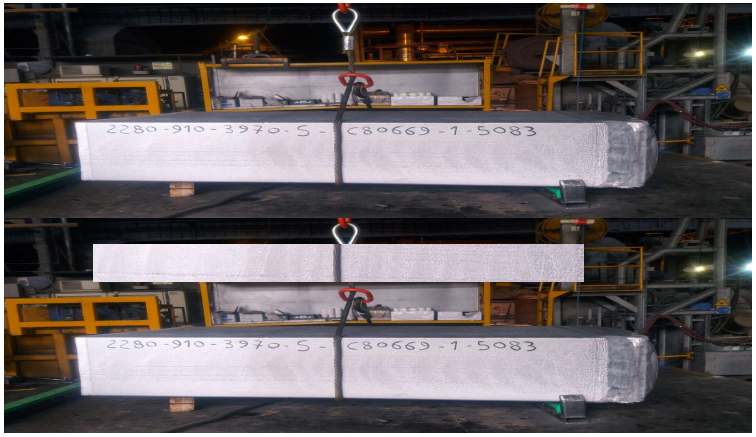
Rough milling finished, detailed processing ongoing

Production high-NA illuminator optics started

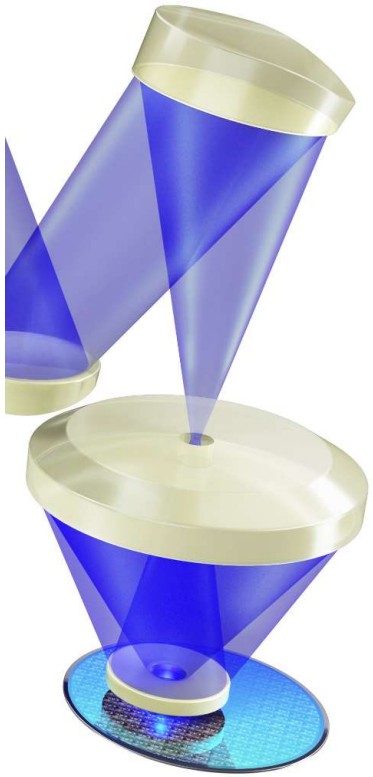
Facet production: milling started

Status manufacturing of POB frame

Rough milling finished, detailed processing ongoing

