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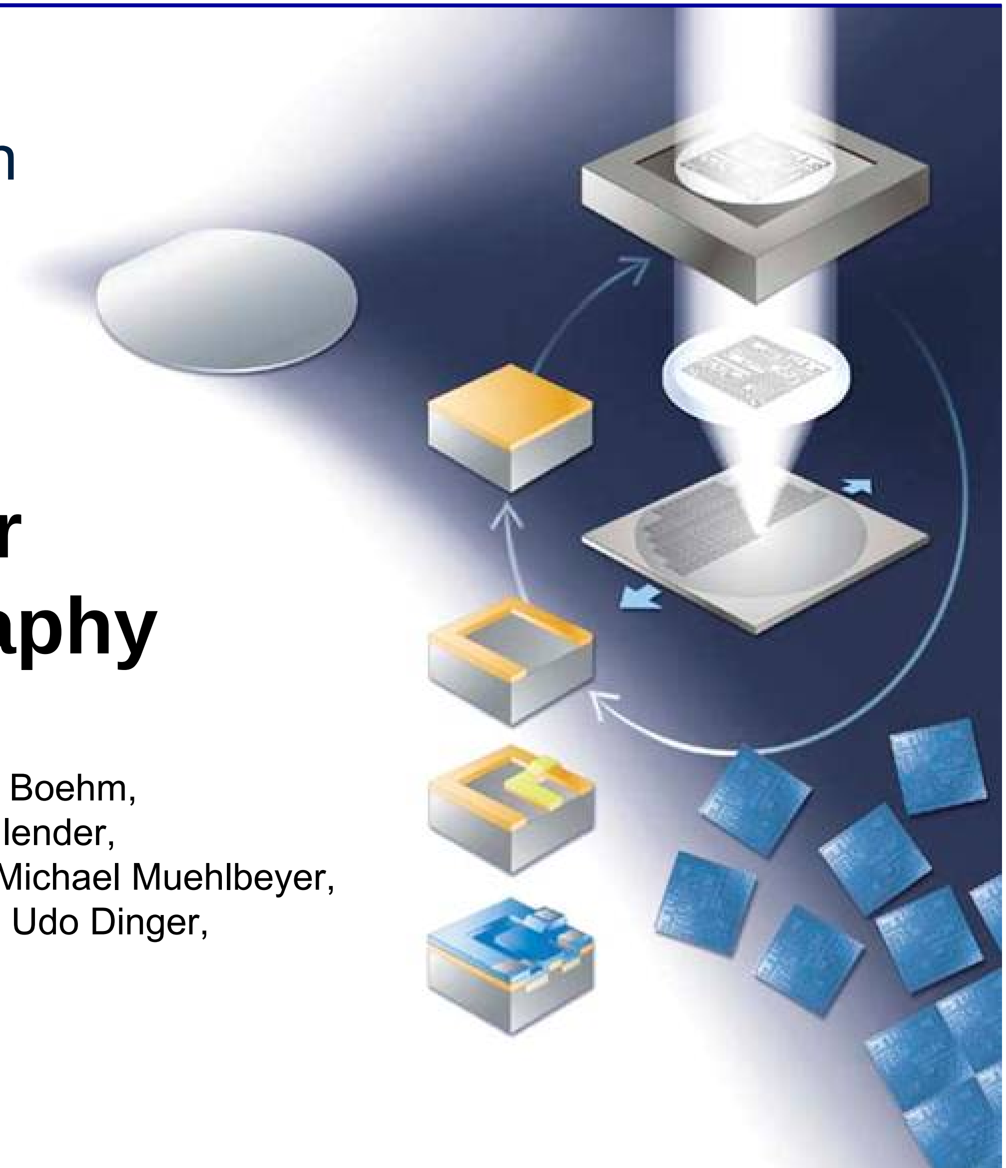
Lithography Optics Division



Optics for EUV Lithography

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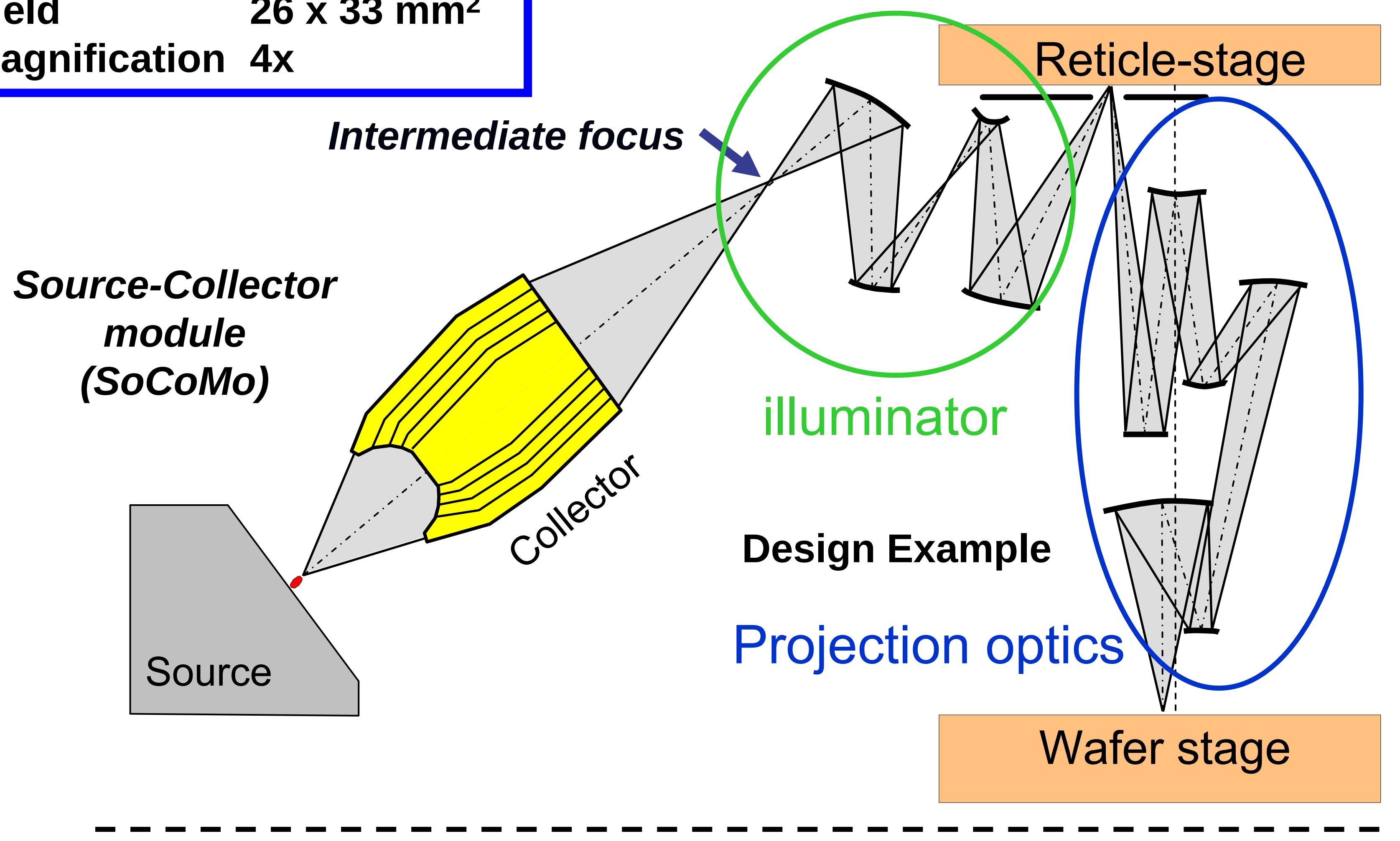
The optical train – Introduction

