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Lithography Optics Division

Optics for EUV Lithography

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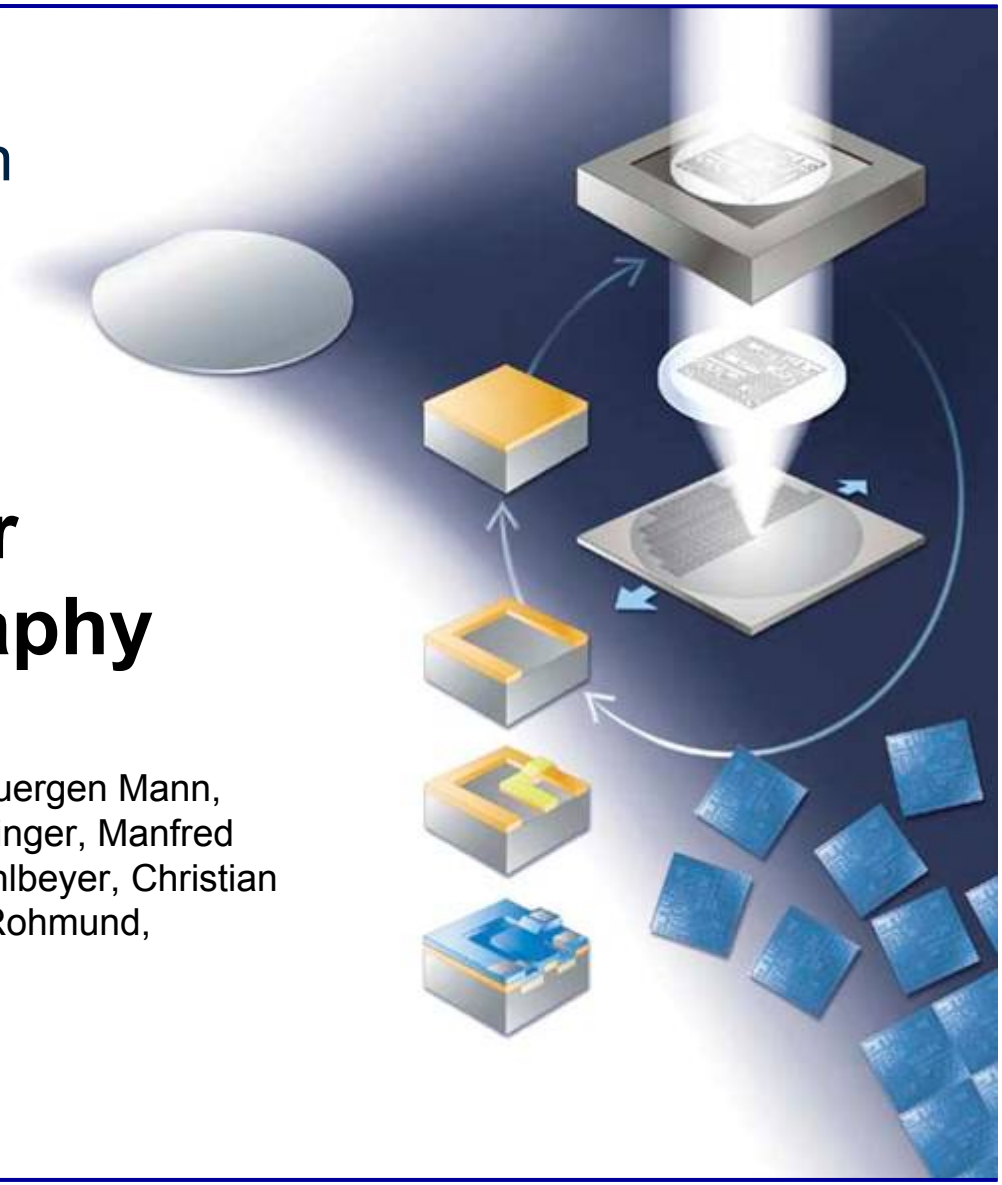

Overview: from the alpha demo tool to high volume production … and into the next decade

- **The present: The EUV Alpha Demo Tool**
  - **The optical train: Illuminator and Projection Optics Box**
  - **Key technologies:**
    - **Optics fabrication**
    - **Coating technology**
    - **Contamination control**

- **The next step: Extendibility of 0.25 NA tools**

- **The next decade: EUV Tools with very high NA (NA>0.3 → NA ≥ 0.5)**

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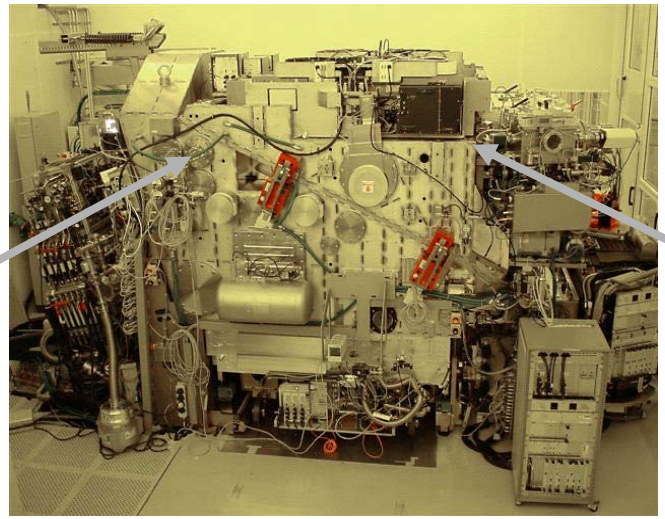
The present:
The EUV Alpha Demo Tool has printed 35 nm lines…