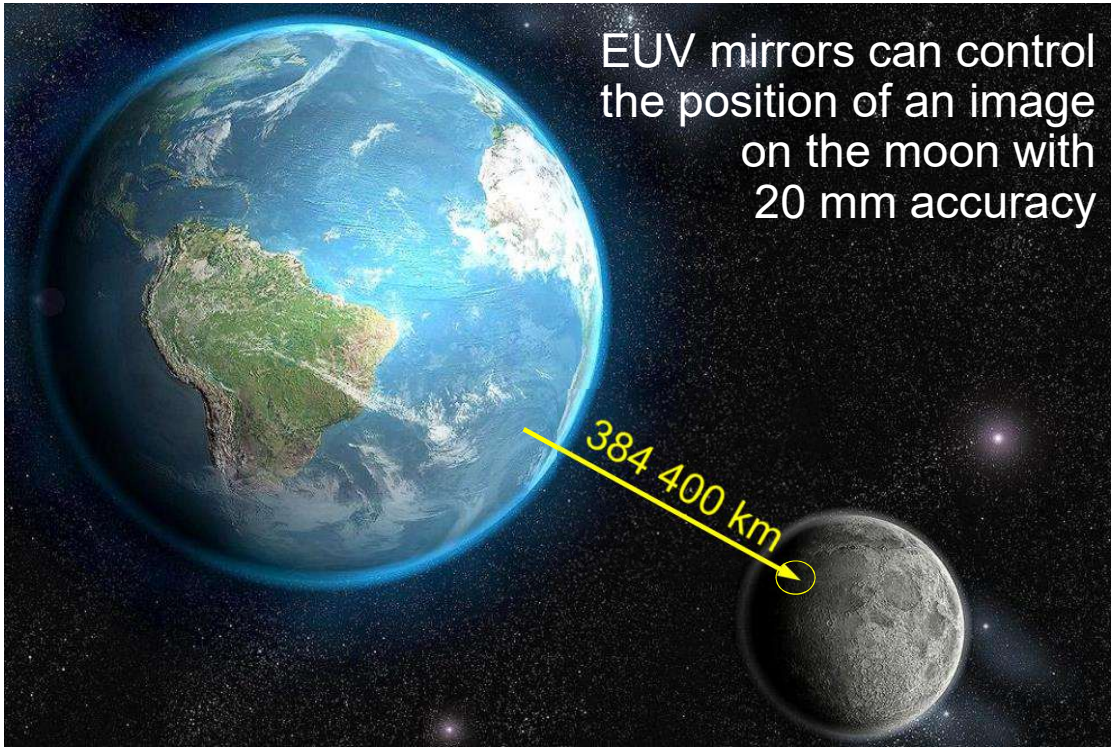


Mirror position control in nanometer range required



All mirrors are actuated
and controlled
to sub nrad accuracy

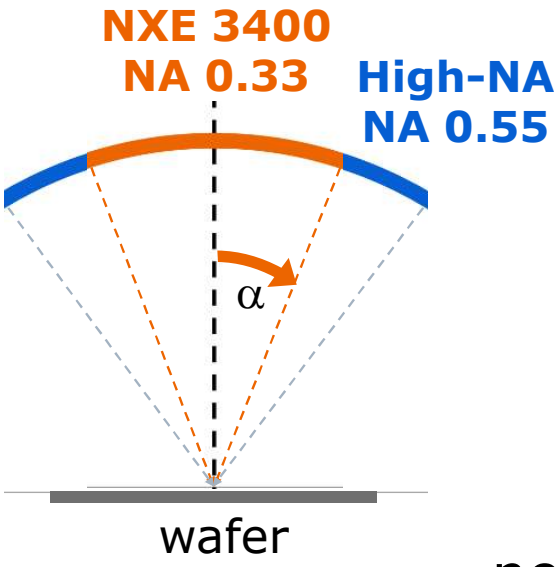
overlay fingerprints and
other perturbations
can be compensated
to very high accuracy