- λ 13.5 nm
- NA 0.25
- Field 26 x 33 mm^2
- Magnification 4x



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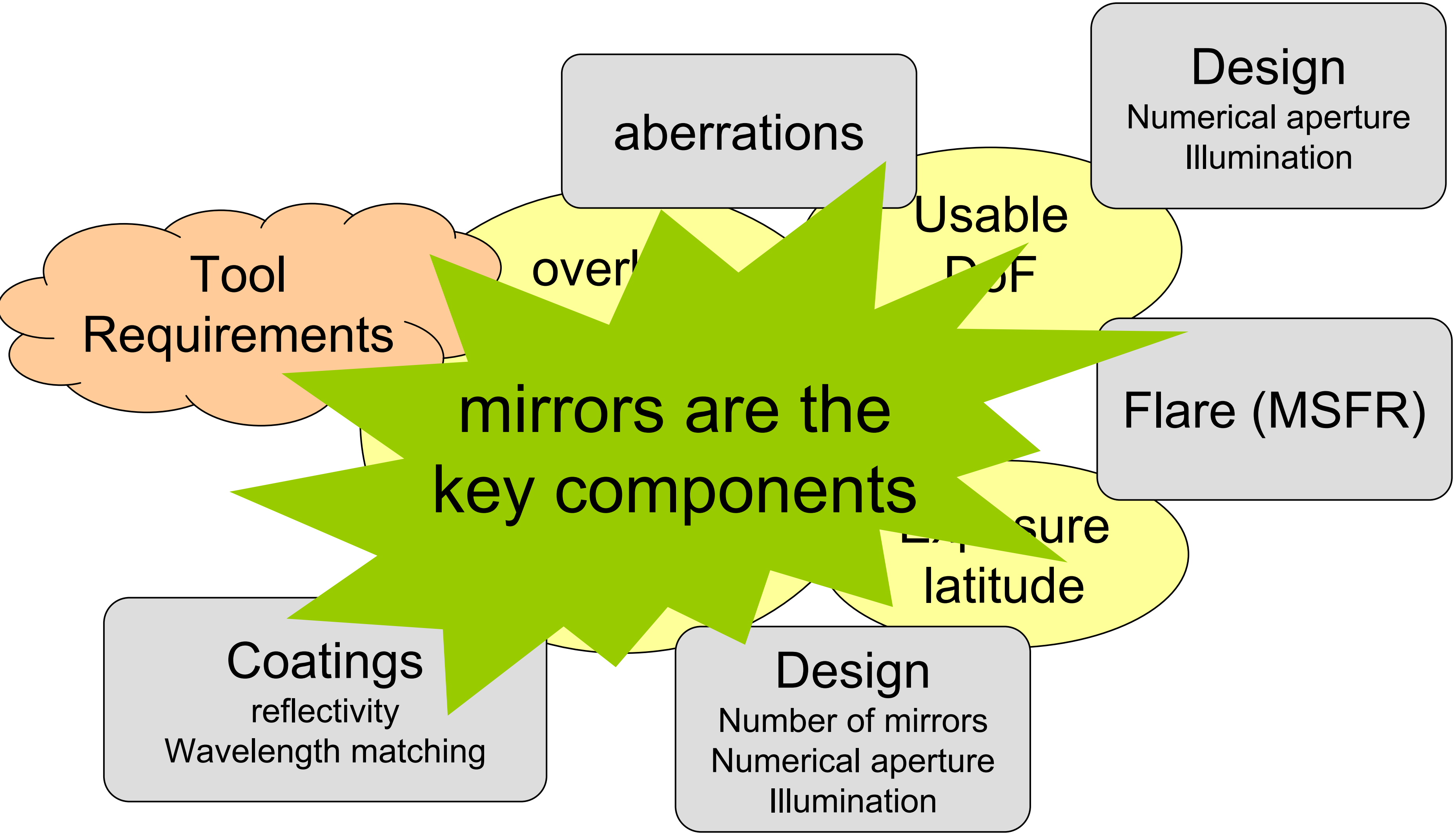
Impact of optics on tool performance



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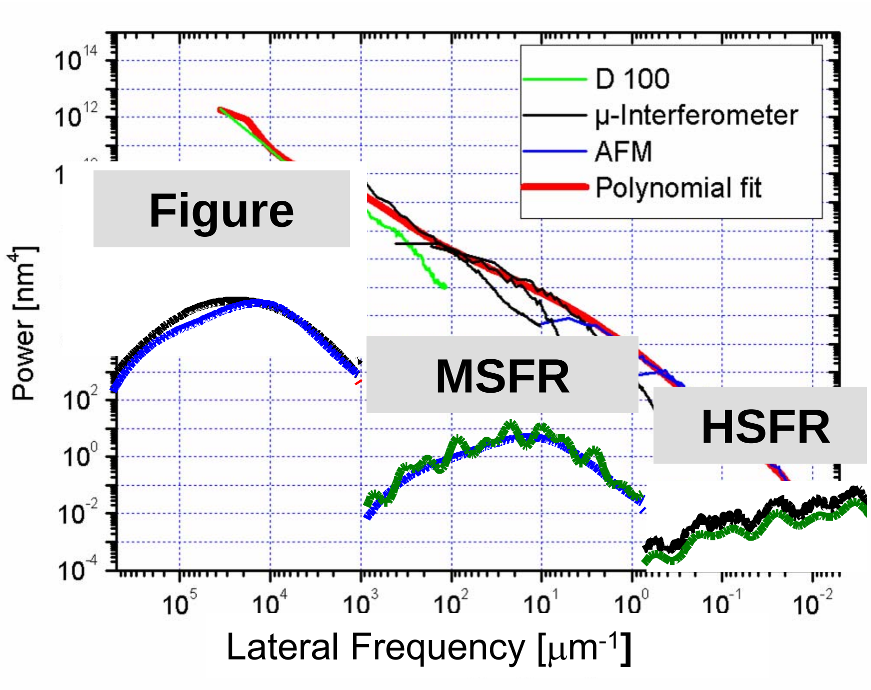
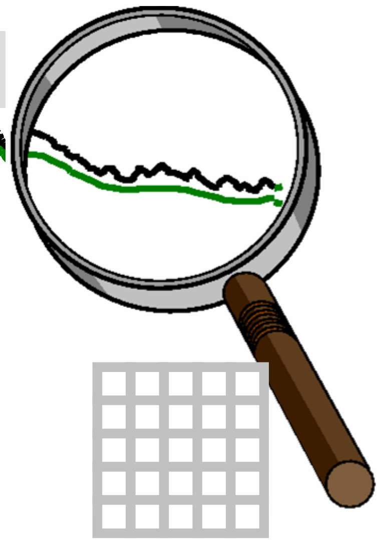
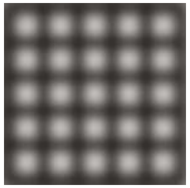
Optics Technology: Fabrication of EUV mirrors

