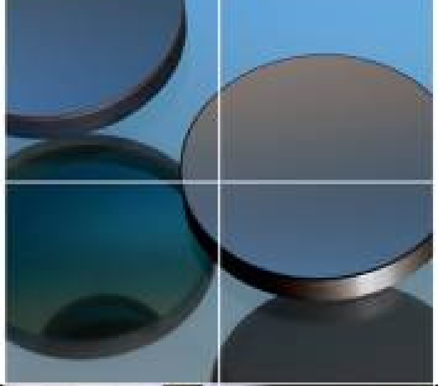
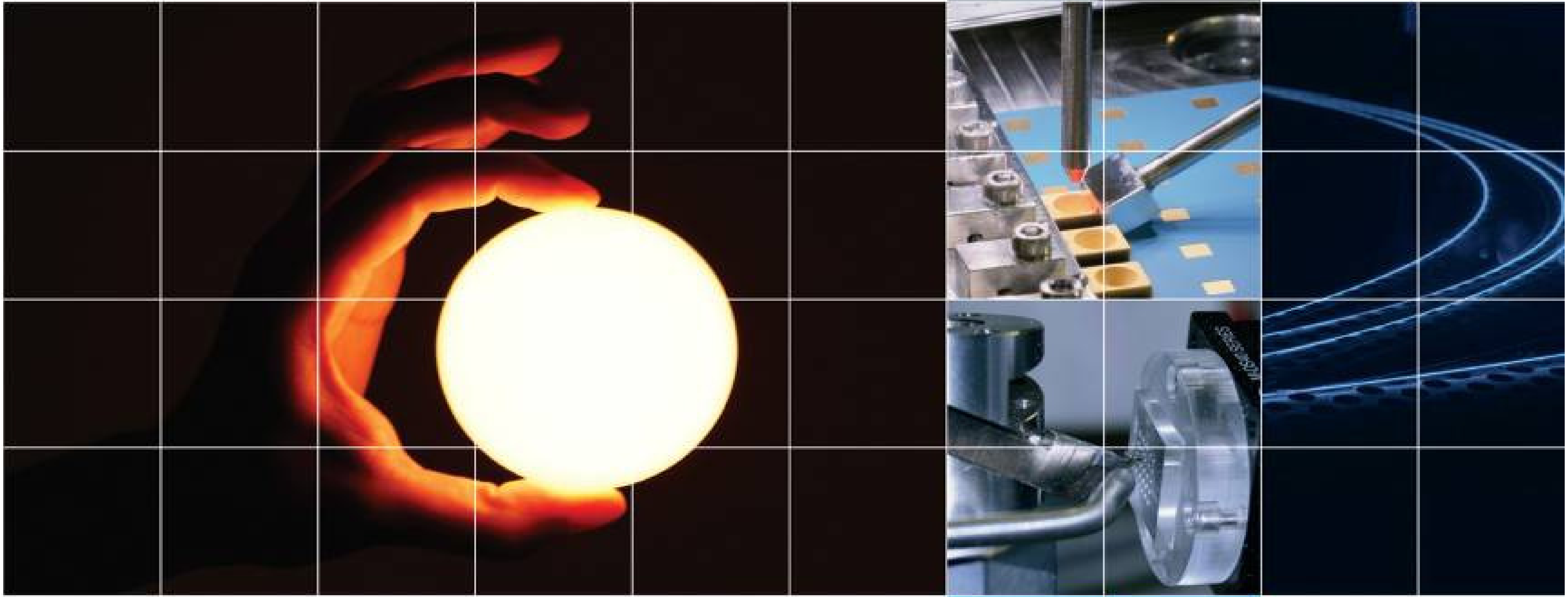
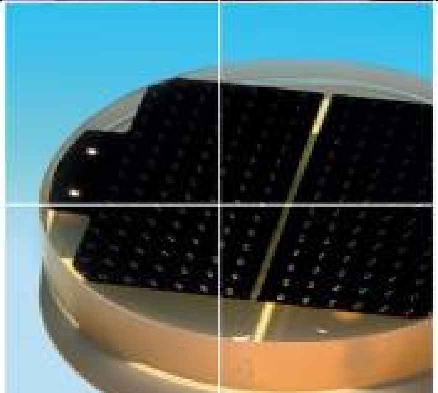
Tailored Light - Licht nach Maß

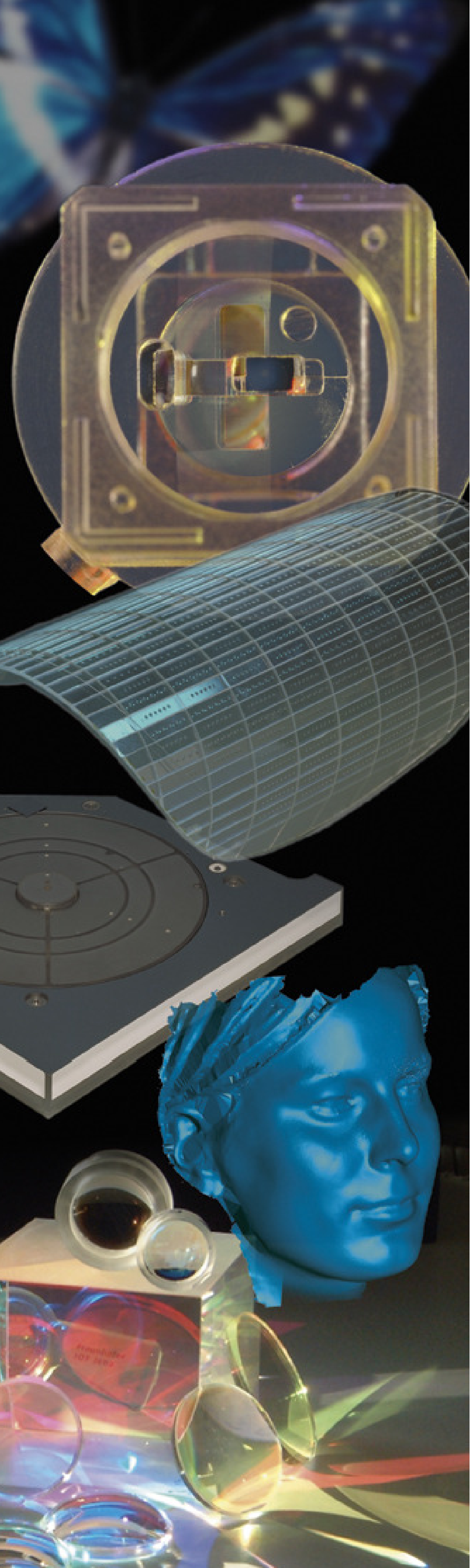
Tailored Light

Fraunhofer IOF









Multilayer optics for EUV and beyond

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Contents

- Introduction
- $\lambda > 13.5$ nm
- $\lambda = 13.5$ nm
- $\lambda < 13.5$ nm
- Summary and Acknowledgement