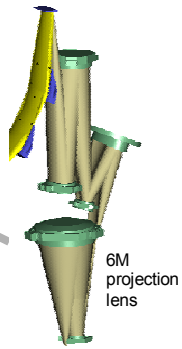
key specifications

NA	0.25
Resolution	< 40 nm
field	26x33 mm^2
Magnification	4x

Illuminator

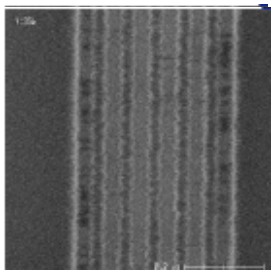


ASML Alpha Demo Tool with ZEISS Optics

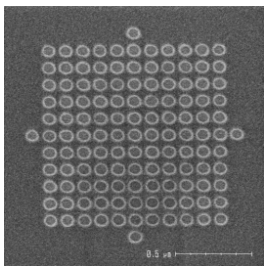


design example

Projection Optics Box



35 nm lines & spaces



55 nm contacts

Imaging Results

The Zeiss optical train for ASML's Alpha Demo Tool is:

- the first full field (26 x 33 mm^2) lithography optics capable of sub 40 nm imaging
- the first prototype for EUV production tools

H. Meiling et al: this conference
R. Groeneveld: this conference

Enabling the Nano-Age World®

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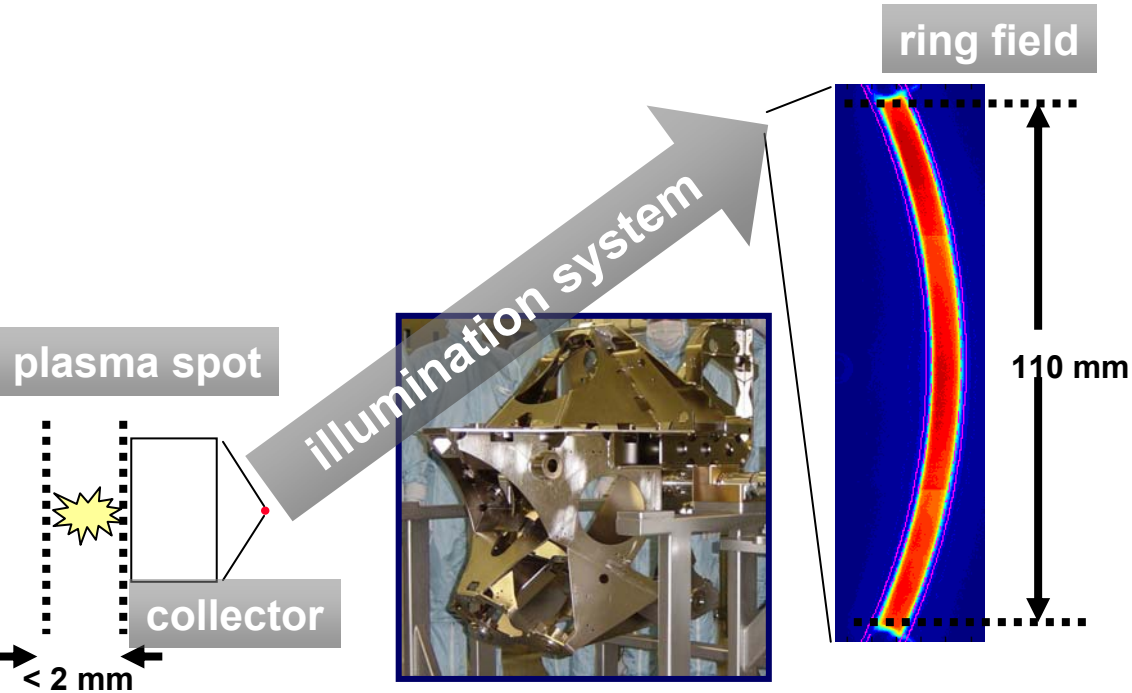
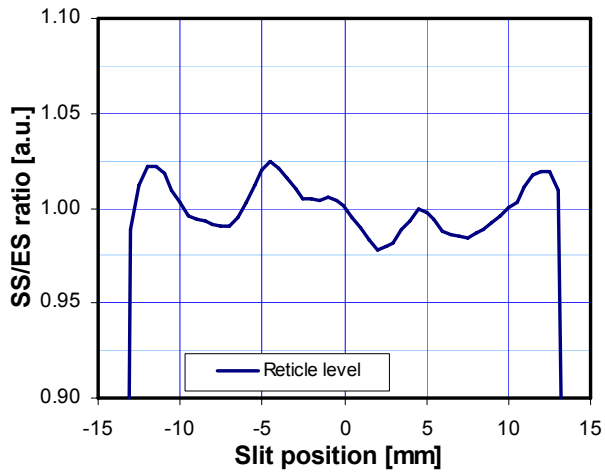
The Illuminator together with the collector transforms an inhomogeneous small plasma spot into a large homogeneous ring field …



Complex mirror groups and mirrors with large dimensions enable the desired beam shaping performance
Example: the world's largest EUV mirror (~ 0.5 m)

