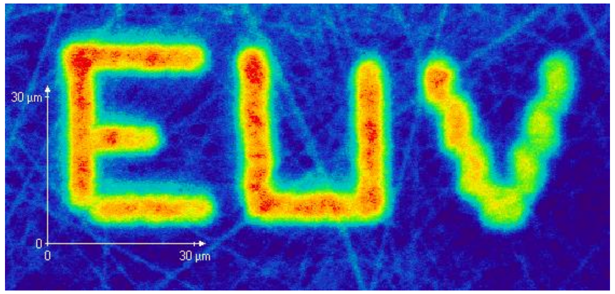

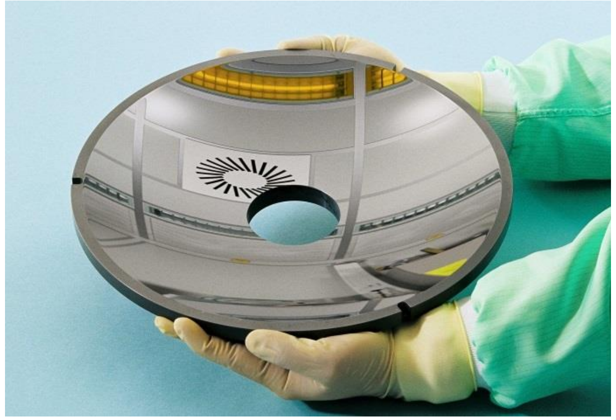

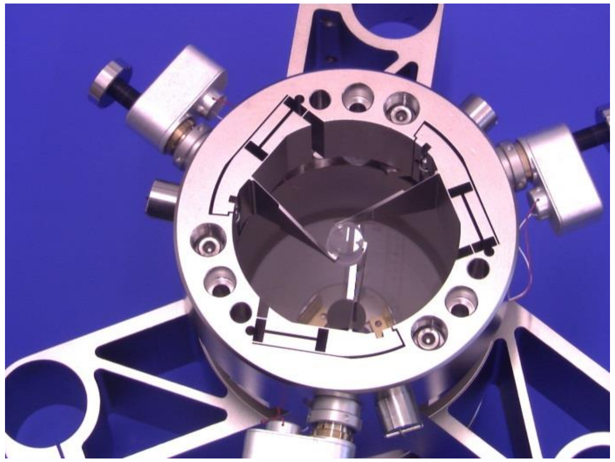

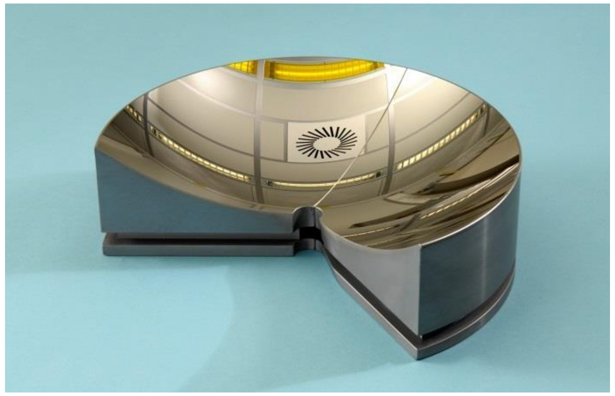

Multilayer Optics for 1 nm to 13.5 nm: Can we reduce the litho wavelength further?

2018 International Workshop on EUV and soft X-Ray Sources

Torsten Feigl, Hagen Pauer, Tobias Fiedler, Marco Perske, Philipp Naujok

optiX fab GmbH, Jena

Prague, November 6, 2018

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Outline

- Introduction
- Multilayers for 1 nm … 13.5 nm – low reflectance, narrow bandwidth
- Narrow band sources meet narrow band multilayers
- Summary

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- *History*

1997: Start of EUV multilayer development @ Fraunhofer IOF
2013: August 1st: Operations start @ **optiX fab.**
TODAY: Delivery of **11,052 EUV and X-ray mirrors** to customers

- *Mission* Fabrication of customized EUV optics and optical components for EUV lithography @ 13.5 nm, for EUV, soft and hard X-ray applications, synchrotron and FEL beamlines, metrology, R&D, HHG sources, etc.