The image position
needs to be stable to <<1nm

Angles and the last mirror

Unprecedented size and weight need automatic handling

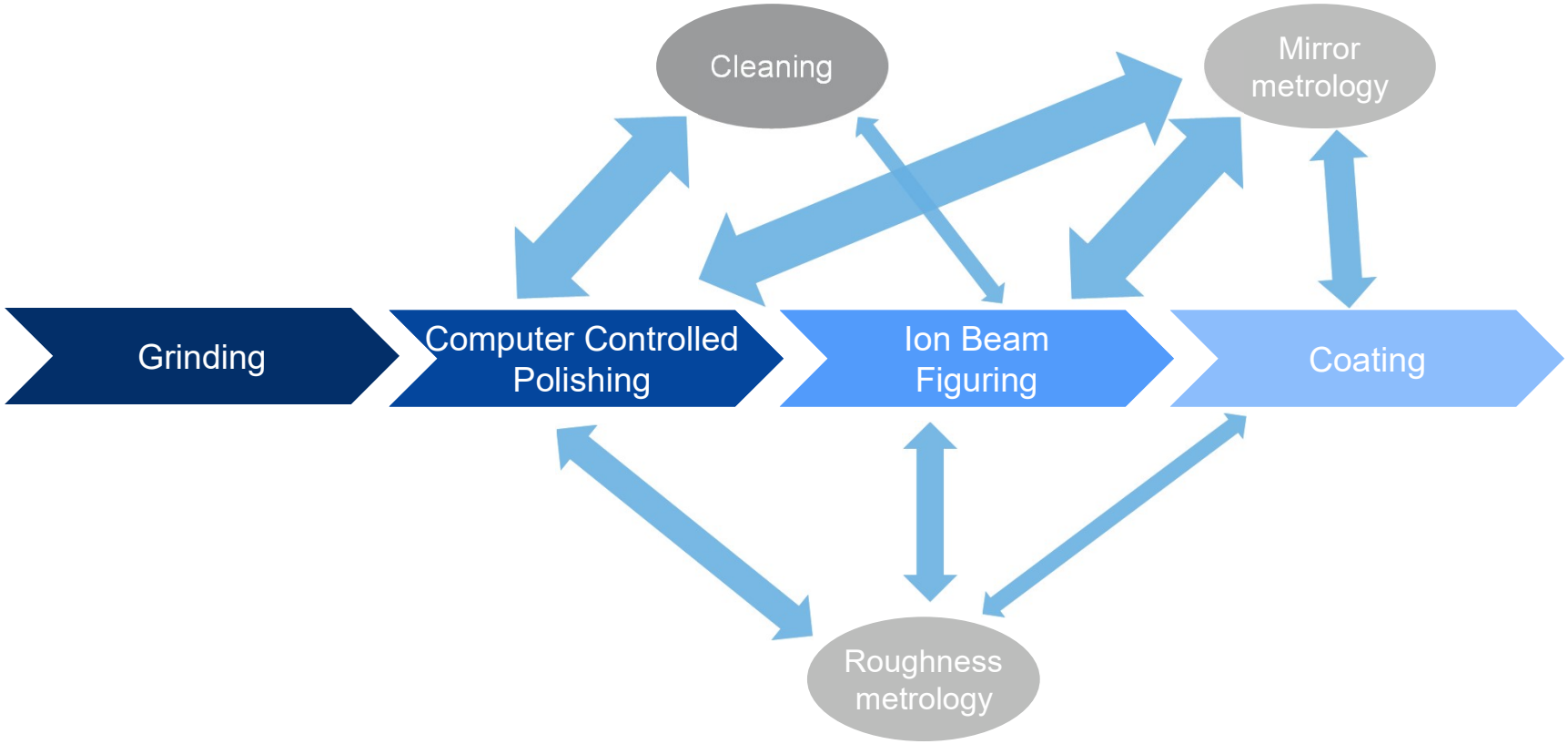


Mirrors become really large and heavy

Automated fab for mirror handling and new production infrastructur required

This is how it looks

Optics manufacturing process



Thickness of arrow indicates quantity of interactions between tools

Optics manufacturing process

Cleaning

Mirror metrology