Alpha Demo Tool Results

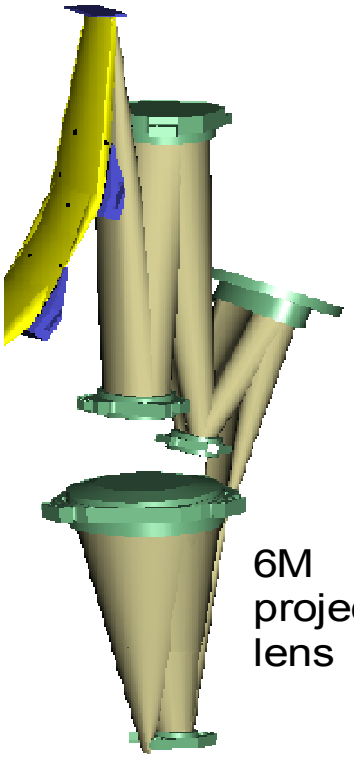


Uniformity(uncorrected) < 2.5 %

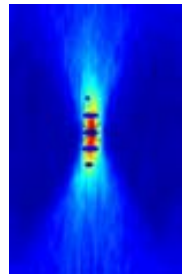
Telecentricity < 0.3 mrad

Ellipticity < 12% (measured with Xe source – for Sn better value expected)

… and the Projection Optics ensures (almost) perfect imaging of the reticle structures into the wafer plane



design example



Ring field of the optics in the wafer plane and „aerial image“ (50 nm through focus) measured with an EUV source

Alpha Demo Tool: new result

RMS (Z5-Z36) < 1.1 nm

→ Sub 40 nm imaging is possible

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

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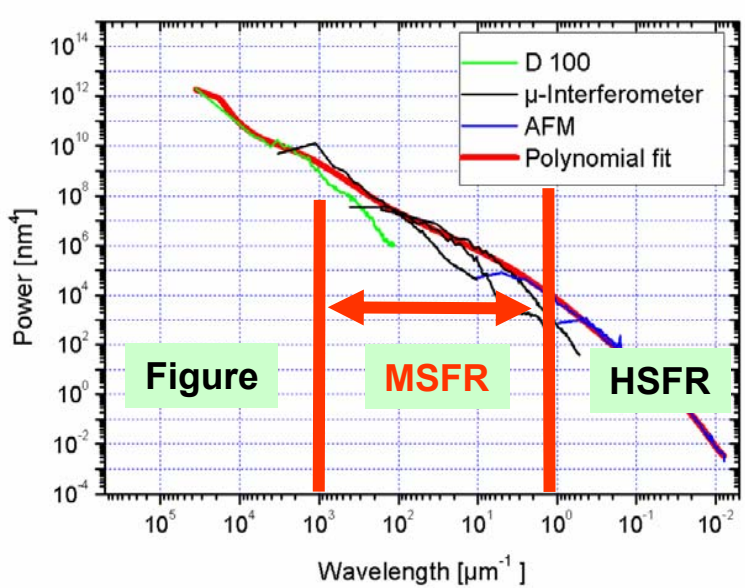
- Due to the small wavelength EUV is extremely sensitive to flare

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

- **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)



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

Power spectral density (example)

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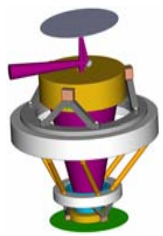
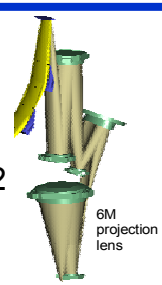
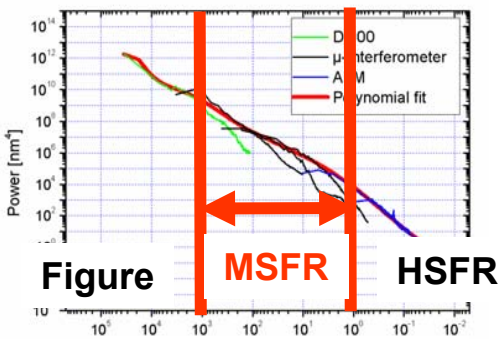