Torsten Feigl


Marco Perske


Hagen Pauer


Tobias Fiedler


Philipp Naujok

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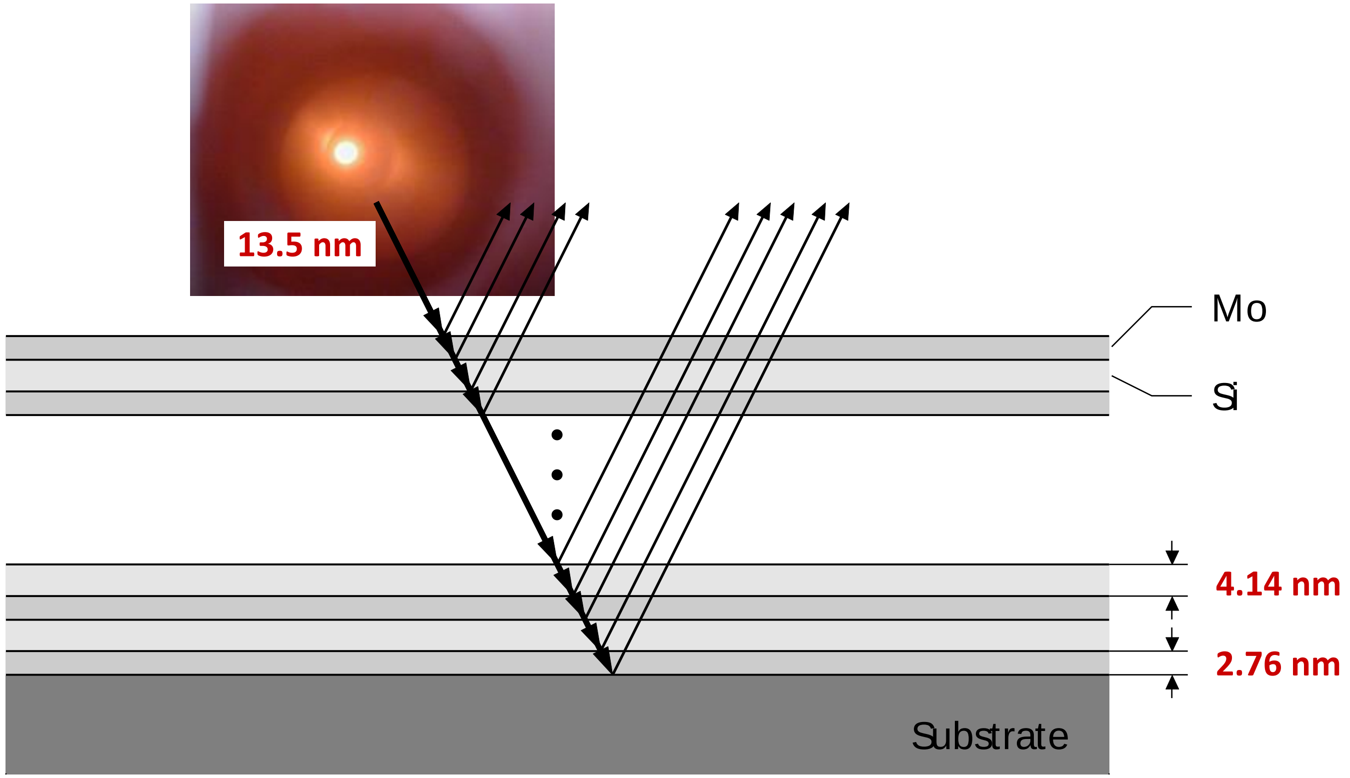
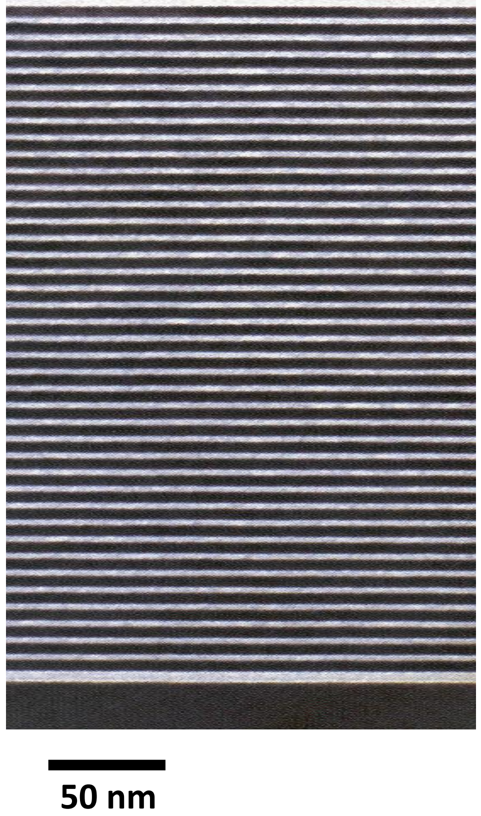
Multilayer mirror – principle of constructive interference