Contents

- Introduction
- $\lambda > 13.5$ nm
- $\lambda = 13.5$ nm
- $\lambda < 13.5$ nm
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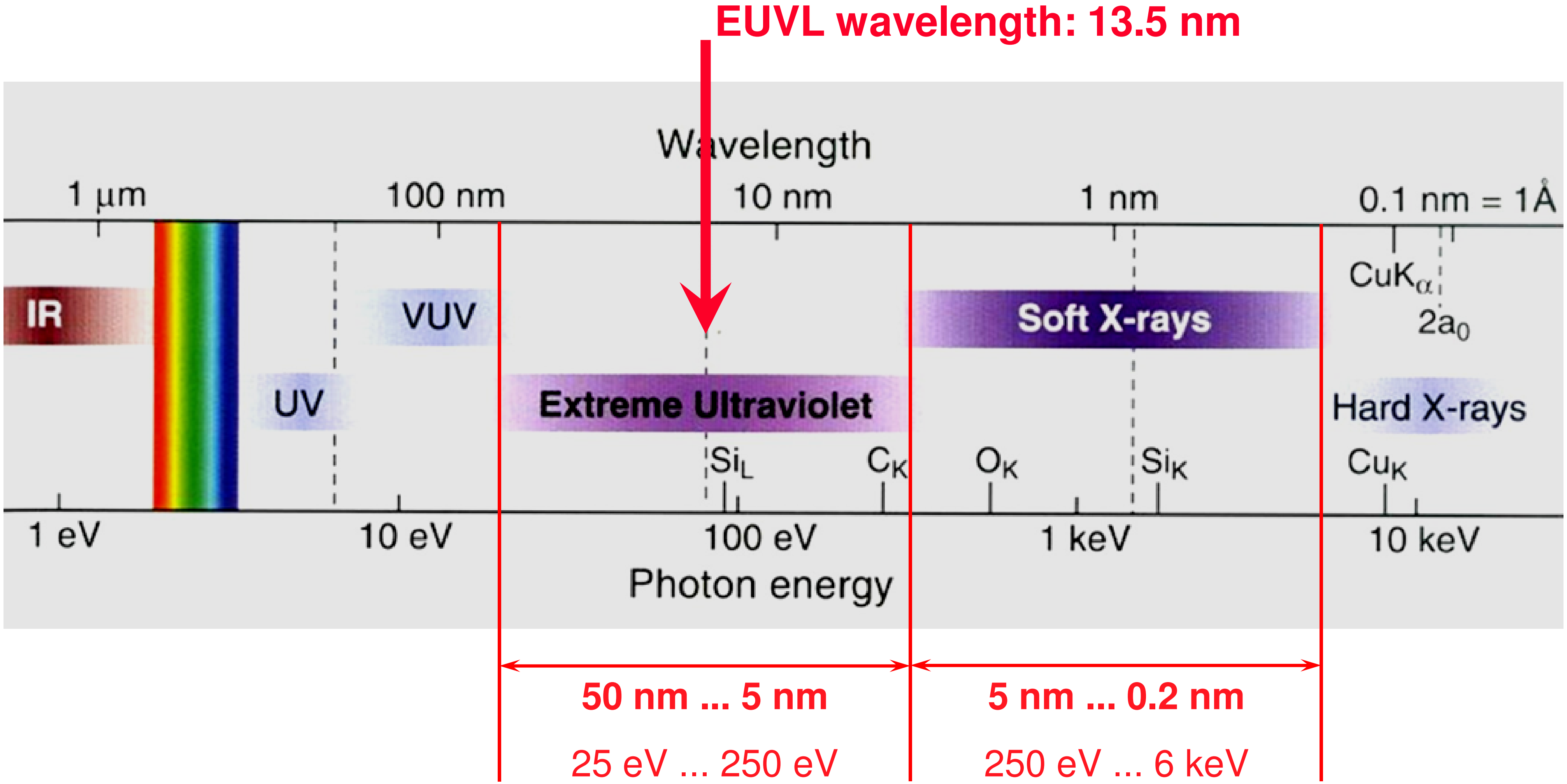
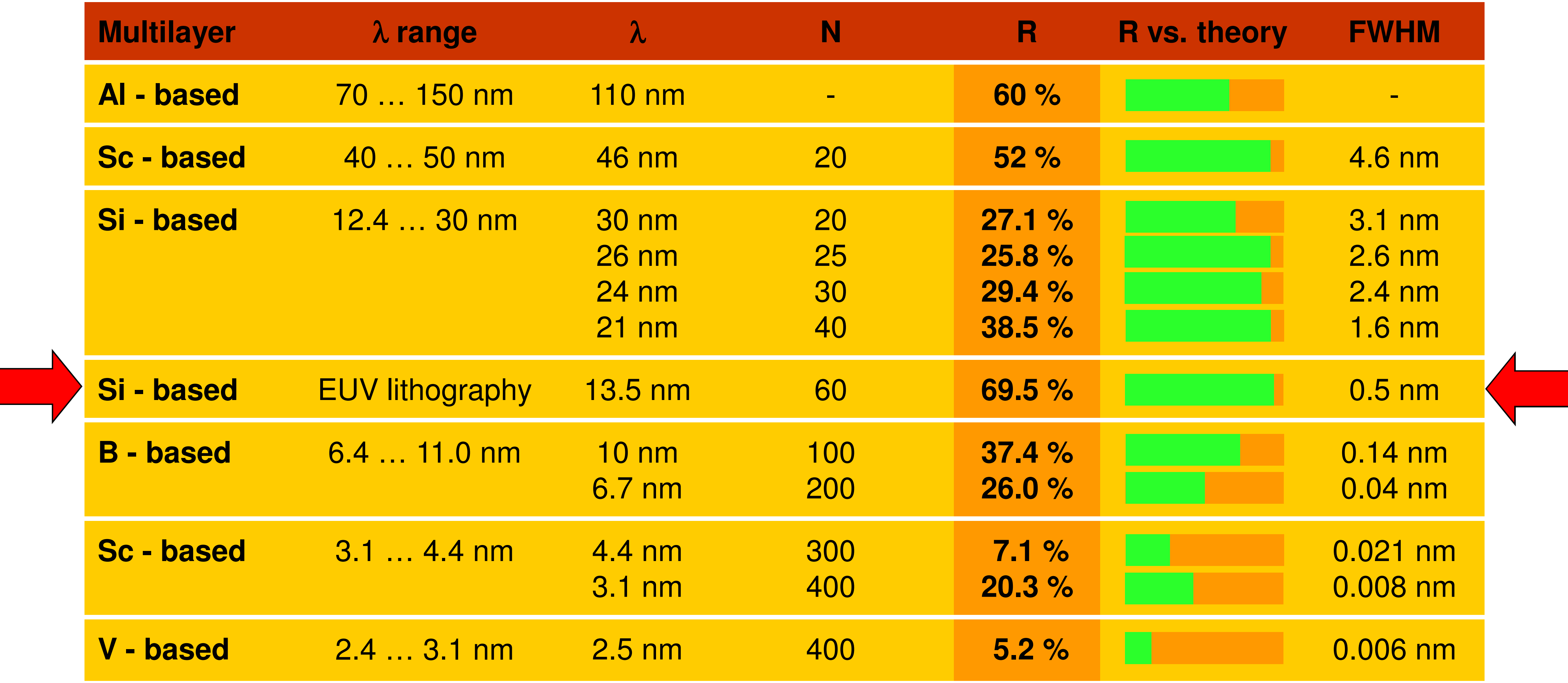
XUV spectral region



Normal incidence EUV and soft X-ray multilayers @ Fraunhofer IOF



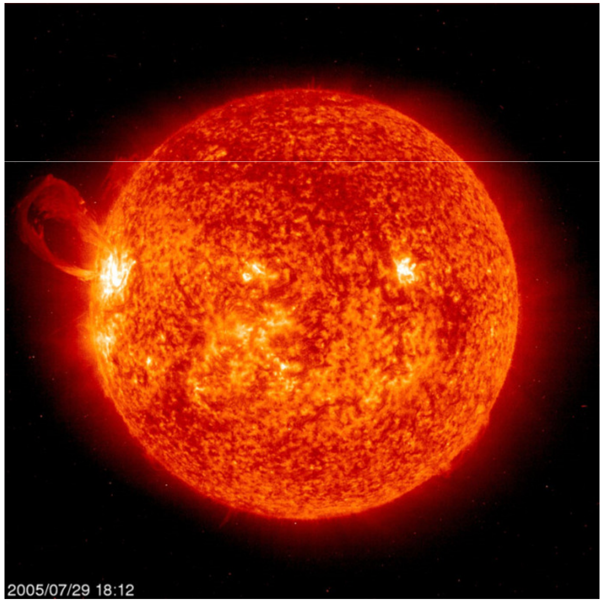
Multilayer	λ range	λ	N	R	R vs. theory	FWHM
Al - based	70 … 150 nm	110 nm	-	**60 %**		-
Sc - based	40 … 50 nm	46 nm	20	**52 %**		4.6 nm
Si - based	12.4 … 30 nm	30 nm	20	**27.1 %**		3.1 nm
		26 nm	25	**25.8 %**		2.6 nm
		24 nm	30	**29.4 %**		2.4 nm
		21 nm	40	**38.5 %**		1.6 nm
Si - based	EUV lithography	13.5 nm	60	**69.5 %**		0.5 nm
B - based	6.4 … 11.0 nm	10 nm	100	**37.4 %**		0.14 nm
		6.7 nm	200	**26.0 %**		0.04 nm
Sc - based	3.1 … 4.4 nm	4.4 nm	300	**7.1 %**		0.021 nm
		3.1 nm	400	**20.3 %**		0.008 nm
V - based	2.4 … 3.1 nm	2.5 nm	400	**5.2 %**		0.006 nm

Contents

- Introduction
- $\lambda > 13.5$ nm
- $\lambda = 13.5$ nm
- $\lambda < 13.5$ nm
- Summary and Acknowledgement

Spectral range from 40 to 120 nm

- mainly for astronomy and astrophysics
  (to detect emission lines of orbs)
- Coating of high reflective multilayer optics
  (Sc/Si based)
- Coating of broad band mirrors
  (Al single layer + flouride)