2D-isotropic PSD
(example)







figure

→ aberrations

→ CDU, overlay

MSFR

→ in field of view scattering: flare

→ CDU

HSFR

→ reduced reflectivity

→ system throughput

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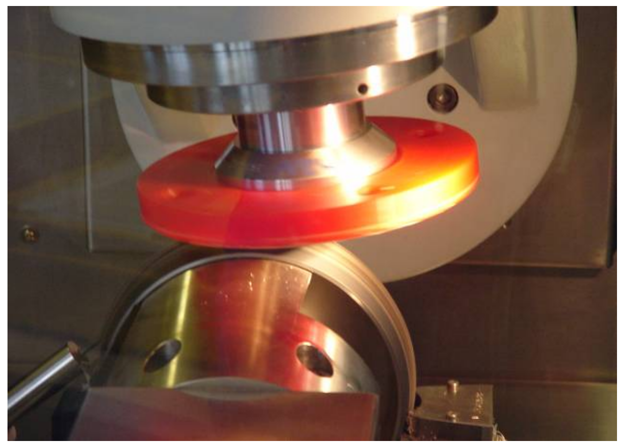
The “right” combination of fabrication technologies…

Computer Controlled Polishing for Deterministic Processes



Fast Magneto Rheological Figuring

Ion Beam Figuring: Atomic Level Figure Control

- **The challenge for optics fabrication:**

  Reduction of the Mid Spatial Frequency Roughness MSFR

  … and at the same time reduction of the figure (→ aberration control) and the HSFR (mirror reflectivity → system transmission)

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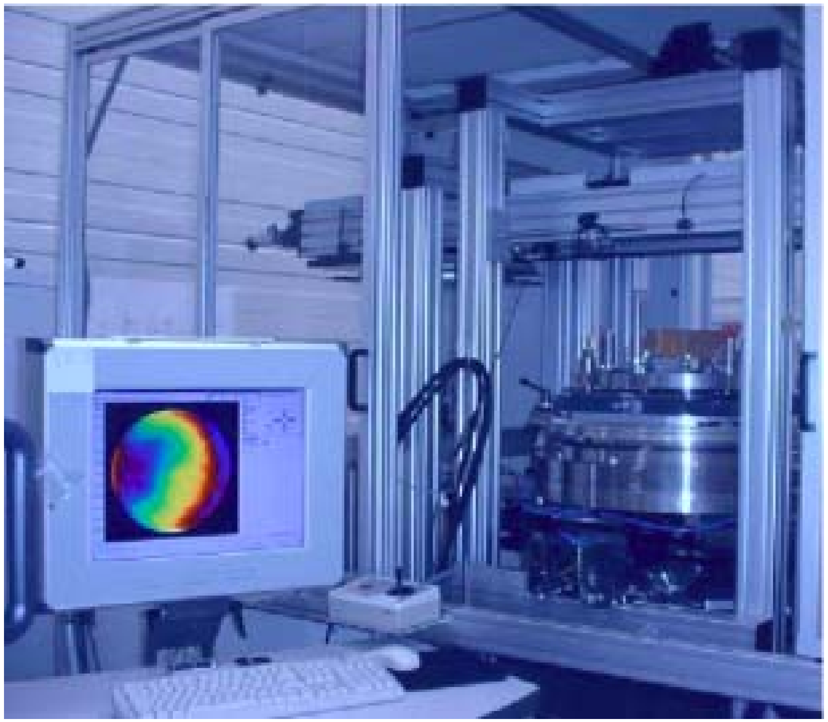
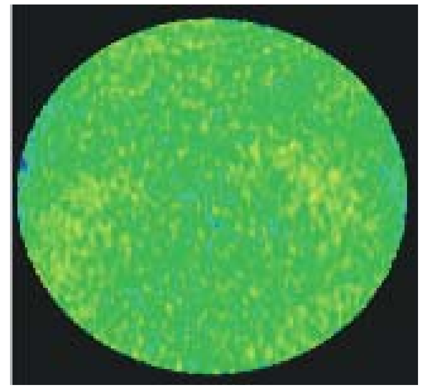
… and improvements in mirror metrology

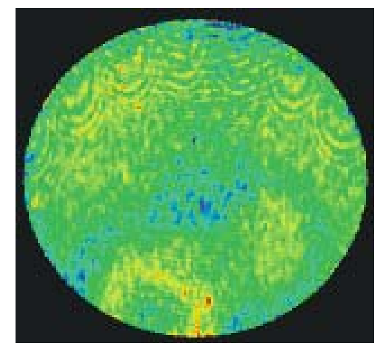
… enable very low figure values and reduced long wavelength MSFR contributions





12 pm RMS Repeatability

20 pm RMS Reproducibility



- statistical errors (repeatability):
  E_S = 12 pm RMS surface figure !!!
- statistical errors + adjustment errors (reproducibility):
  E_J = 20 pm RMS surface figure !!!