Grinding

Computer Controlled Polishing

Ion Beam Figuring

Coating

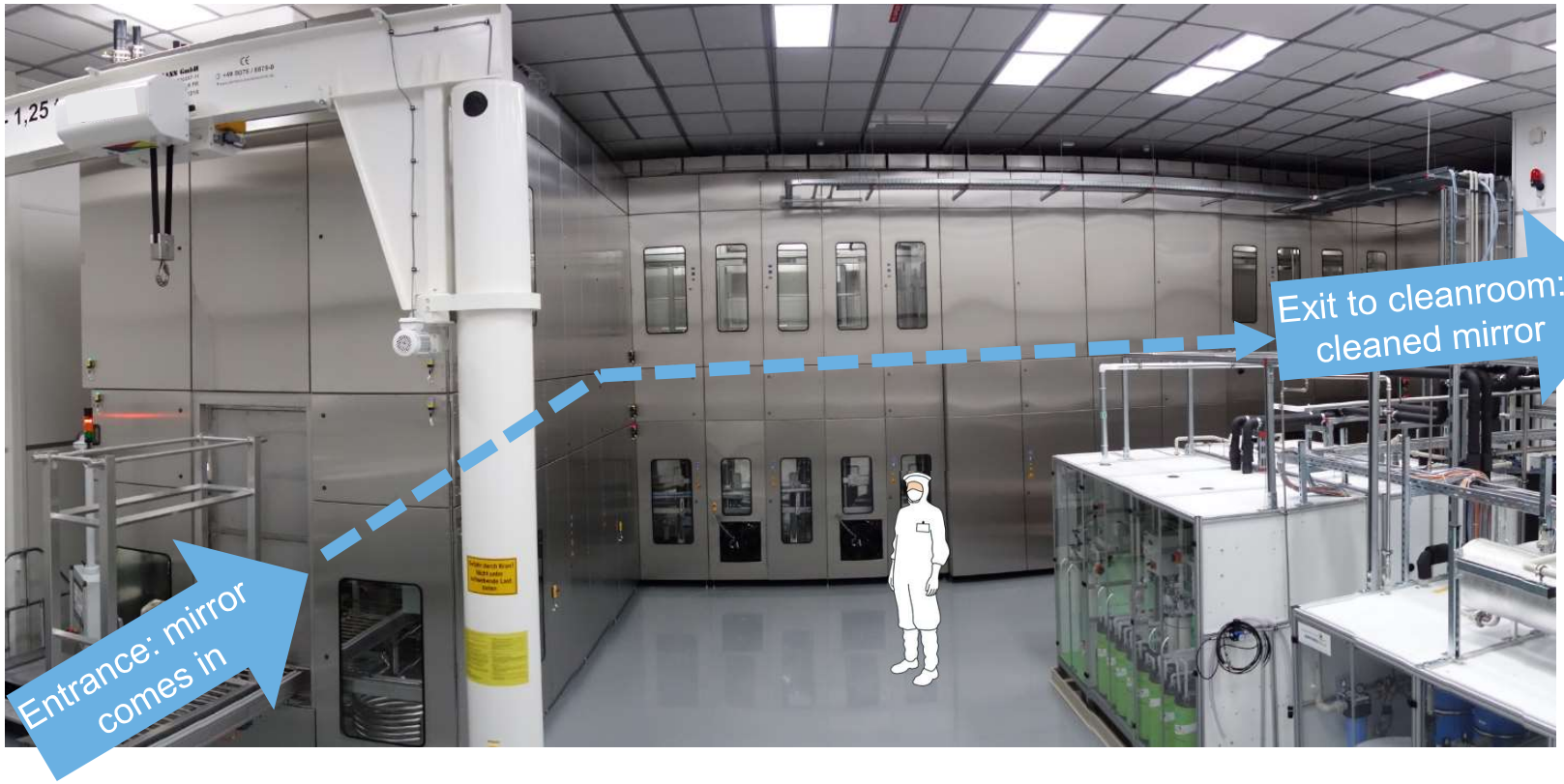
Roughness metrology

Thickness of arrow indicates quantity of interactions between tools

New coating facility for large mirrors installed and running

- Delivered with 13 trucks
- weight: 64 tons, length: 13m
- volume of vacuum chamber ~ 30m³;

Fully automated mirror cleaning facility installed and running



Handling robot, that takes over cleaned mirror.