Source: http://sohowww.nascom.nasa.gov/gallery

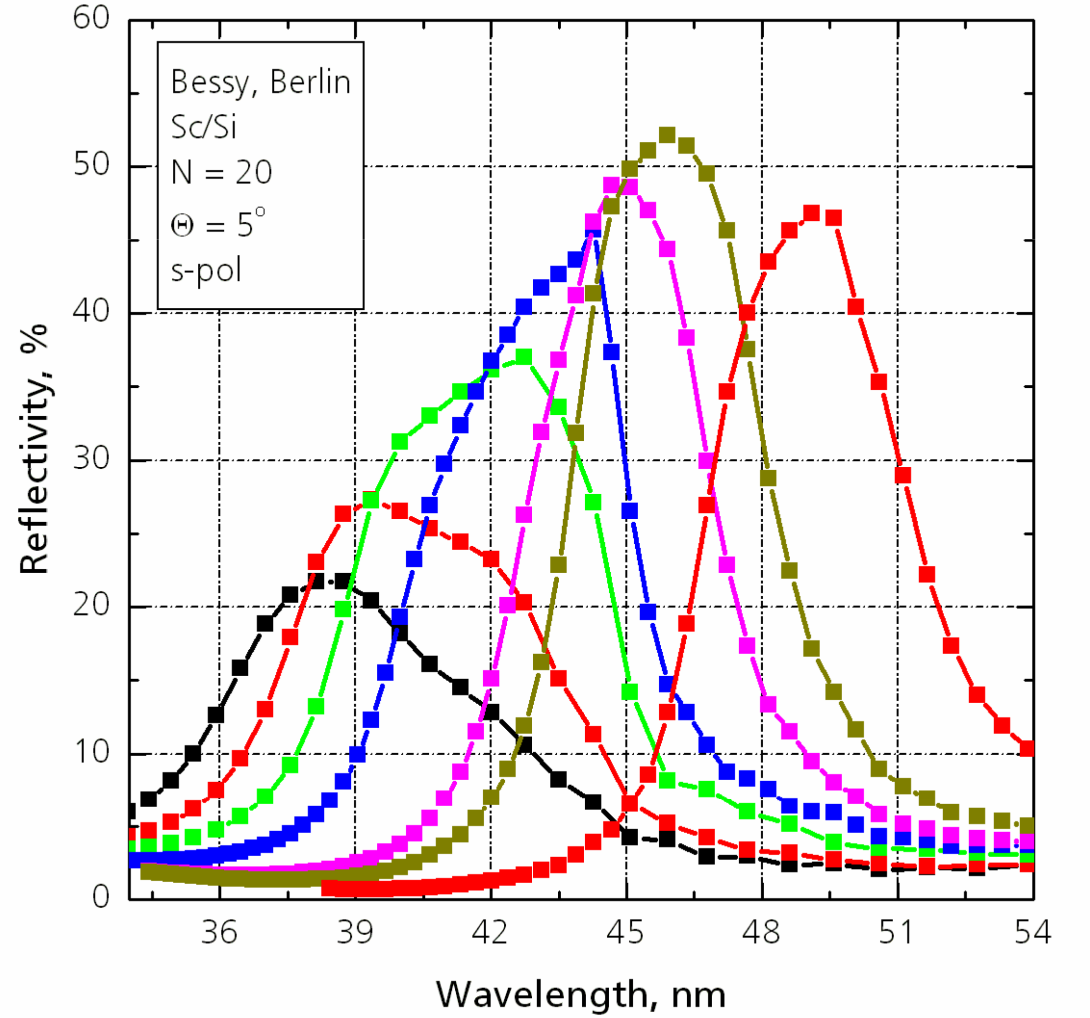
Spectral range from 40 to 120 nm

Multilayer	λ	N	R	FWHM
Sc - based	46 nm	20	**52 %**	4.6 nm

Reflectance of

- Sc/Si multilayer mirrors

designed at different wavelengths in the spectral range from λ = 36 to 50 nm



S. Yulin et al., “Enhanced reflectivity and stability of Sc/Si multilayers”, SPIE 5193, 2004

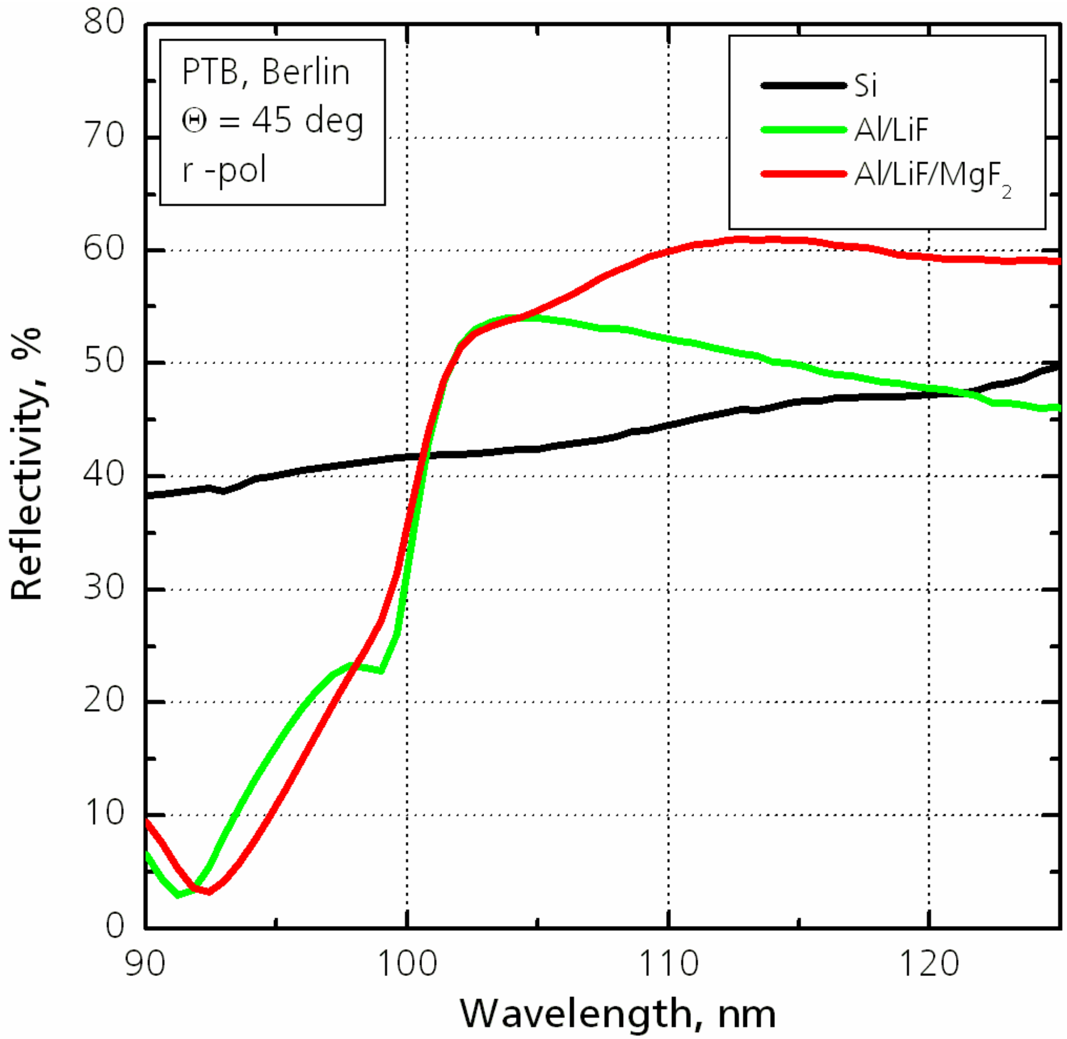
Spectral range from 40 to 120 nm

Multilayer	λ	R
Al - based	110 nm	**60 %**

Reflectance of

- Al/LiF,
- Al/LiF/MgF$_2$ and
- Si coatings

in the spectral range from λ = 90 to 125 nm



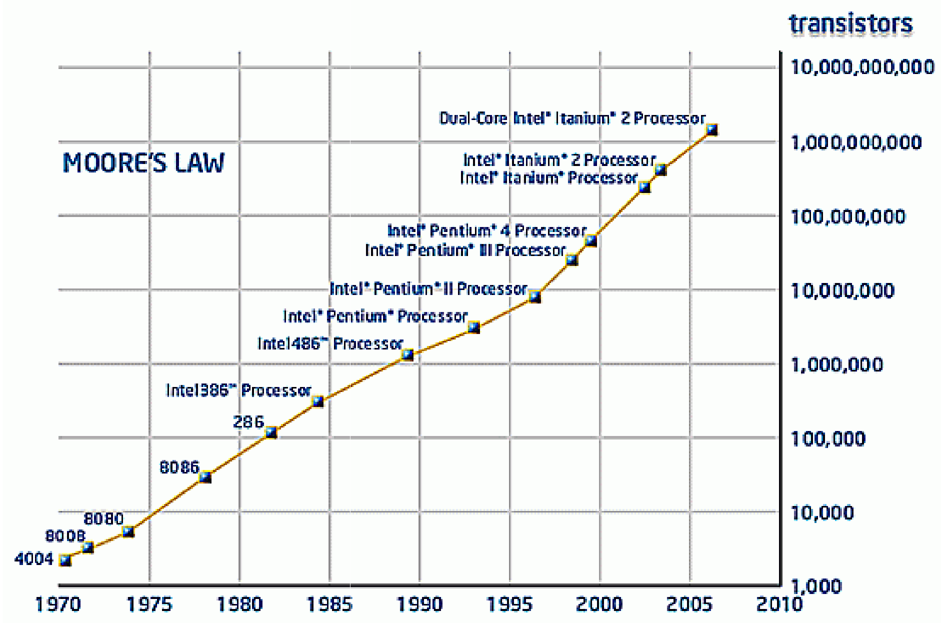
S. Yulin et al., “Hochreflektierende EUV/Röntgen-Mehschichtspiegel”, Photonik 2, 2008