New result on EUV mirror
Figure = 0.04 nm rms
MSFR = 0.13 nm rms
HSFR = 0.07 nm rms

Optics Fabrication: Flare is determined by the Mid Spatial Frequency roughness

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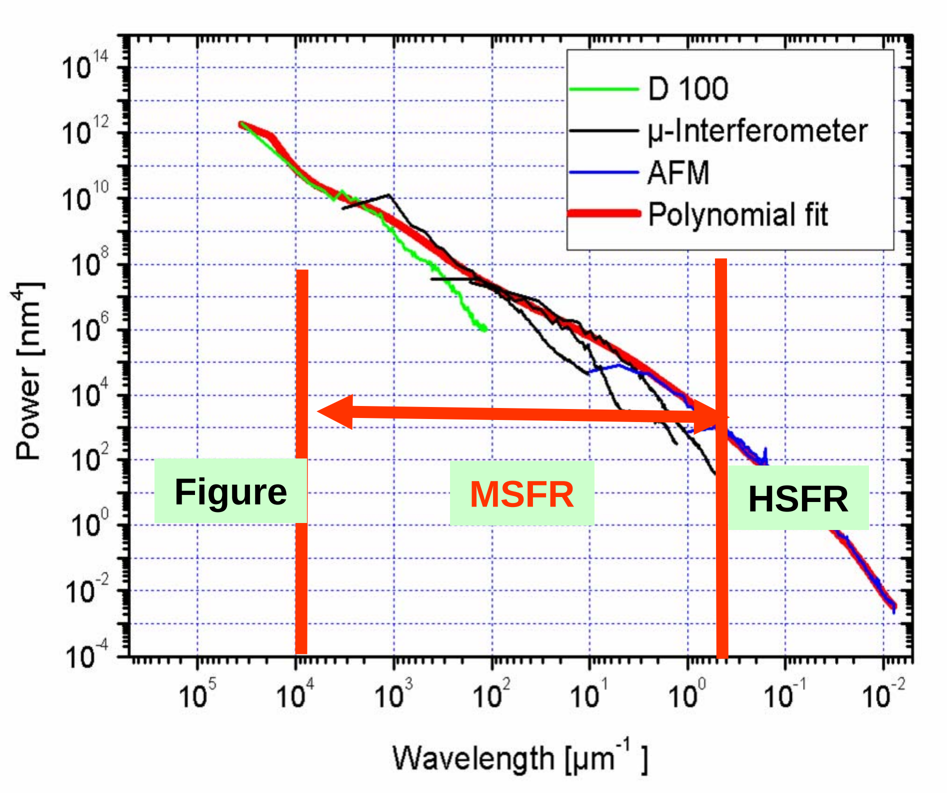
- Due to the small wavelength EUV is extremely sensitive to flare

$$Flare \propto n_{mirrors} \cdot (\mathrm{MSFR}/\lambda)^2$$

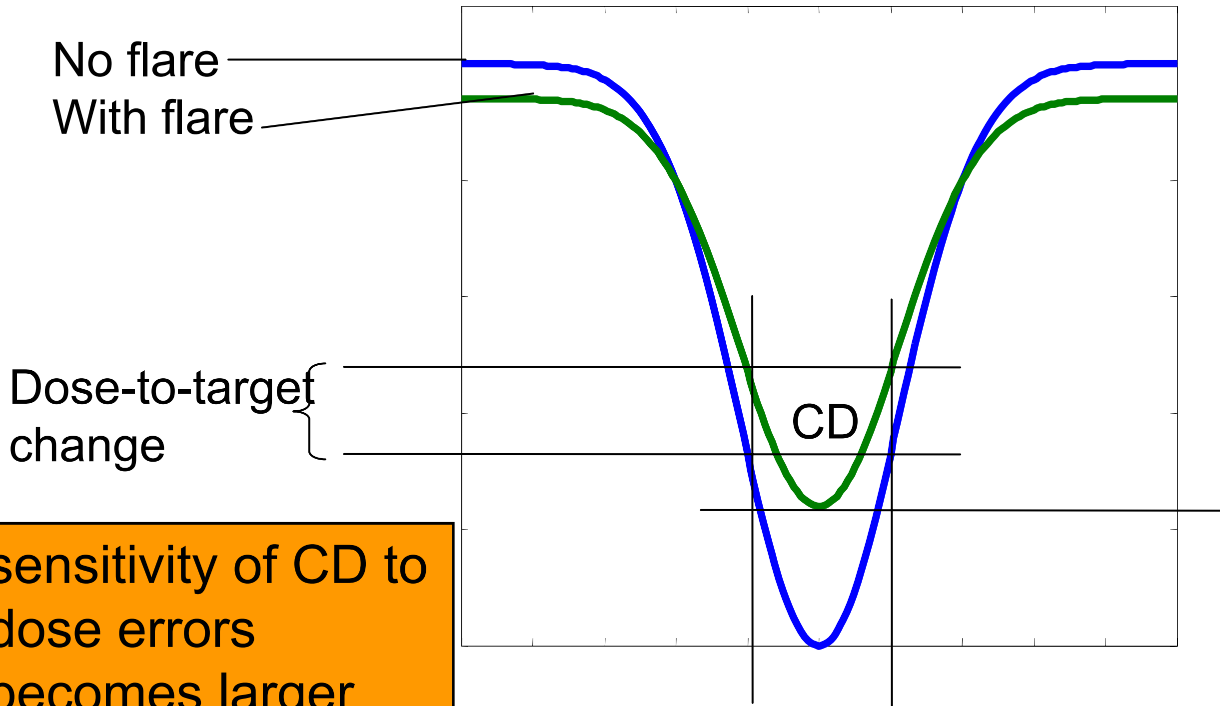


Power spectral density (example)

Definition: All wavelengths of the Power Spectral Density which generate in-field scattering contribute to the MSFR