First mirror ground

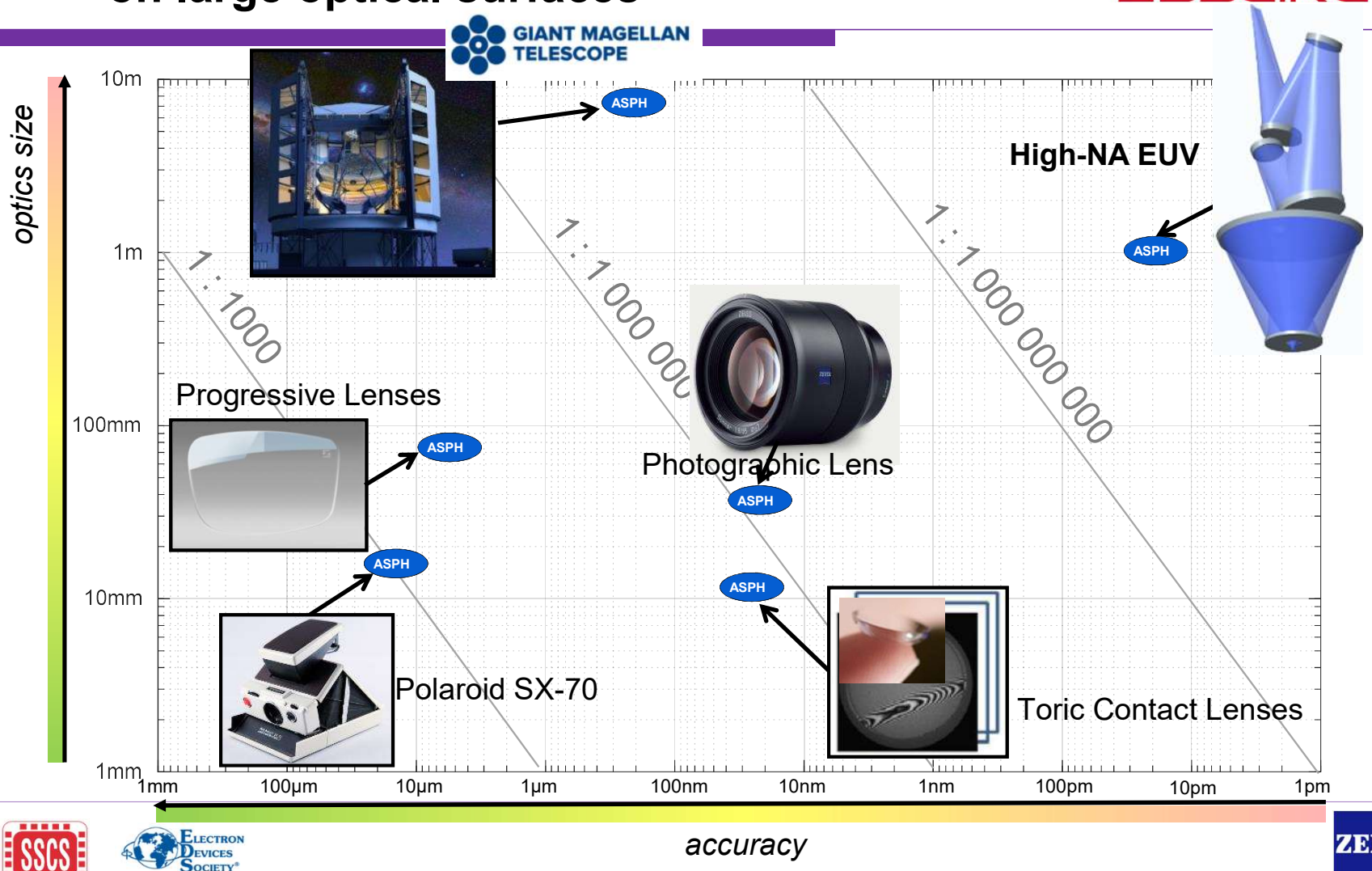
Outline

1 Design features of High-NA EUV optics

2 Manufacturing of mirrors and frames

3 Mirror metrology for High-NA EUV

High-NA requires high accuracy mirrors on large optical surfaces