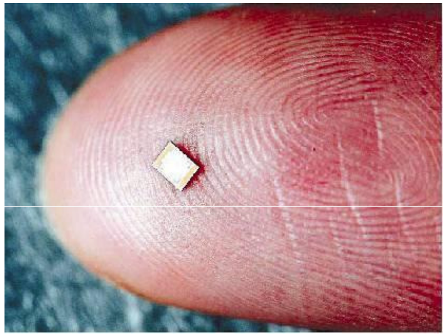
Contents

- Introduction
- $\lambda > 13.5$ nm
- $\lambda = 13.5$ nm
- $\lambda < 13.5$ nm
- Summary and Acknowledgement

EUV Lithography driver: Moore’s Law

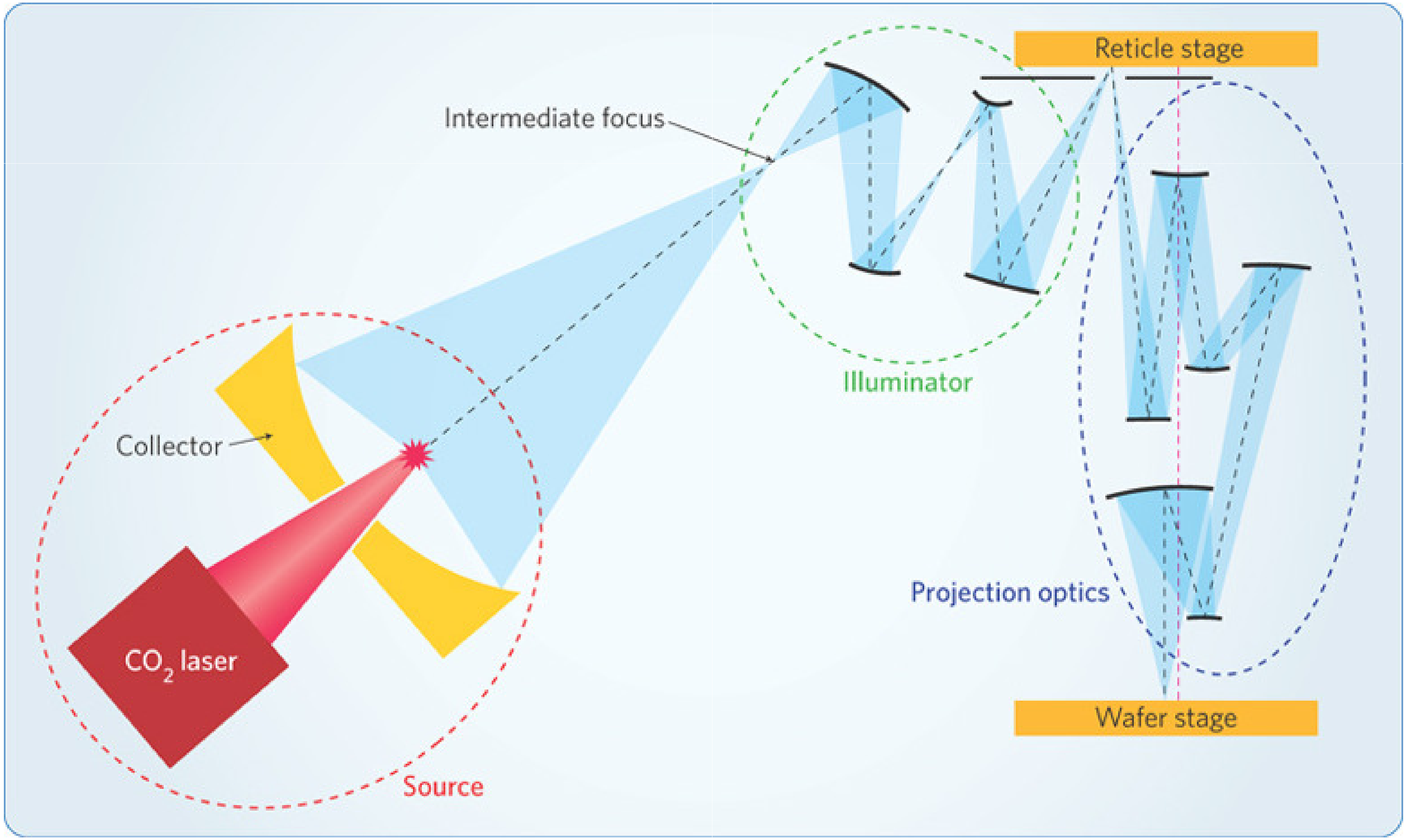
TRADIC (TRansistorized Airborne DIgital Computer) , 1955





$\lambda = 13.5$ nm

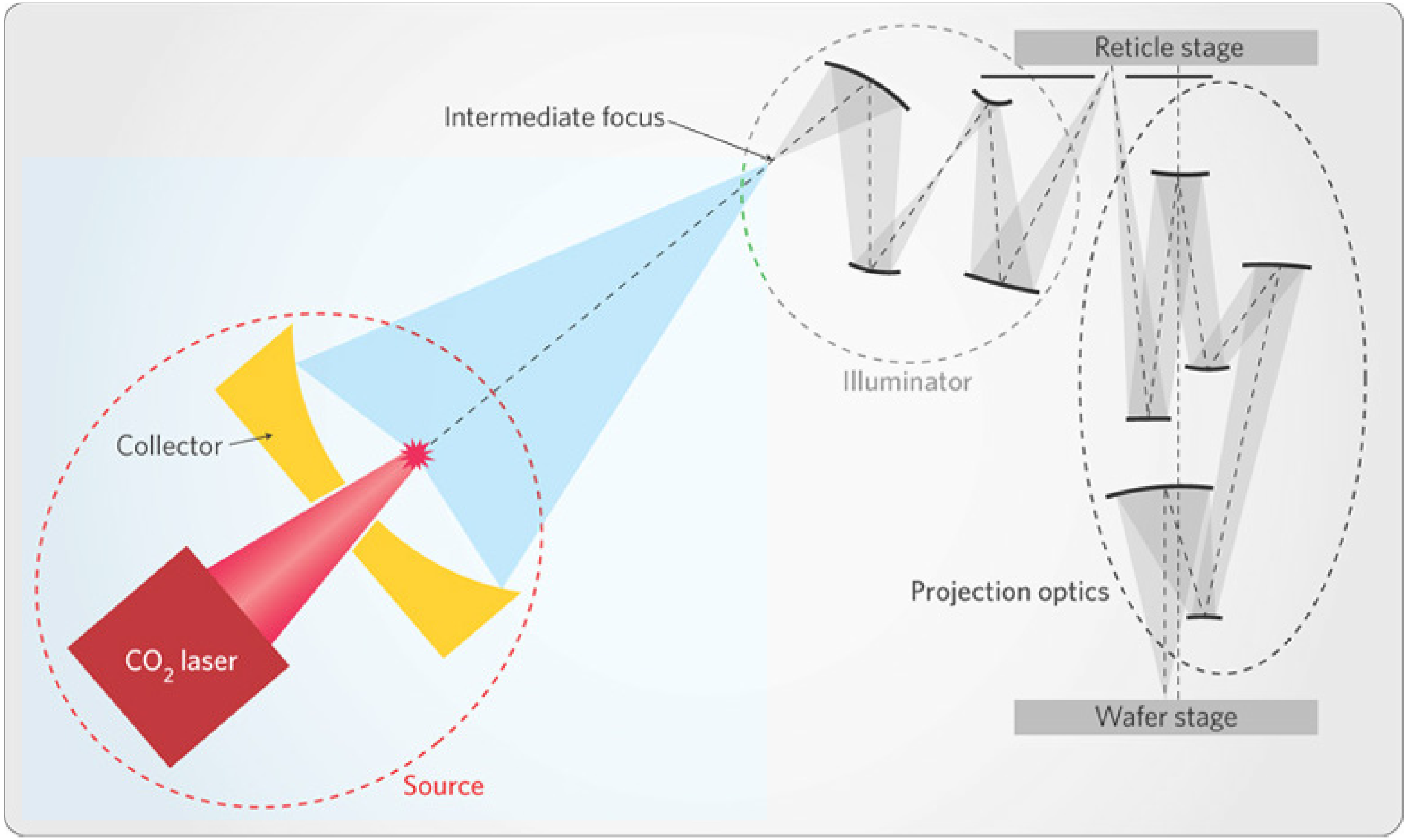
EUV lithography: Reflective optics under vacuum conditions