Main challenge: flare reduction

Intensity cross-section



largest impact of flare on isolated features on bright-field masks

sensitivity of CD to dose errors becomes larger

proximity effects in dependence of the local reticle transmission

flare reduces overlap of process windows due to dose offsets

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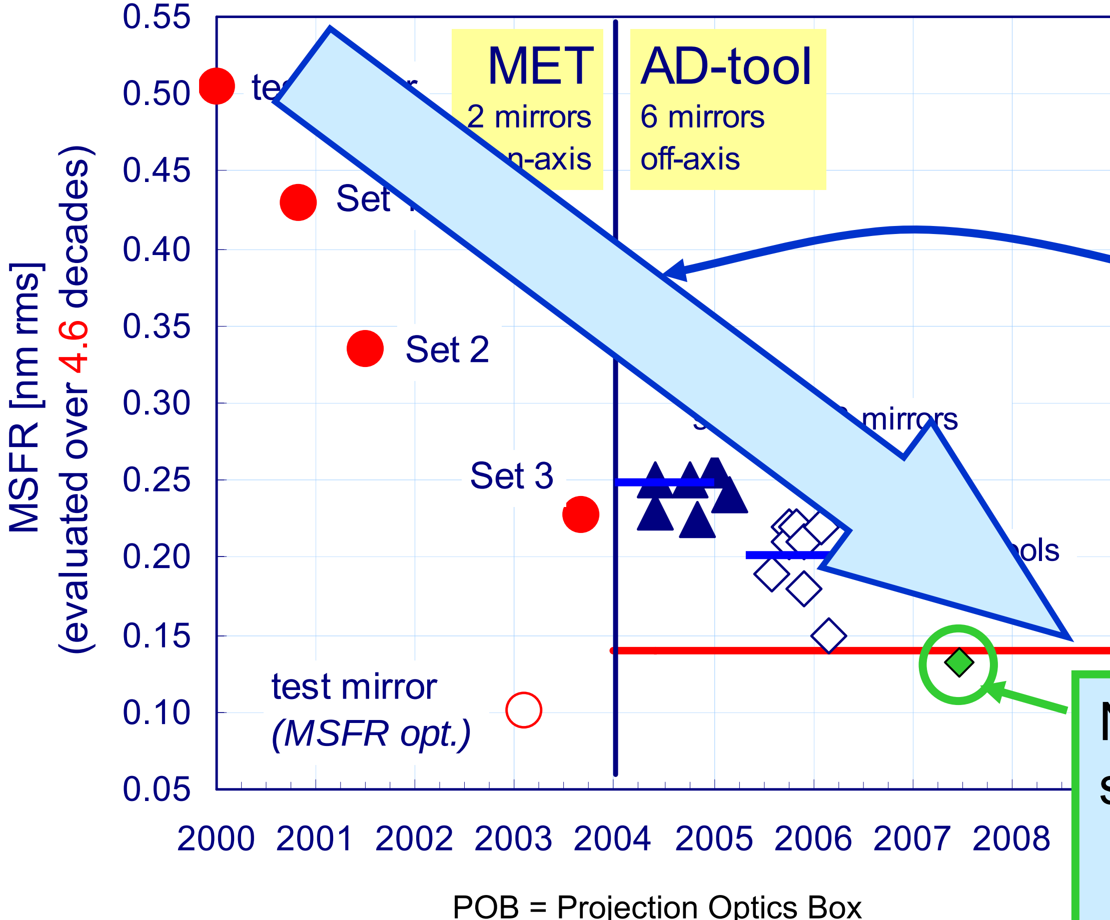
Progress in flare reduction

Flare is calculated for a 2 µm line in a bright field

$$Flare \propto n_{mirrors} \cdot (\mathrm{MSFR}/\lambda)^2$$



Development focuses on material, polishing, and figuring

8% flare

New result on EUV mirror supports flare level < 8%

Figure = 0.04 nm rms

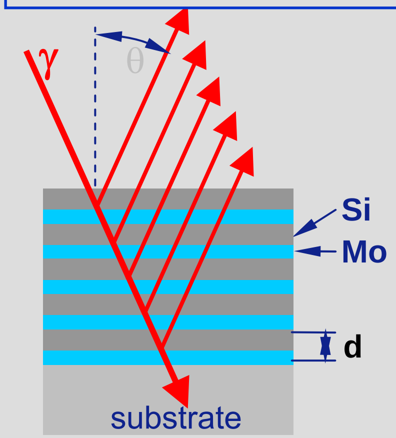
MSFR = 0.13 nm rms

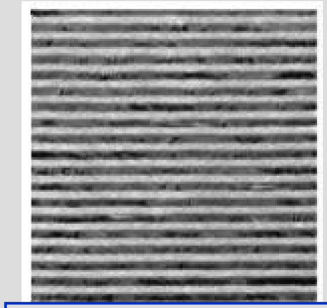
(0.06 nm rms in 3 decades)

HSFR = 0.07 nm rms

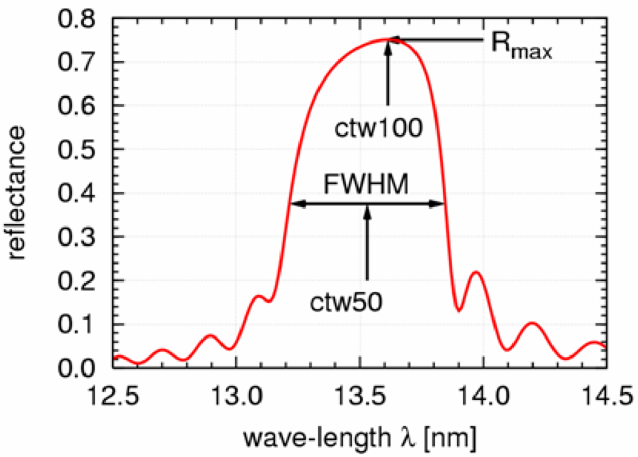
Coating Technology: EUV requires (almost) perfect nanolayers…