2 mirrors
Field: 200 x 600 µm²

6 mirrors
Field: 26 x 33 mm²

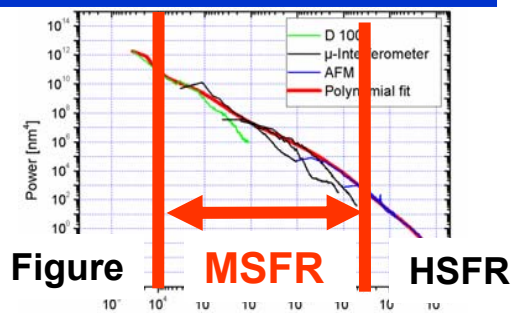


design example



3 decades

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



4.6 decades

Optics Fabrication:
The MSFR is progressing towards production tool requirements

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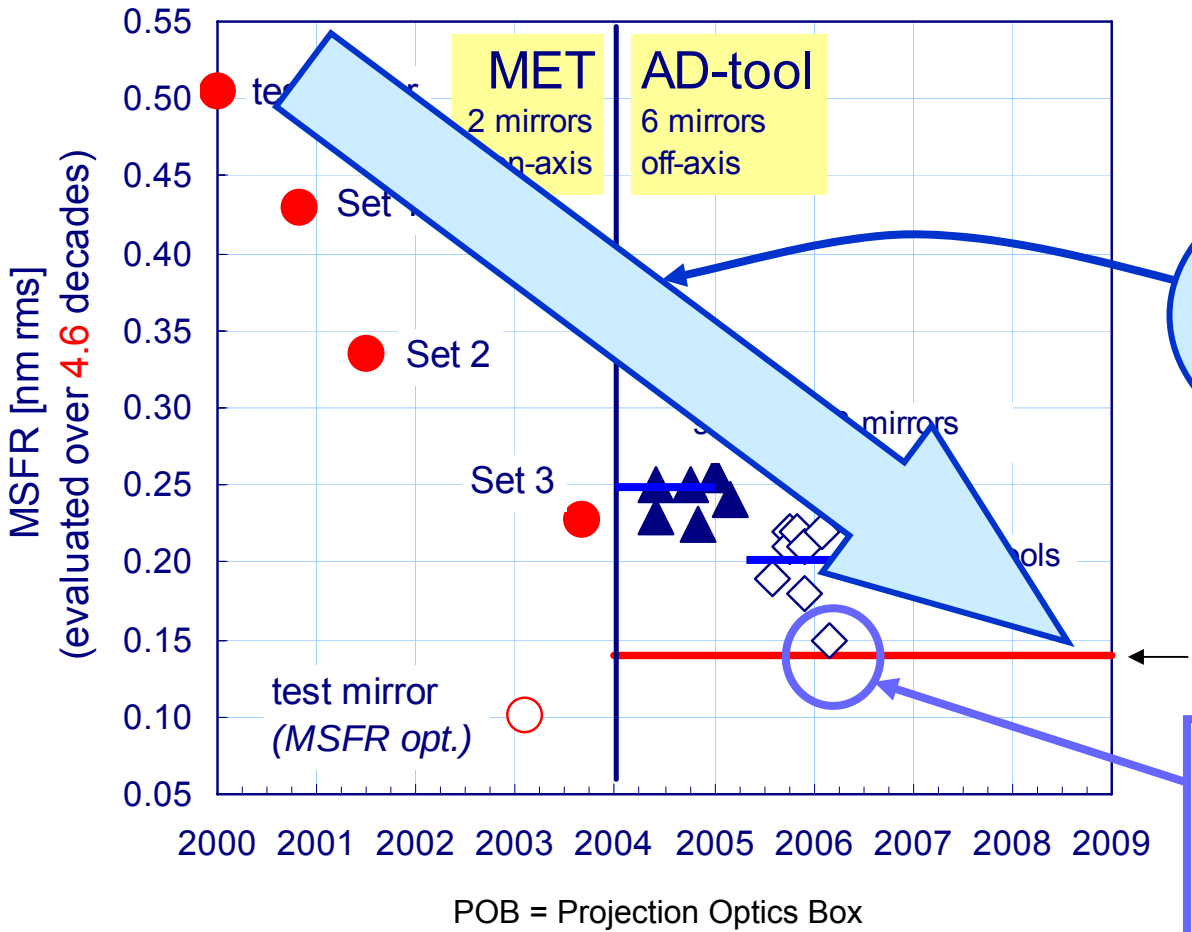
Flare is calculated for a 2 µm line in a bright field



Development focuses on material, polishing, and figuring

- Figure = 0.05 nm rms
- MSFR = 0.15 nm rms
- HSFR = 0.09 nm rms

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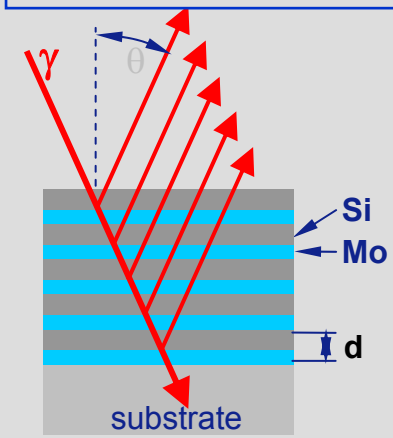
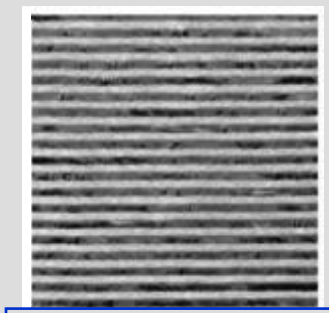
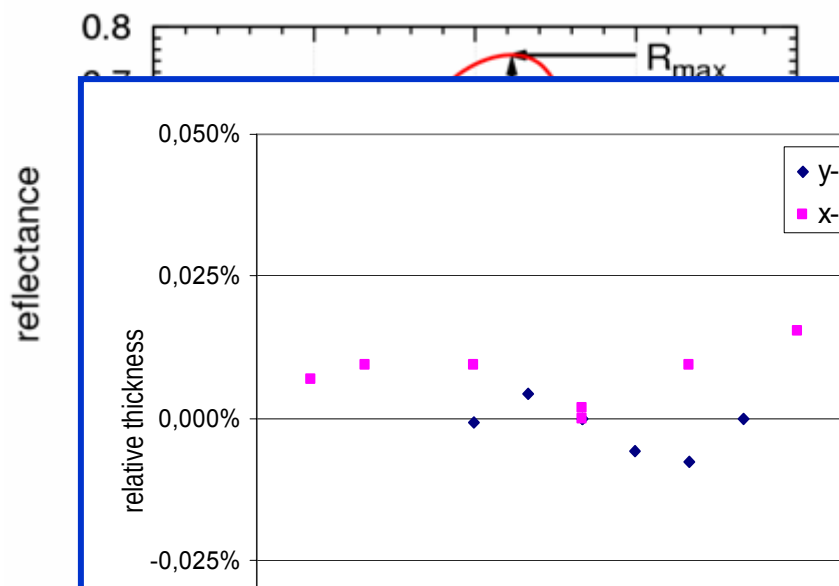
Coating Technology: EUV requires (almost) perfect nanolayers