[*Nature Photonics* **4**, 24-26 (2010)]

λ = 13.5 nm

Coating and characterization of LPP collector optics



[*Nature Photonics* **4**, 24-26 (2010)]

LPP collector coating challenges

R > 65 %

λ = (13.500 ± 0.050) nm

→ Δd = 0.025 nm = 25 pm

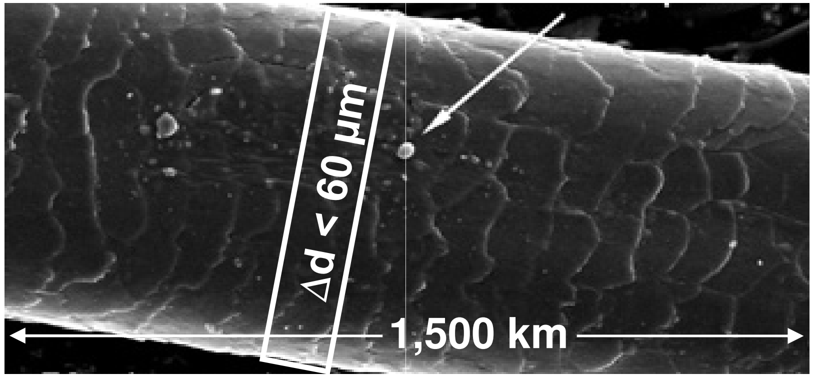
Diameter:	> 660 mm
Lens sag:	> 150 mm
Tilt:	> 45 deg
Weight:	> 40 kg

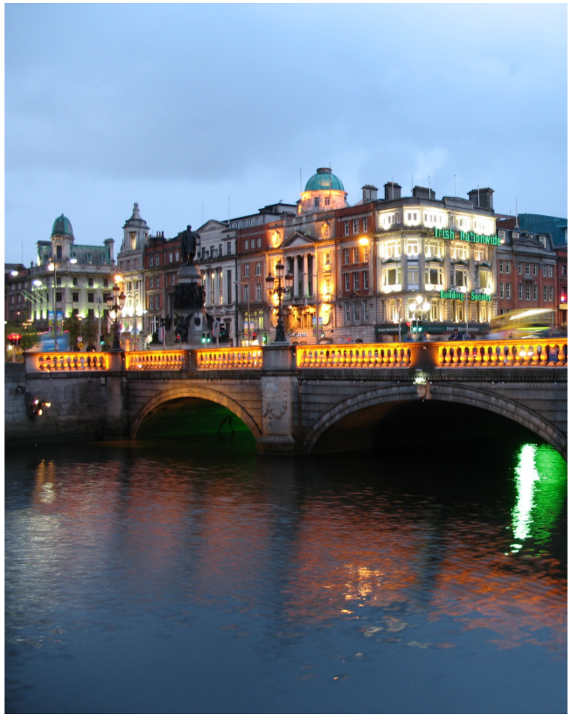
Fraunhofer IOF

CYMER®

LPP collector coating challenges

	EUV collector mirror (Diameter ≈ 660 mm)	**Factor 2.27 Mio.: Jena – Dublin (≈ 1,500 km)**
Bi-layer thickness error	$\Delta d < 25$ pm	$\Delta d < 60$ µm





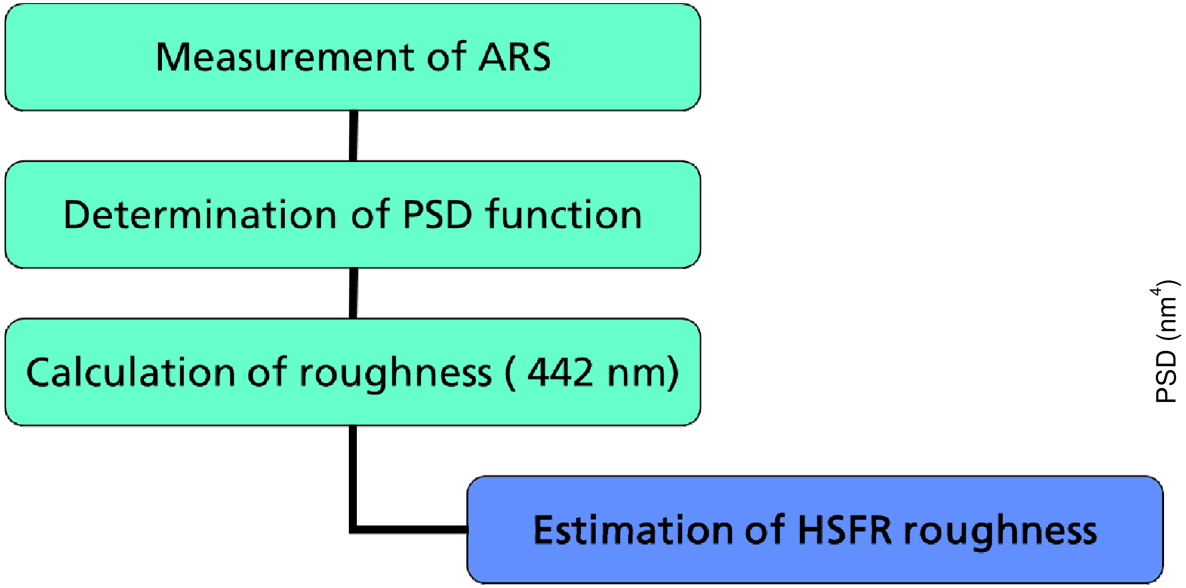
Dublin at night, 20.08.2006,
Hans-Peter Bock hpbock@avaapgh.de

λ = 13.5 nm

Surface characterization of EUV collector substrates - basis

No robust roughness data available so far
(complex geometry, roughness: HSFR < 0.2 nm)

→ New technique:

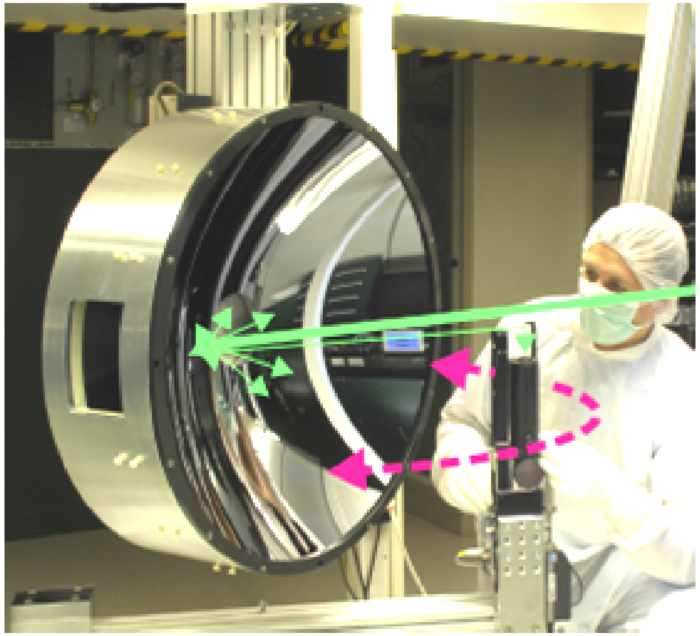


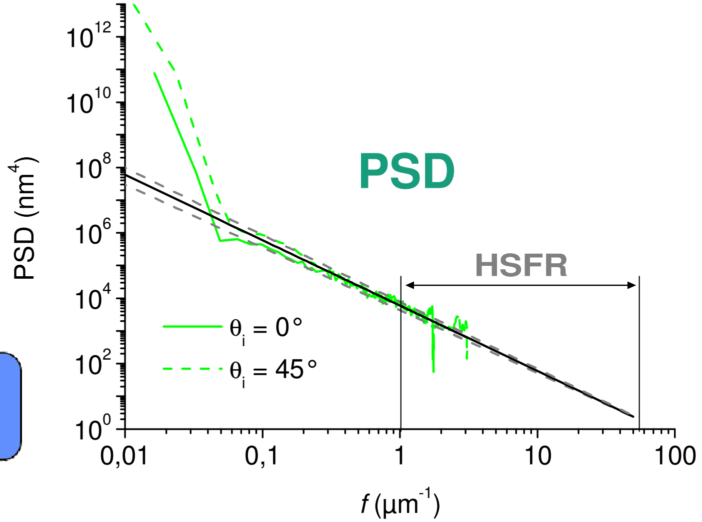
Measurement of ARS

Determination of PSD function

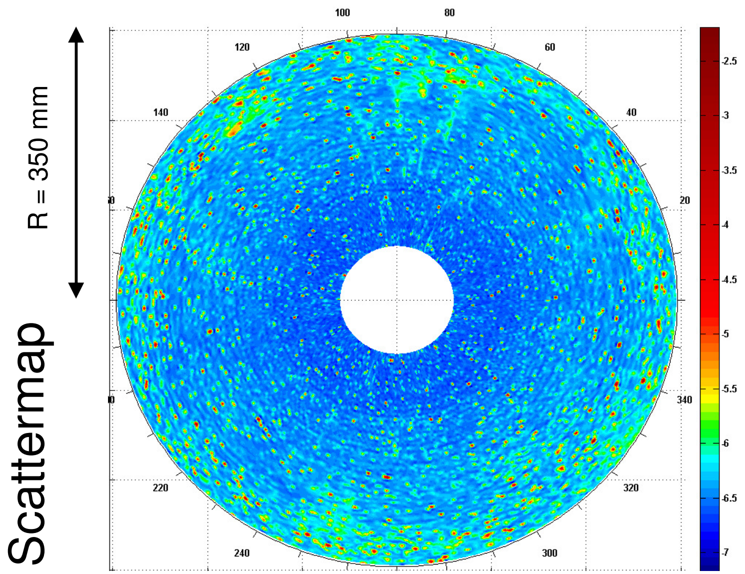
Calculation of roughness (442 nm)