EUV coatings:
Mo/Si
Bragg reflectors





> 50 bilayers

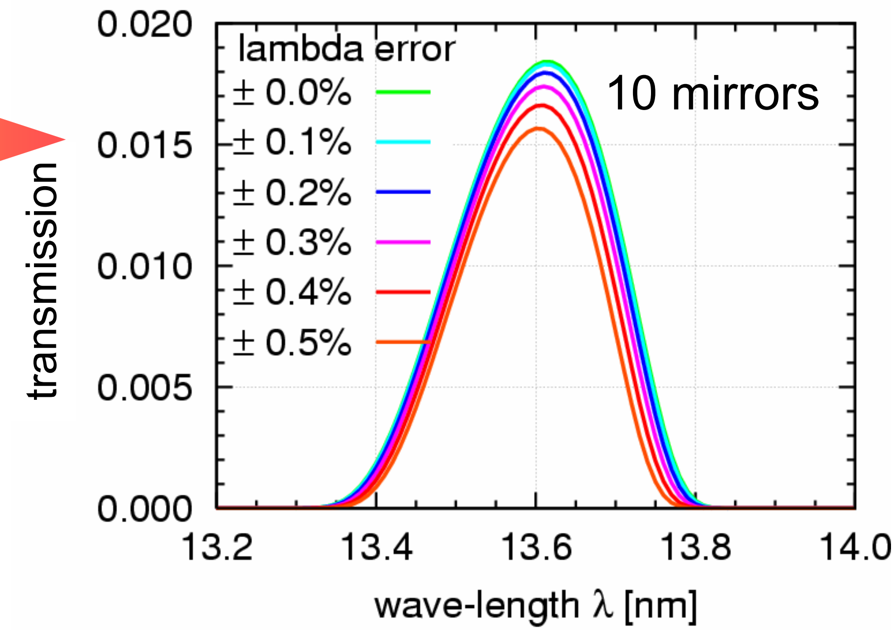


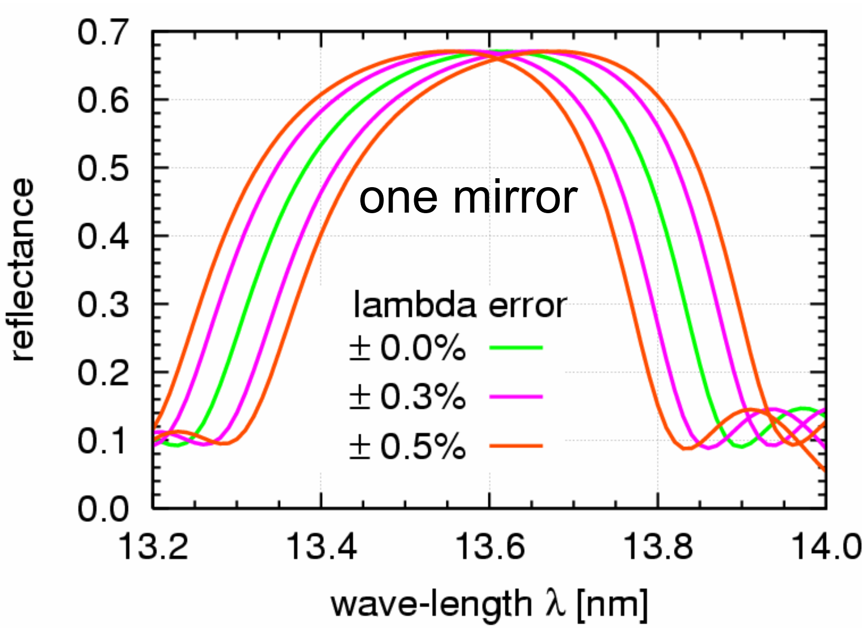
Challenges

high peak reflectance and large FWHM	wave-length matching
> 70% shown	< 0.2% shown

Wave-length matching: transmission of a 10-mirror system

Impact on a generic 10-mirror system





matching	Transmission (integral)
± 0.0%	1.00
± 0.1%	0.99
± 0.2%	0.95
± 0.3%	0.90
± 0.4%	0.83
± 0.5%	0.75

EUV Optics: The future

EUV is introduced as a high k1 technology

Node ¥ NA	0.25	0.35	0.5
32 nm	0.59		1.19
22 nm	0.41	0.57	
16 nm	0.30	0.41	0.59
11 nm	0.20	0.29	0.41

k1 reduction

constant k1

opportunity

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

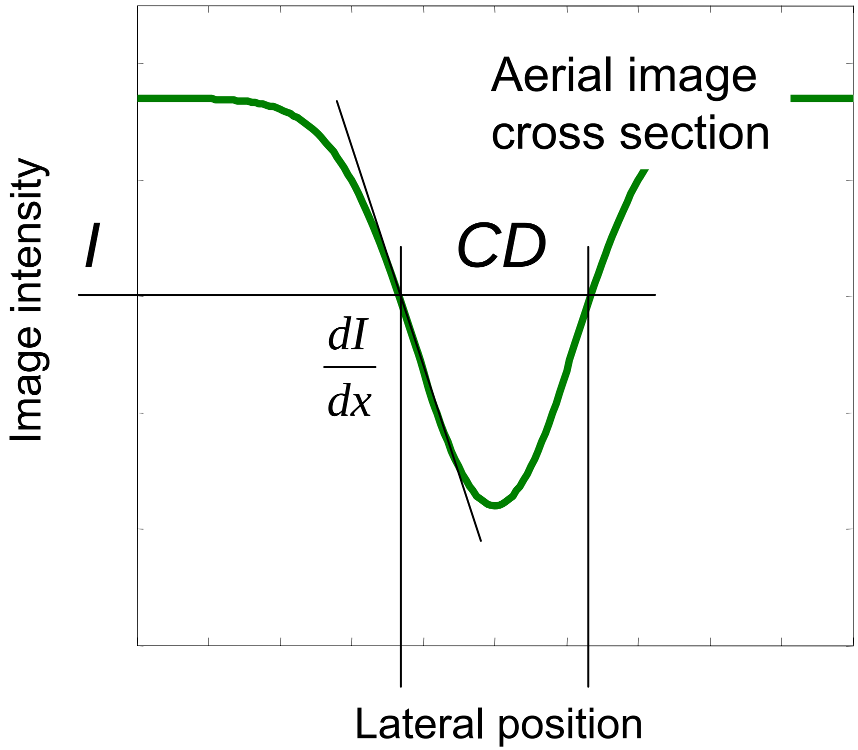
The next step:

0.25 NA projection optics with sigma > 0.7 illumination systems (with oblique illumination) enables:

- 32 nm half pitch production
- 22 nm half pitch R+D

Image log-slope is key parameter

How much contrast (image slope) do we have?