Challenges scale with accuracy and size

Atomic level figuring required

Zugspitze
2962m

High-NA mirror

RMS ~ 20 pm

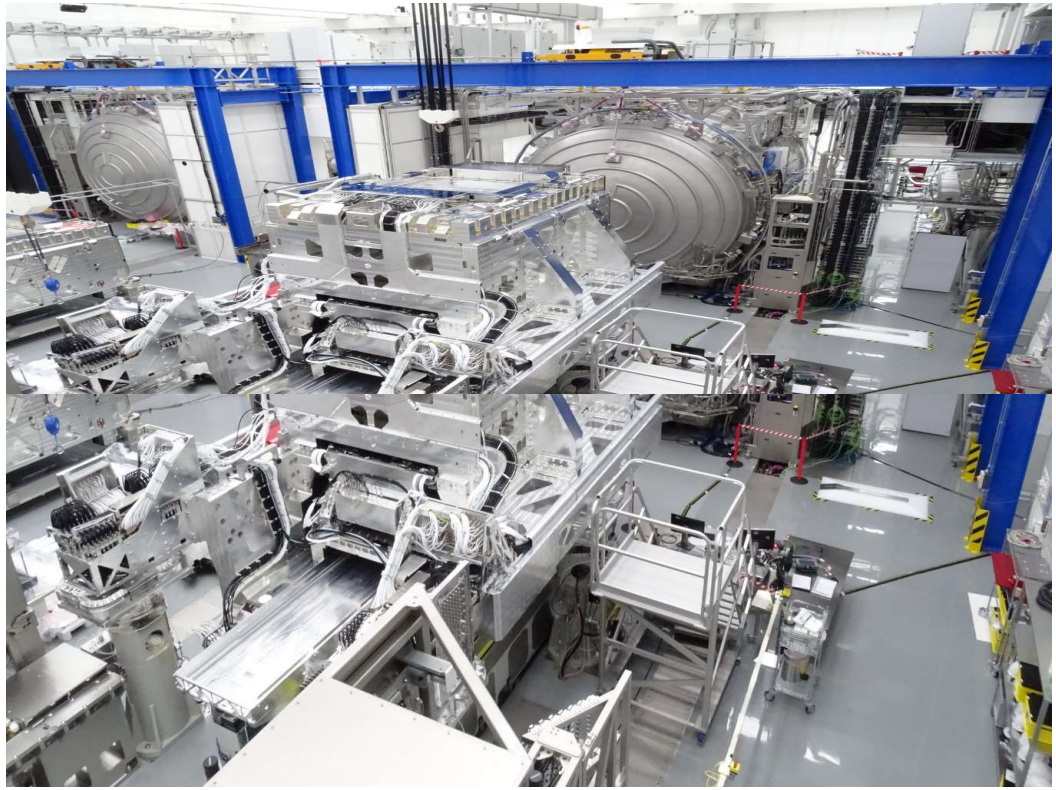
Scale to size of germany by ~ 1 million