Estimation of HSFR roughness





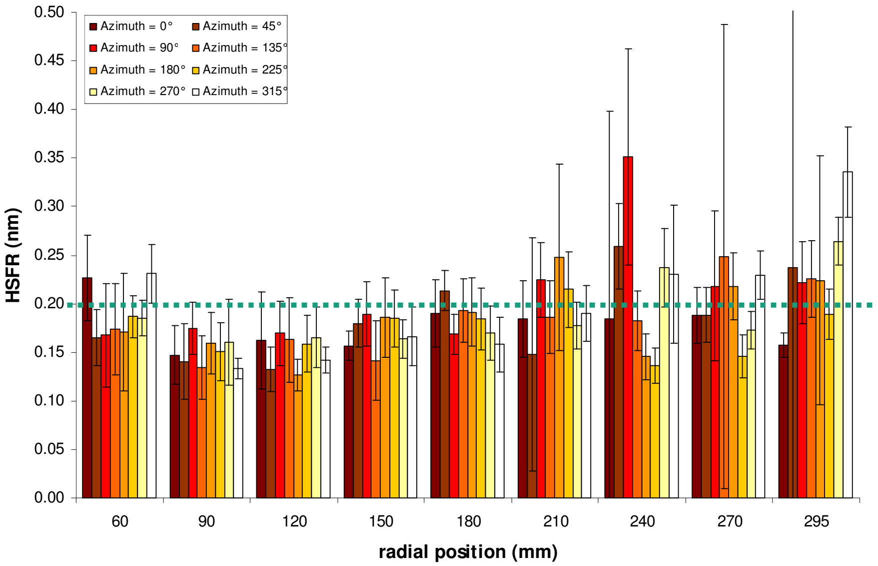
Surface characterization of EUV collector substrates - application



Scattermap

→ Check for roughness distribution, homogeneity, defects

Roughness at different radii



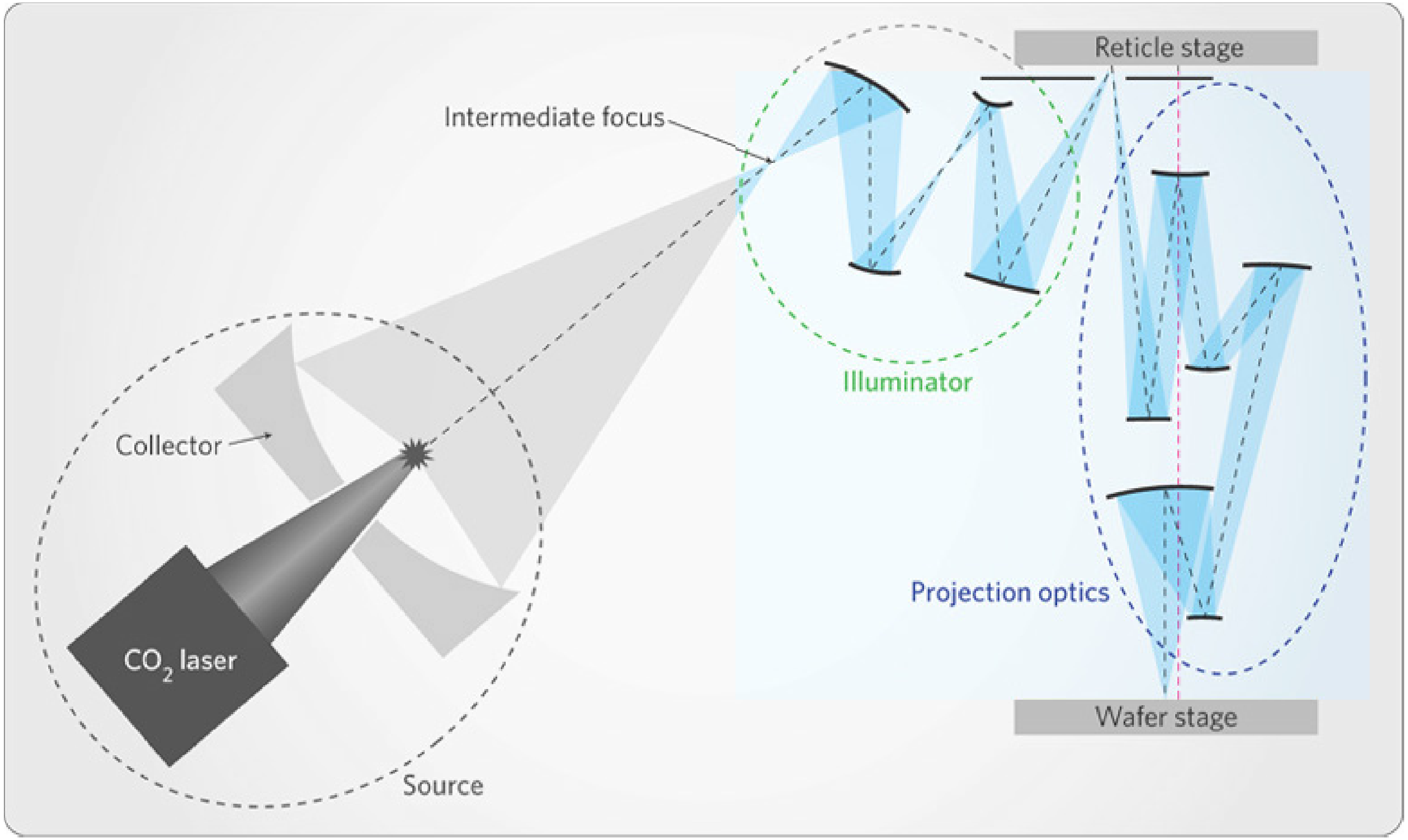
→ Quantitative determination of HSFR

→ **Light scattering technique:**

fast, non-contact, comprehensive, with high sensitivity

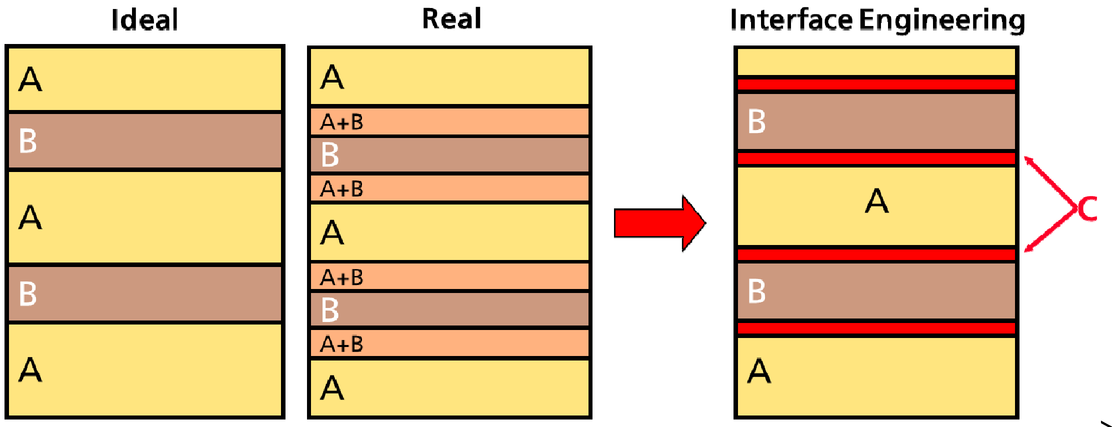
λ = 13.5 nm

Multilayer mirrors for EUV applications



[*Nature Photonics* **4**, 24-26 (2010)]