$$NILS = \frac{1}{I}\frac{dI}{dx}CD$$

$$\frac{\Delta E}{E} = \frac{NILS}{2}\frac{\Delta CD}{CD}$$

NILS is proportional to exposure latitude

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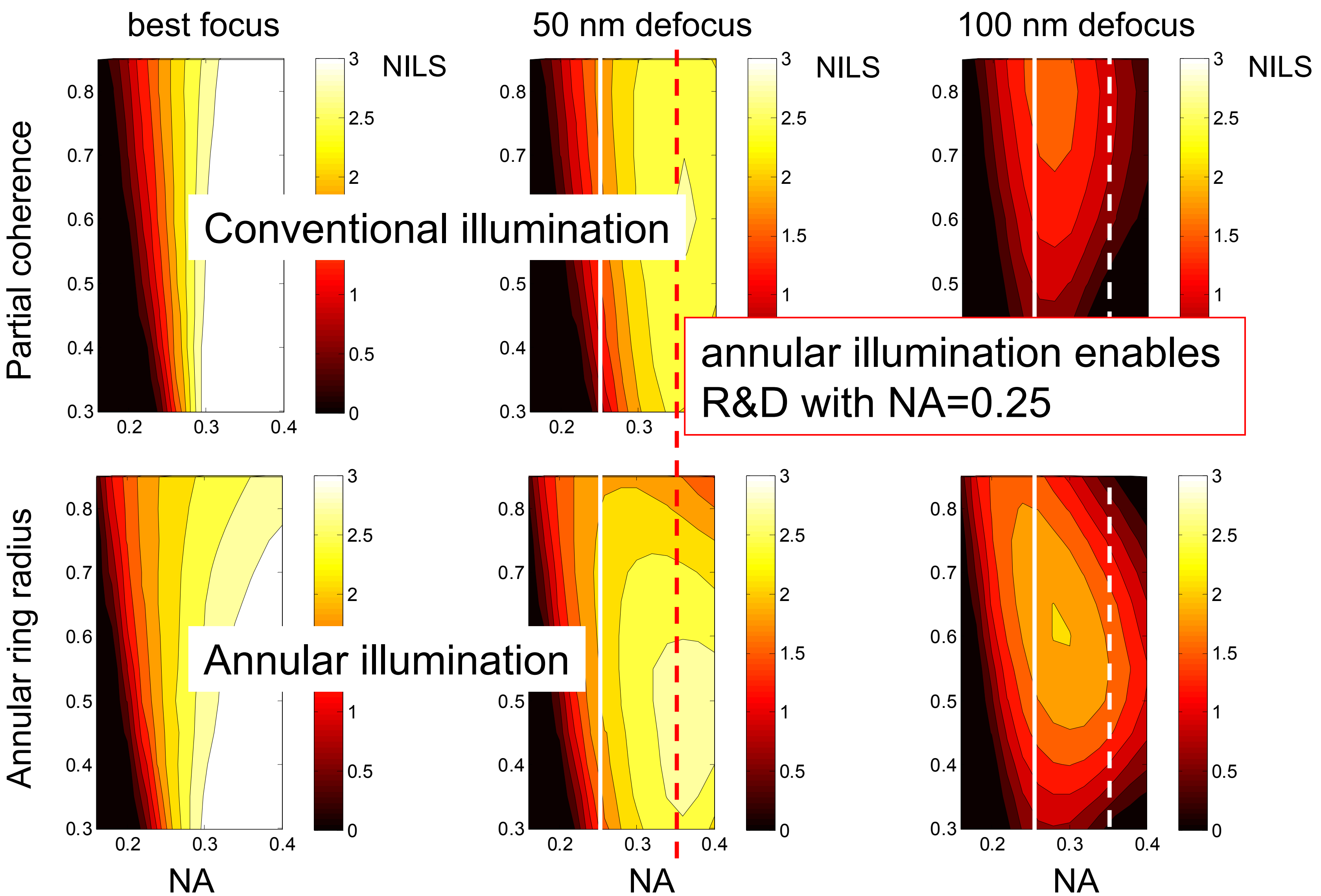
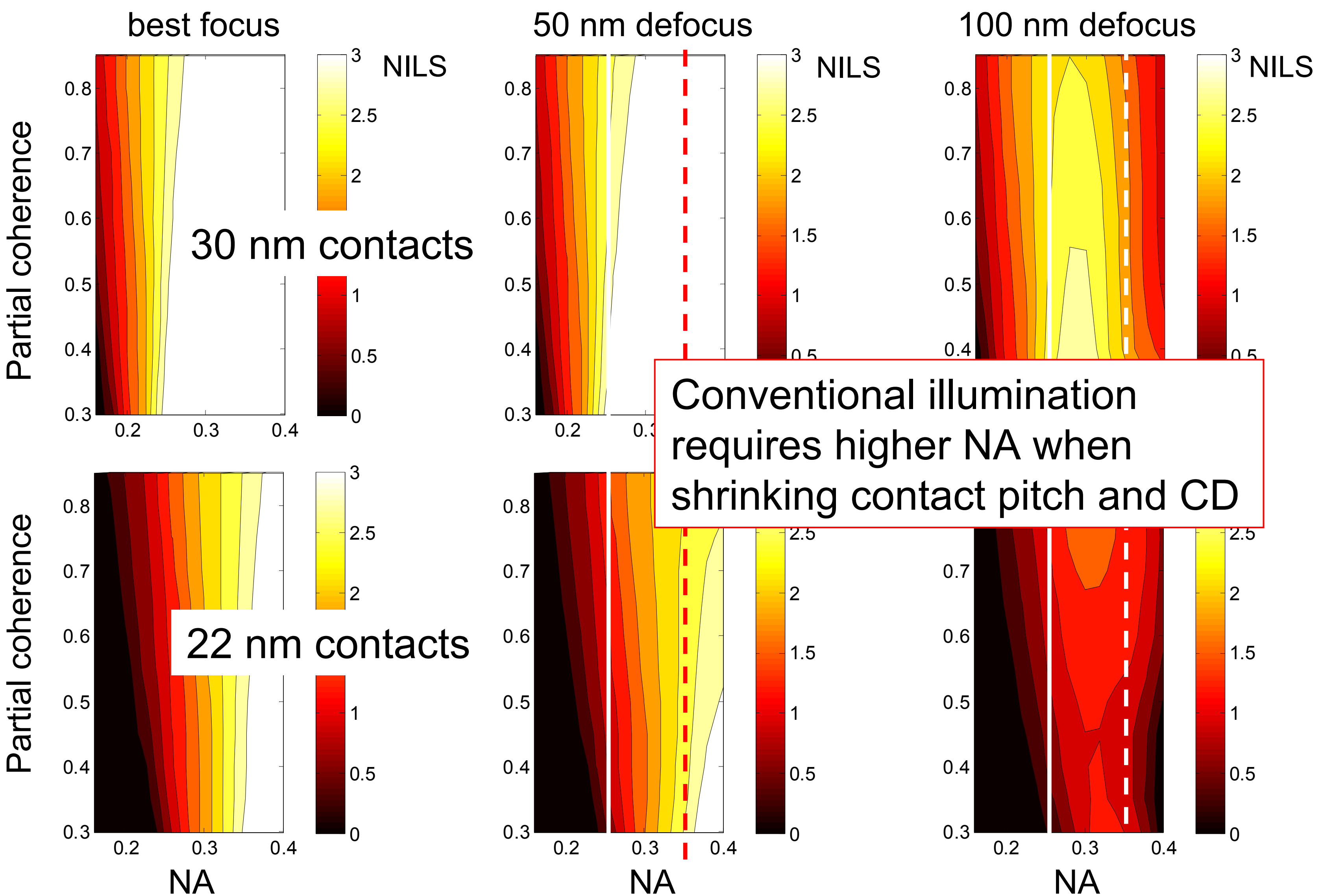
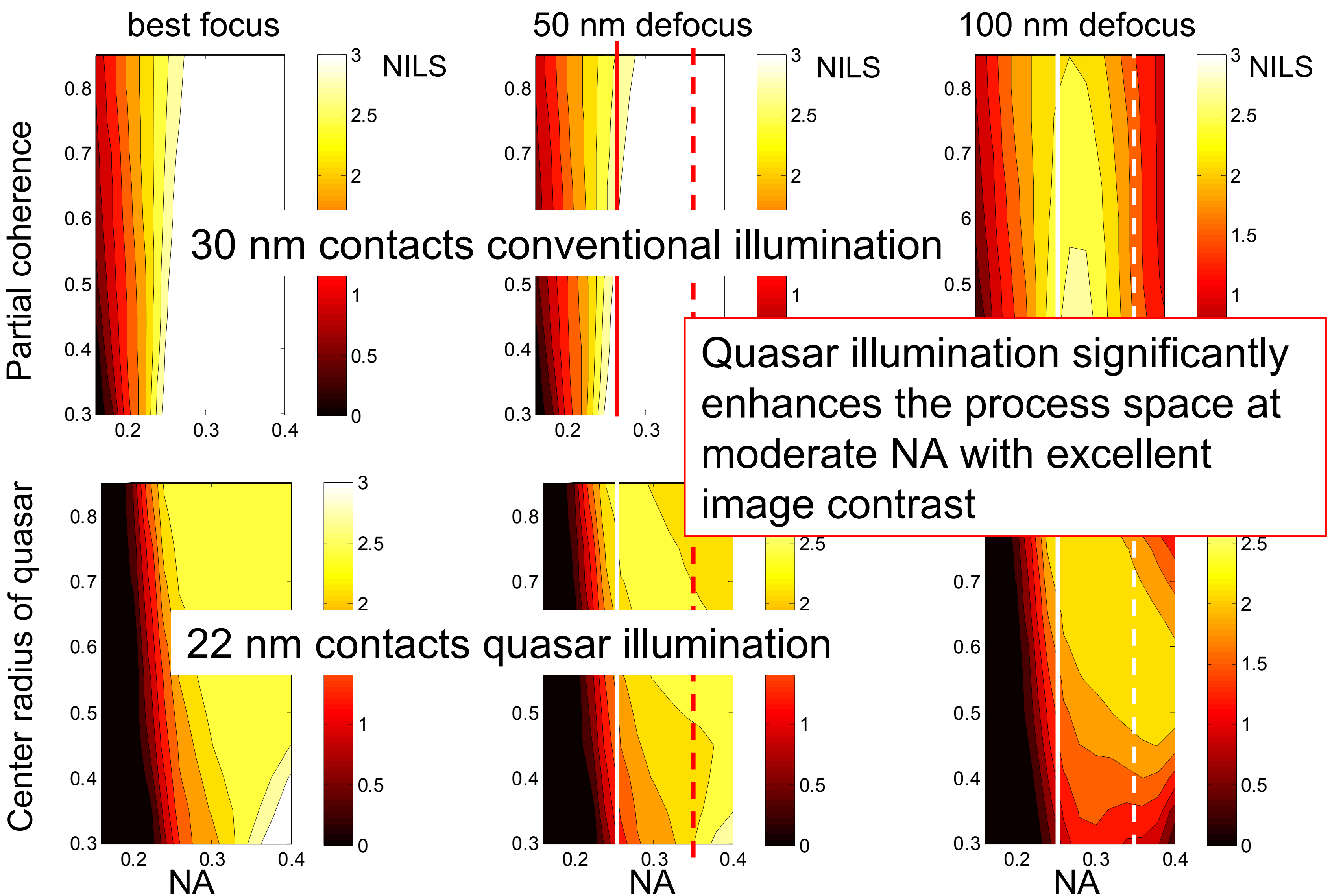
Dense lines 22 nm with conventional and annular illumination