heights of ~20µm in Germany

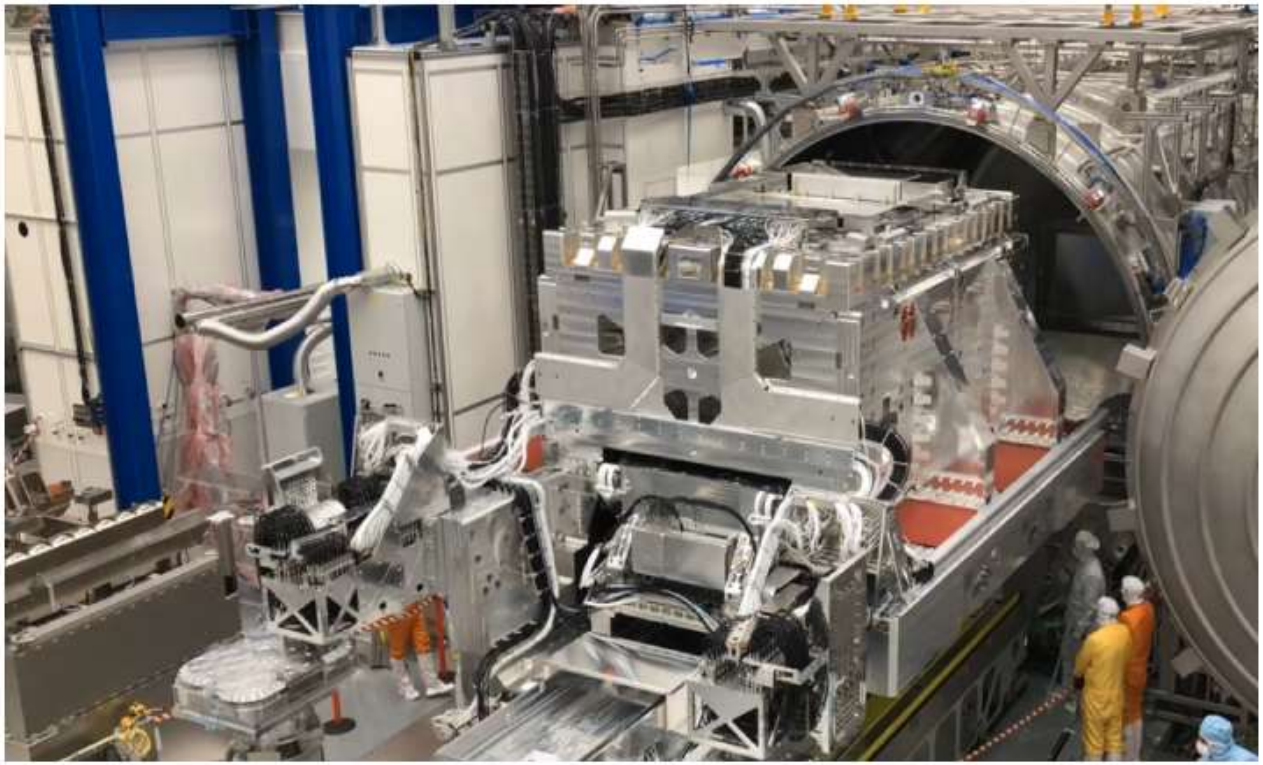
or

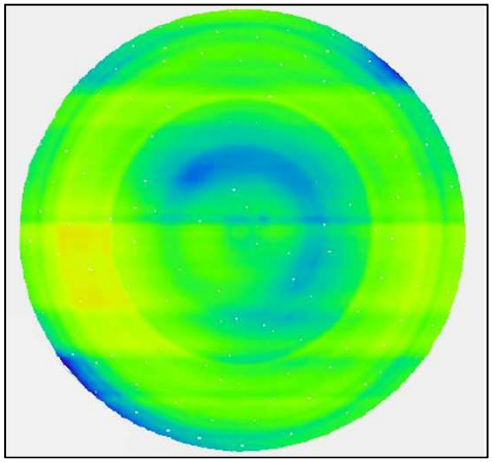
1/5 of a human hair

Tight surface figure specifications in pm range require mirror metrology in vacuum