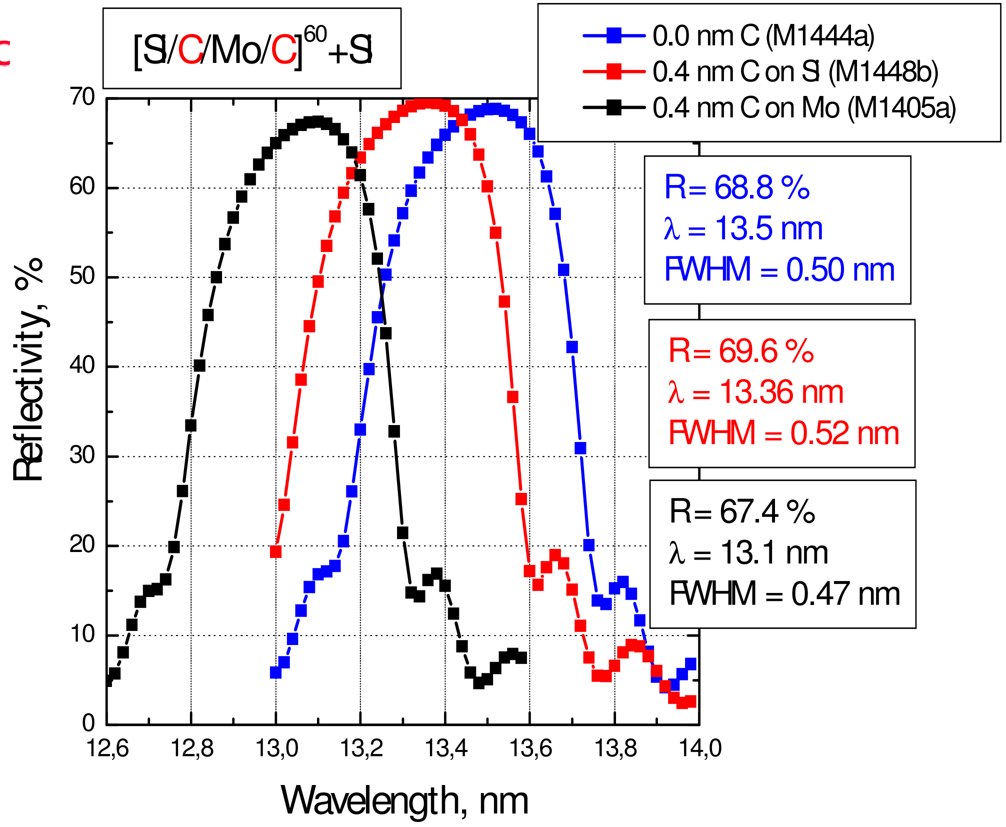
Enhancement of Reflectivity by Interface Engineering



- Optimized Design: [Mo/Si/C]
- R (without C) = 68.8 %

+ 0.8%

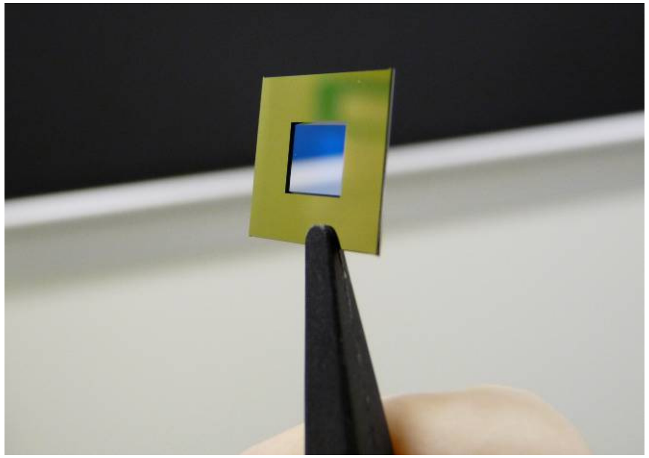
- R (with C on Si) = 69.6 %



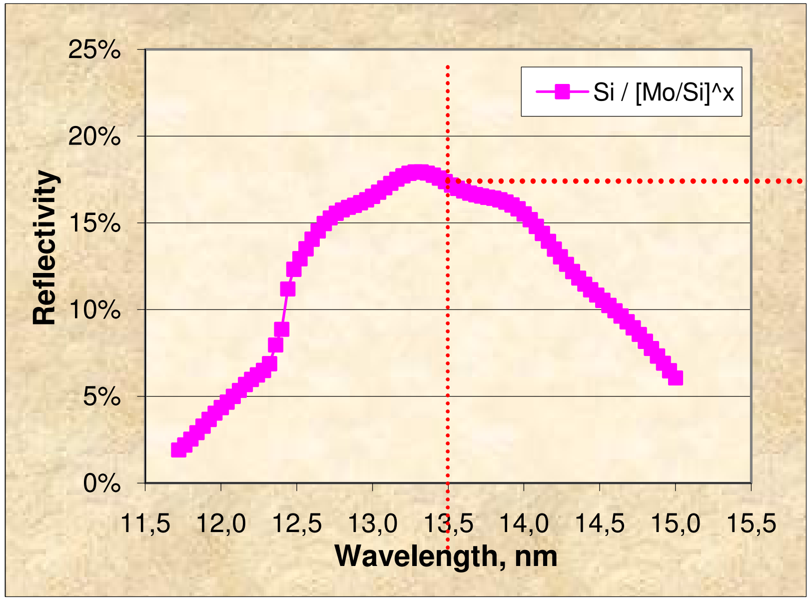
S. Yulin et al., “Interface-engineered EUV multilayer mirrors”, MEE 83, 2006

Beam splitter

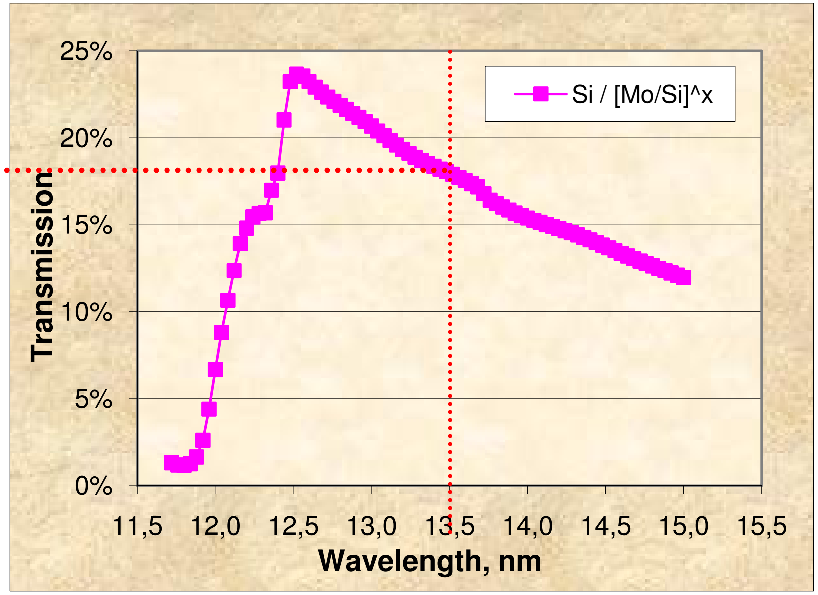
- AOI = 45 deg
- Design: SiN membrane / $[Mo/Si]^x$
- R @13.5 nm = T @13.5 nm = 18%



Reflectivity



Transmission



Contents

- Introduction
- $\lambda > 13.5$ nm
- $\lambda = 13.5$ nm
- $\lambda < 13.5$ nm
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Spectral range from 6 to 12 nm