30 nm and 22 nm dense contacts – conventional illumination

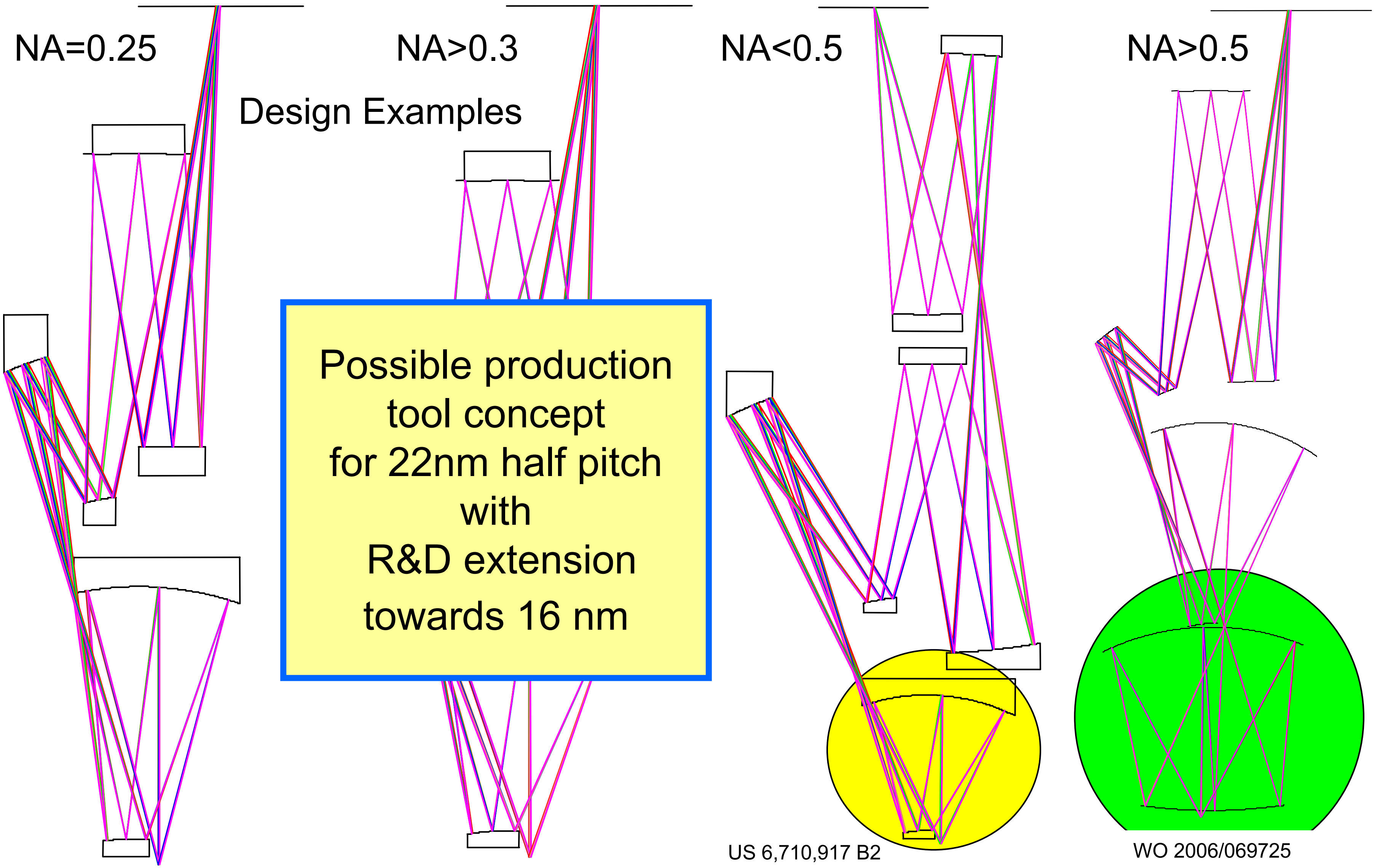


dense contacts with conventional and quasar illumination



Quasar illumination significantly enhances the process space at moderate NA with excellent image contrast

And another step: Extendibility of EUV – design concepts



Summary

- key technologies are progressing towards production tool requirements
  - mirror figure
  - flare
  - coating technology (reflectivity, wavelength matching)

- Improved NA = 0.25 systems will address
  → 32 nm half pitch (production)
  → 22 nm half pitch (R+D)

- optical designs with NA > 0.3 support 22 nm half pitch production

- with designs for even higher NA´s (≥ 0.5) resolutions down to 16 nm and beyond arise at the horizon

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