High-NA mirror metrology operational

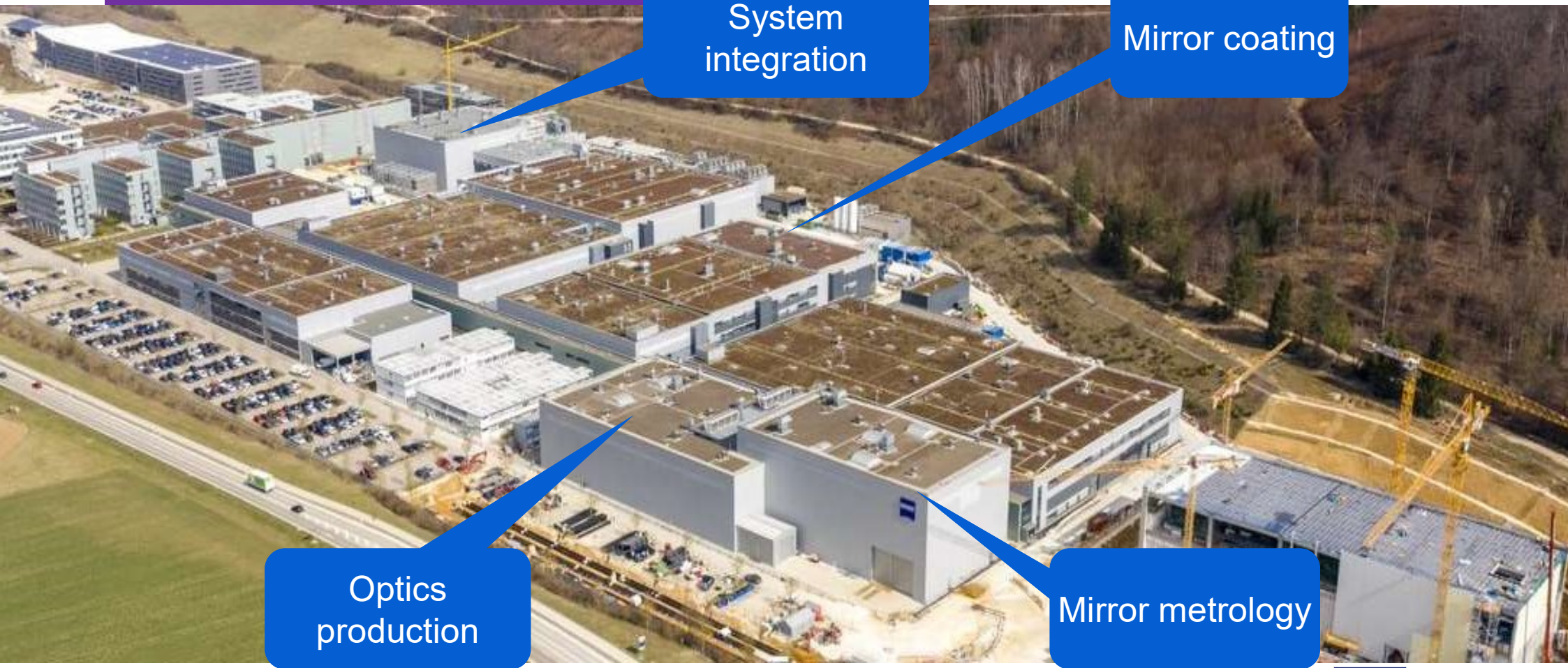




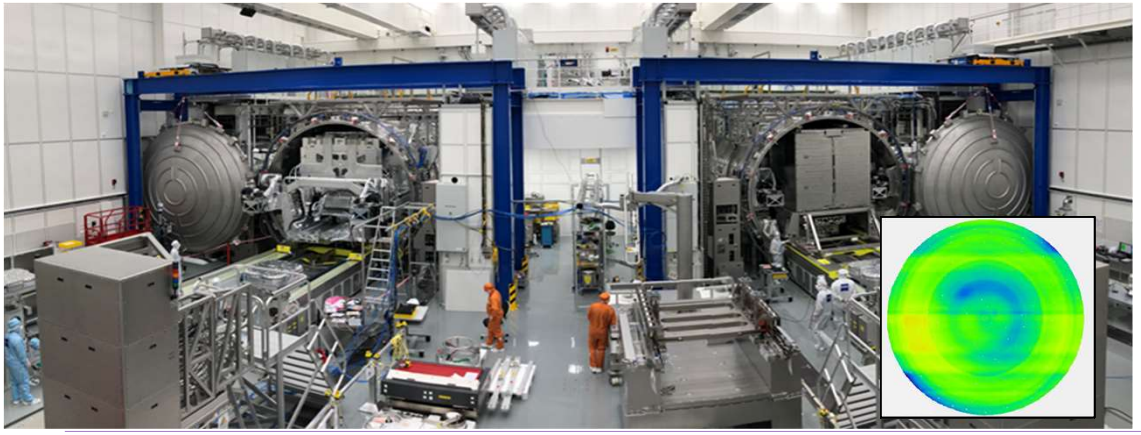
First sharp mirrors have been measured!

Summary

Status Carl Zeiss SMT campus: High-NA facilities



Summary



- We are producing mirrors and frames for first High-NA EUV optics at full speed.
- First measurements with novel mirror metrology for extreme aspheres have been achieved.

ZEISS European Autumn School

Lithography Optics
29./30. September 2020

- Learn key aspects about the world of advanced optics for nanoelectronics
- Connect with students, scientists and experts from all over Europe
- Take part in sessions with high-profile speakers

IPCEI on Microelectronics

ZEISS

Seeing beyond

Further information: www.zeiss.com/ corporate/int/newsroom/events/european-autumn-school.html

Acknowledgement

This work has been funded by the German **Federal Ministry for Economic Affairs and Energy** (BMWi) in the frame of the "**Important Project of Common European Interest on Microelectronics**" (IPCEI-ME).

Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

The IPCEI is also funded by Public Authorities from France, Italy and U.K.