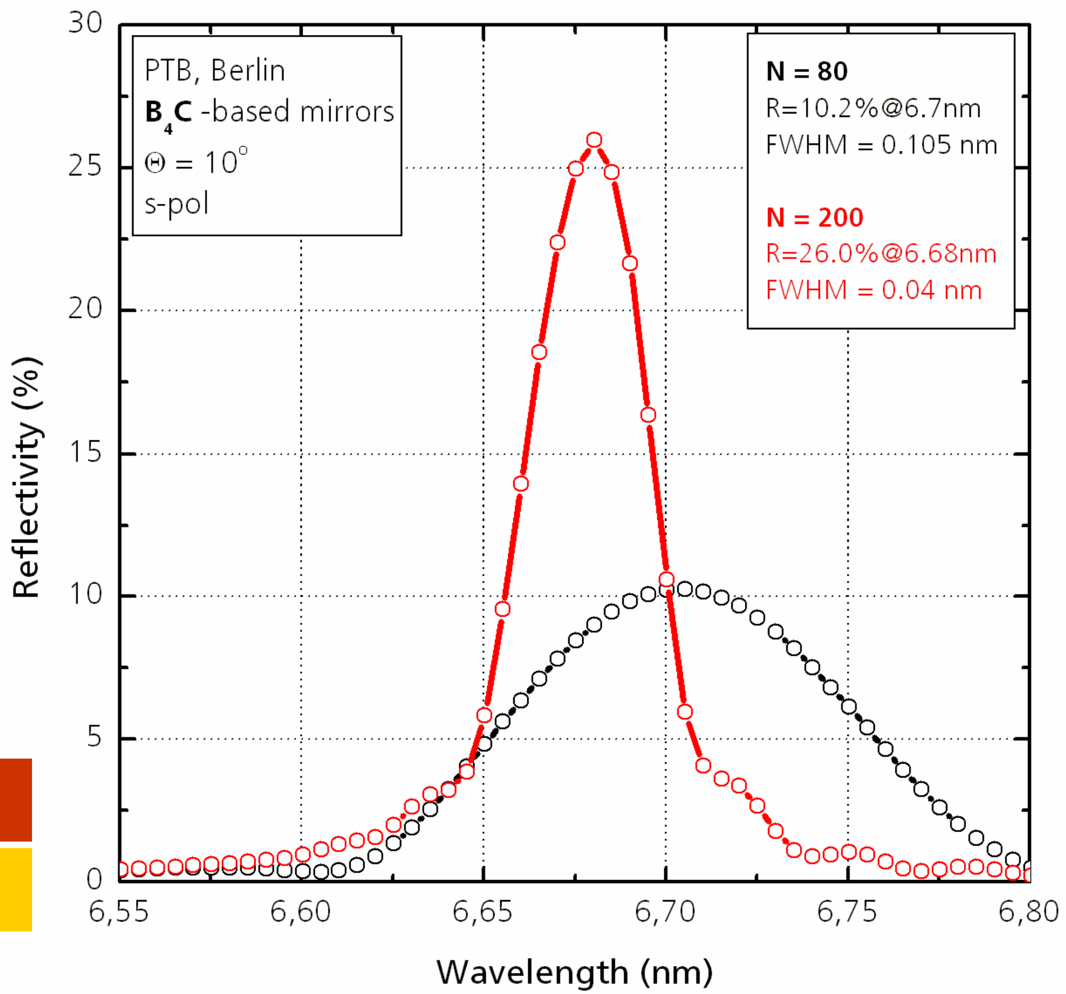
Reflectance of B_4C- based multilayer mirrors:

80 bilayers: R = 10.2 %

200 bilayers: R = 26.0 %

Higher reflectivities can be obtained by interface engineering

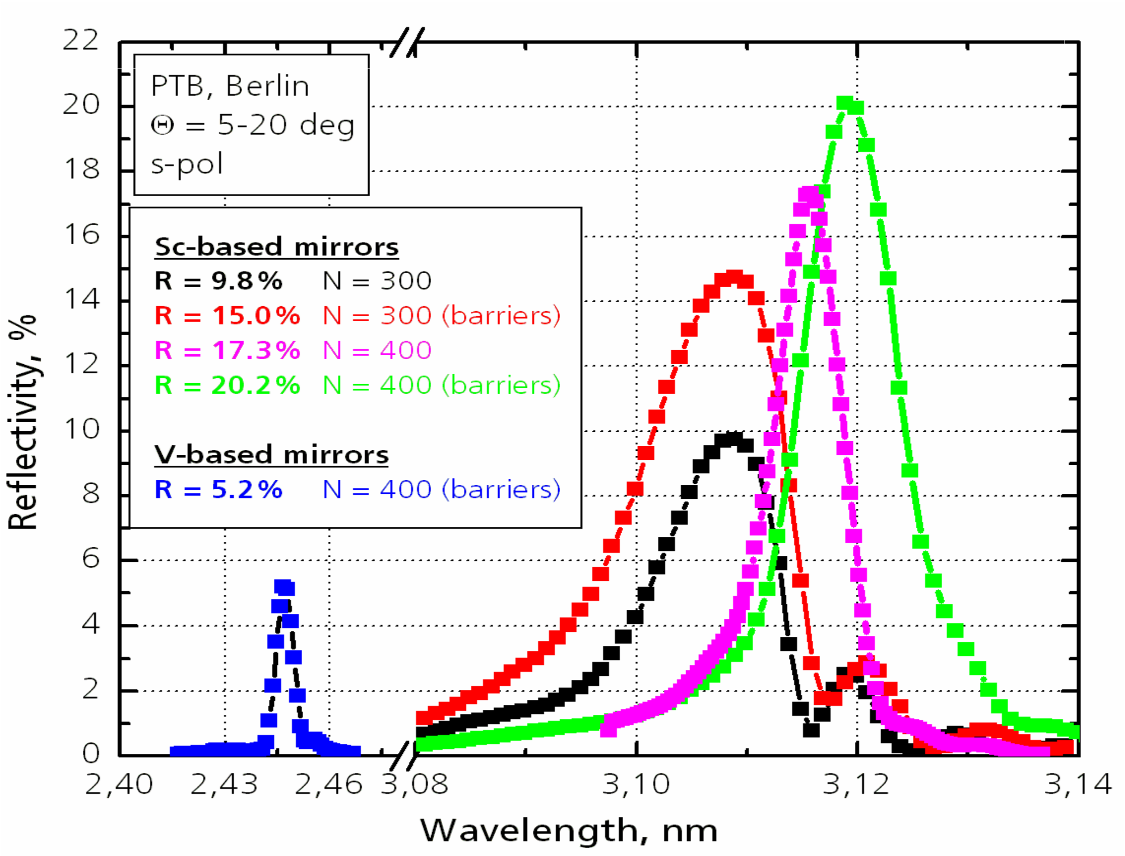
Multilayer	**λ**	**N**	**R**	**FWHM**
B - based	6.7 nm	200	**26.0 %**	0.04 nm



S. Yulin et al., “Hochreflektierende EUV/Röntgen-Mehschichtspiegel”, Photonik 2, 2008

Spectral range from 2 to 5 nm

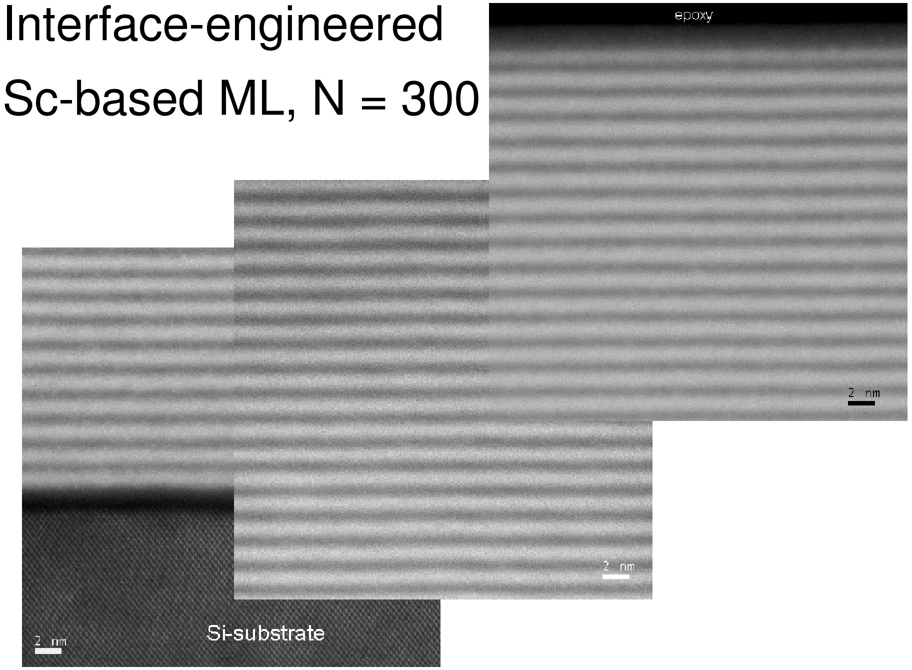
Enhanced reflectance of Sc- and V-based multilayer mirrors with interface-engineering



S. Yulin et al., “Hochreflektierende EUV/Röntgen-Mehschichtspiegel”, Photonik 2, 2008

Multilayer	λ	N	R	FWHM
Sc - based	4.4 nm 3.1 nm	300 400	**7.1 %** **20.2 %**	0.021 nm 0.008 nm
V - based	2.5 nm	400	**5.2 %**	0.006 nm

Interface-engineered Sc-based ML, N = 300



Contents

- Introduction
- $\lambda > 13.5$ nm
- $\lambda = 13.5$ nm
- $\lambda < 13.5$ nm
- Summary and Acknowledgement

Summary

XUV multilayers	- High-reflective multilayers for $\lambda = 2 \ldots 150$ nm
EUV multilayers	- $R > 65$ % and d-spacing accuracy of $\Delta d < 25$ pm on world's largest EUV multilayer mirror (Ø > 660 mm) - Different optical designs concerning application (beam splitters, polarizers, broadband designs…)
Surface characterization	- Light scattering for HSFR substrate characterization
Interface engineering	- Enhanced stability and reflectivity
Applications	- Growing number of non-EUVL applications

Acknowledgements

- Project partners for financial support of R&D work
- PTB Berlin team for EUV reflectivity measurements
- EUV project team @ Fraunhofer IOF:

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Christina Hüttl, Thomas Müller, Michael Scheler, Ronald Schmidt,
Sven Schröder, Wieland Stöckl, Marcus Trost, etc…

Thank you!