EUV coatings:
Mo/Si
Bragg reflectors





> 50 bilayers



Very low deviation from average layer thickness over large curved diameter:
<±0.015% ≅ ±0.001 Nanometer/Bilayer

Challenges

- reflectance … nce
- absolute th… (wave-lengt…
- lateral unifo…
- film stress … a
- thermal stability … several 100 °C

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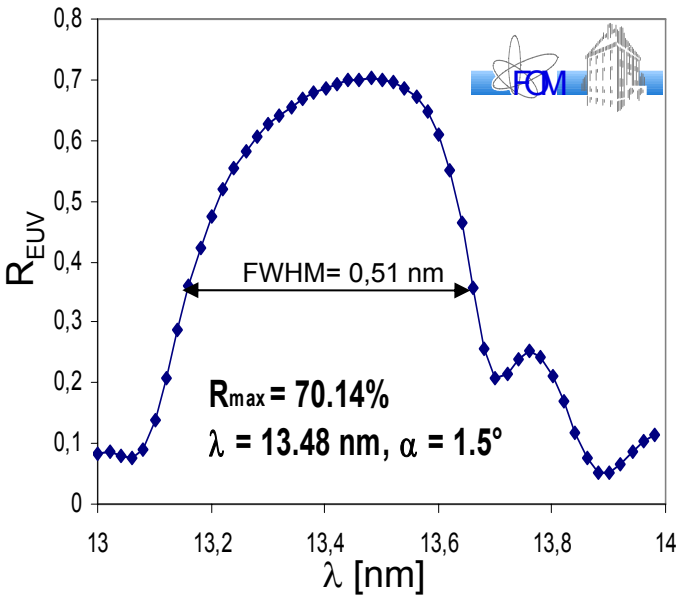
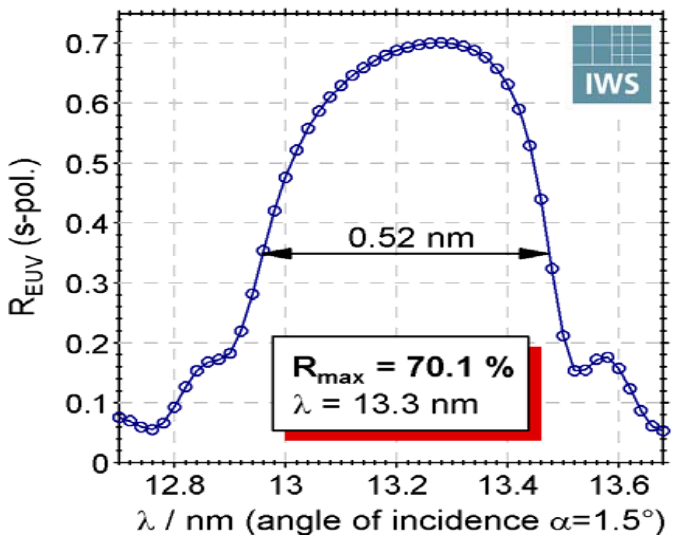
Coating technology: higher reflectivities enable increased throughput

- An infrastructure for the coating of large off-axis mirrors has been set up: Several sets of Alpha Demo Tool Optics have been successfully coated
- Path towards higher reflectivity: more than 70% reflectivity achieved by Zeiss partners





A. Yakshin et al: this conference

S. Braun et al: this conference

- Next step/next challenge: transfer results to large off-axis mirrors

Contamination mitigation is required to maintain tool productivity

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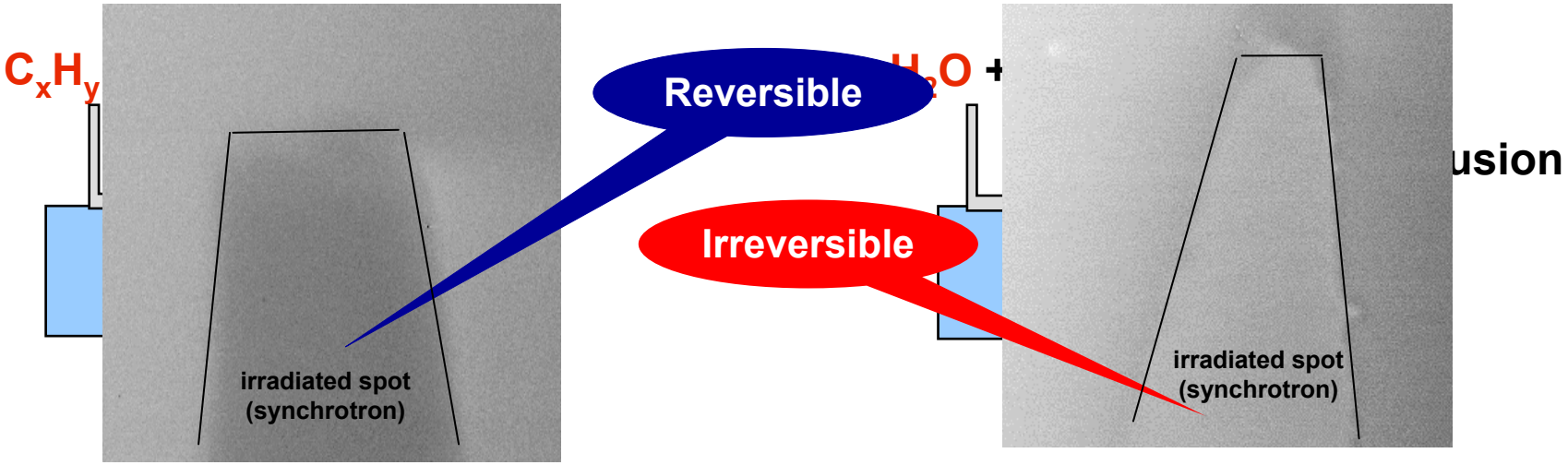
Carbon growth:

1% loss per nm carbon

Oxidation:

3% loss per nm additional oxide



Optics contamination mitigation strategy includes

- clean vacuum environment (materials, gases, equipment…)
- selection of materials applied in vacuum
- oxidation resistant mirror coatings
- carbon cleaning, without mirror degradation

Note: reflectivity loss does impact tool productivity rather than imaging performance

B. Wolschrijn et al: This conference
T. Stein et al: Optics contamination Workshop

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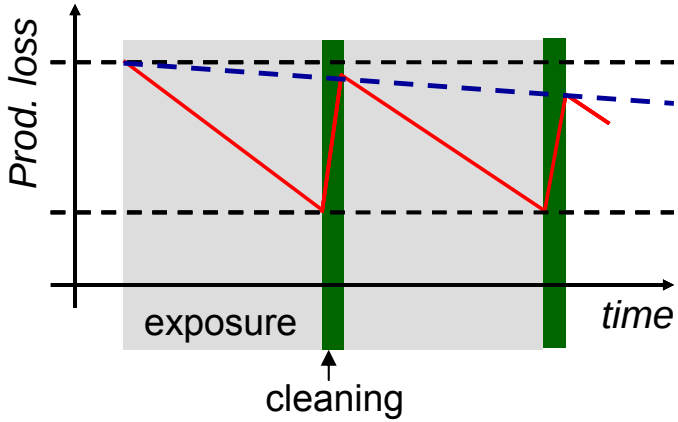
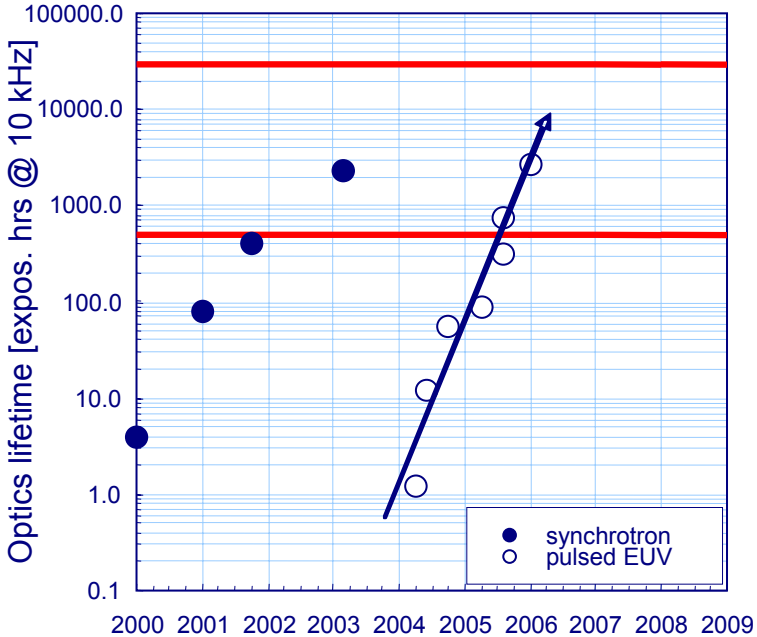
Contamination Control Strategies ensure tool productivity





Illumination > 10.000 hrs

- **Experimental MTBC > 100 hrs**
- **Experimental # cleanings x 10-100**
- **Scaling x 10-100**

Production tool optics usage requirements seem feasible …

eventhough improvements are still required

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EUV Optics: The future

EUV is introduced as a high k1 technology

Node \ NA	0.25	0.35	0.5
32 nm	0.59	0.83	1.19
22 nm	0.41	0.57	0.81
16 nm	0.30	0.41	0.59
11 nm	0.20	0.29	0.41

opportunity

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

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

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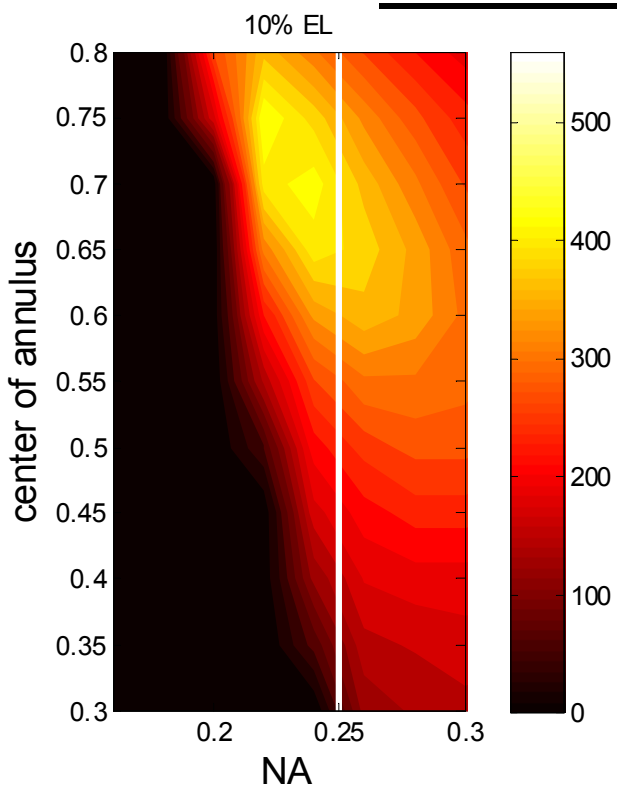
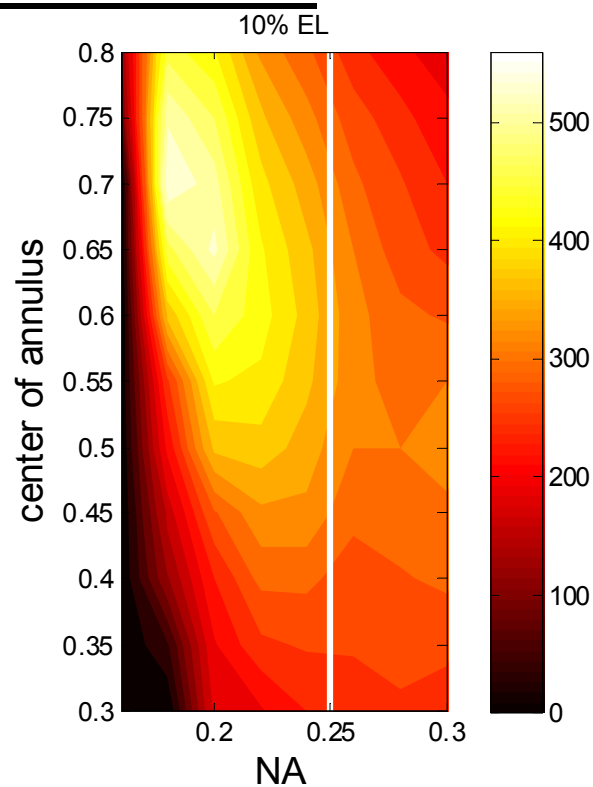
Extendibility of NA = 0.25 tools

Aerial image calculation

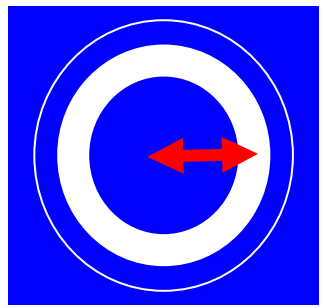


22 nm dense lines



30 nm contacts

- 10% CDU
- 10% flare
- rectangular process window



Constant ring width: 0.25
Center offset: parameter

- **In the aerial image we have a large depth of focus for 22 nm dense lines and for 30 nm dense contacts with NA=0.25 and annular illumination!**
- **To fully use this imaging potential, a high contrast resist is required**

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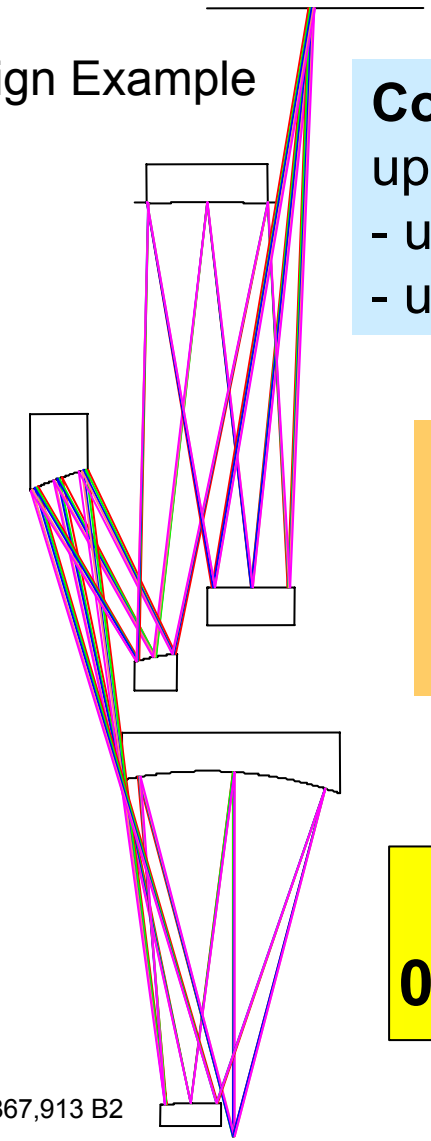
And another step: Extendibility of 0.25 NA design concepts

Design Example



US 6,867,913 B2

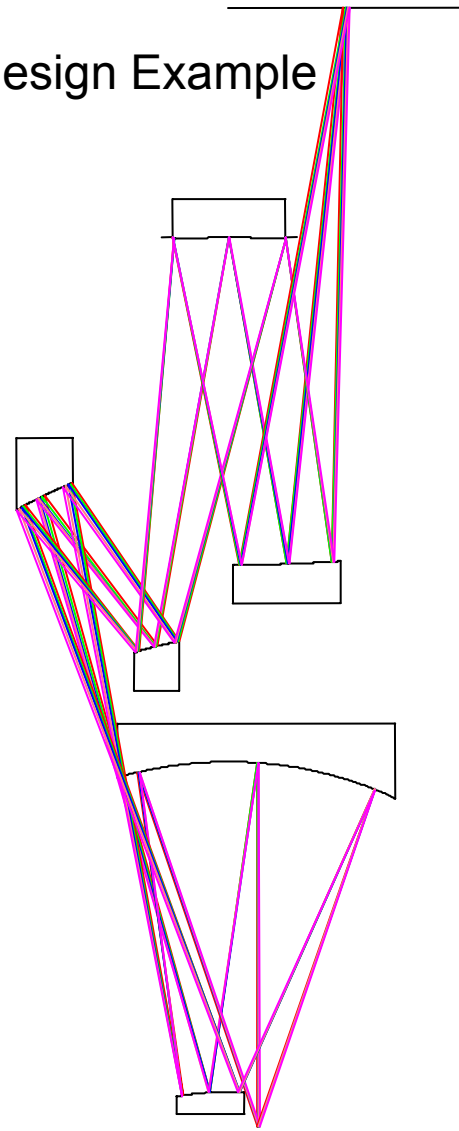
Concepts are extendable…
up to NA > 0.3 including:
- unchanged field size
- unchanged chief ray angle at mask

… a
Lar
- Hi
- Large angles of incidence

Possible production tool concept
for 22nm half pitch with
R&D extension towards 16 nm

NA
0.25……> 0.3

Design Example



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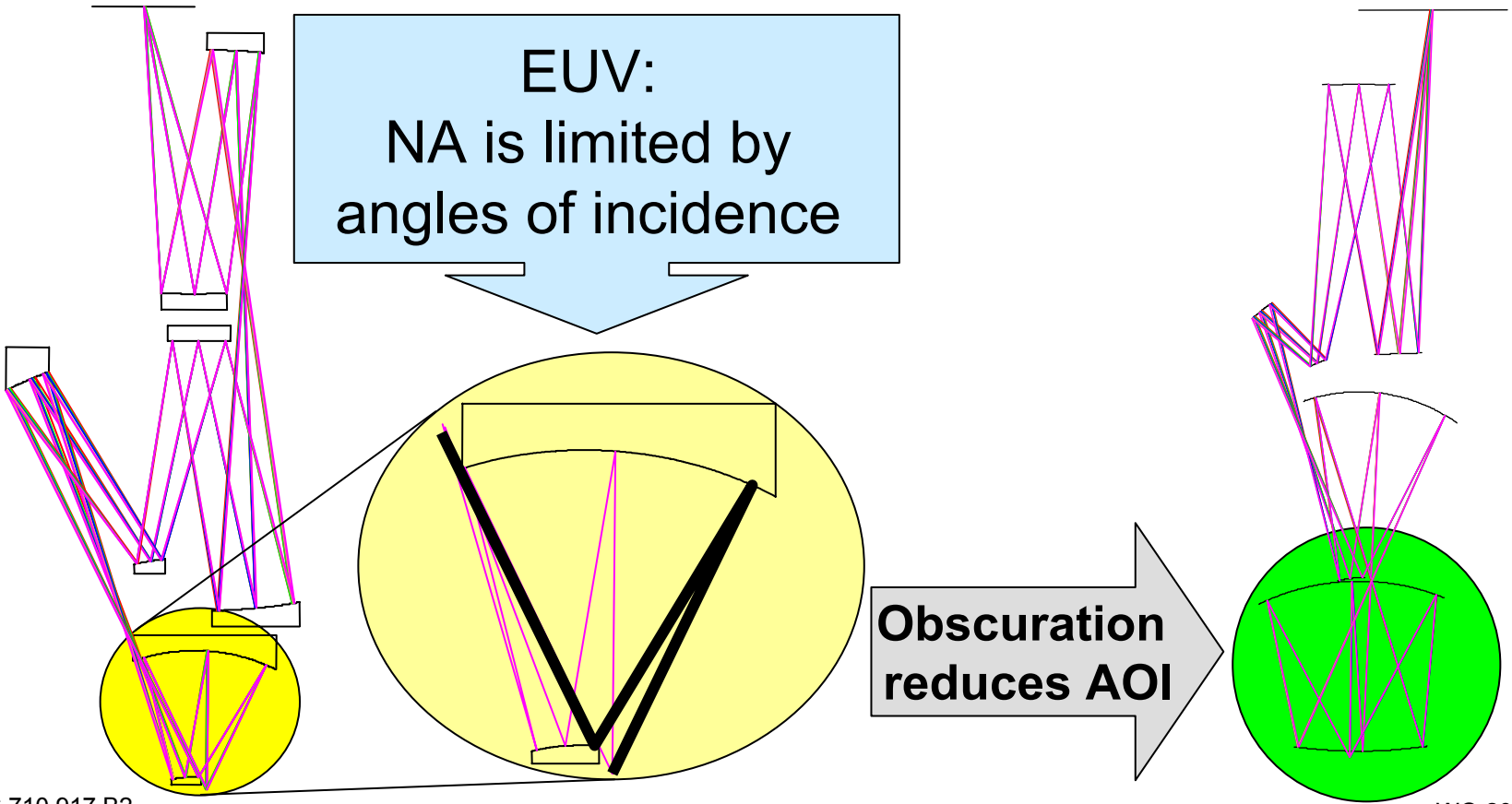
The next decade: Super High NA EUV systems

8M-System (no obscuration)
➔ NA < 0.50

8M-System(obscured)
NA > 0.50



US 6,710,917 B2

WO 2006/069725

Different paths to very high NA systems are possible

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Summary

- **The present**: Optical Trains for the Alpha Demo Tools
  - → we have demonstrated the capability to build optics for full-field systems with sub 40 nm resolution
  - → key technologies (e.g. flare reduction, coating technology, contamination control strategies) are progressing towards production tool requirements

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

- **The next decade:**
  - → optical designs with NA > 0.3 support 22 nm half pitch production
  - → with even higher NAs (≥ 0.5) resolutions down to 16 nm and beyond arise at the horizon

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Acknowledgment

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- Philips
- Heidenhain
- The teams at ASML and Zeiss
- …and many others

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