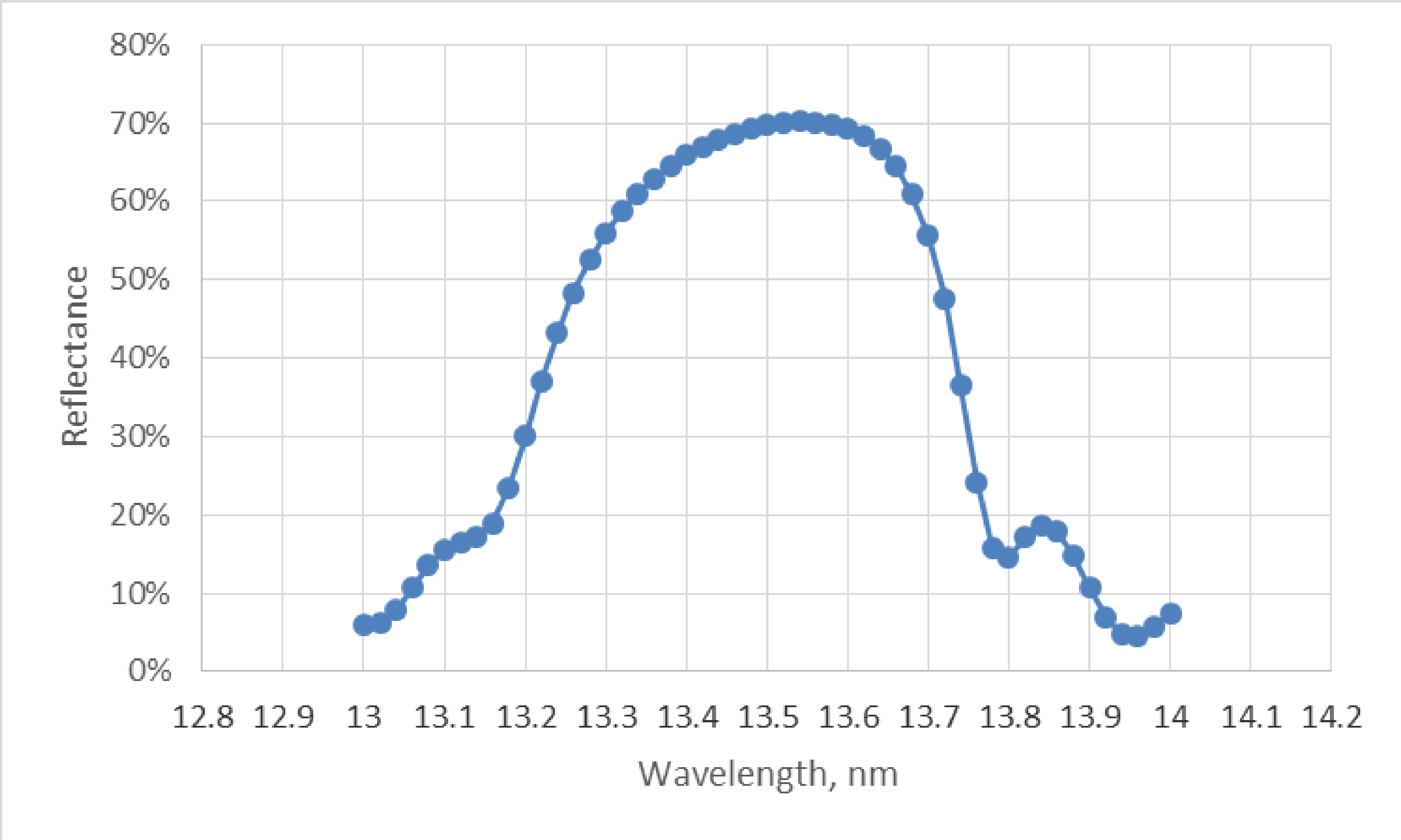


E. Spiller, *Low-loss reflection coatings using absorbing materials*, Appl. Phys. Lett. **20**, pp. 365-367, 1972.



Mo/Si multilayer, TEM

Multilayers for 13.5 nm



R = 70.12 %

λ = 13.48 nm

FWHM = 0.528 nm

AOI = 5 deg.

Measured @PTB Berlin

ML coatings for short wavelengths

- main issues for ML coatings at shorter wavelengths ($\lambda < 13.5$ nm):

1st: lower reflectance

typical experimental values
for near normal incidence:

13.5 nm: $R \leq 70$ %

6.7 nm: $R \leq 65$ %

4.4 nm: $R \leq 15$ %

2.4 nm: $R \leq 20$ %

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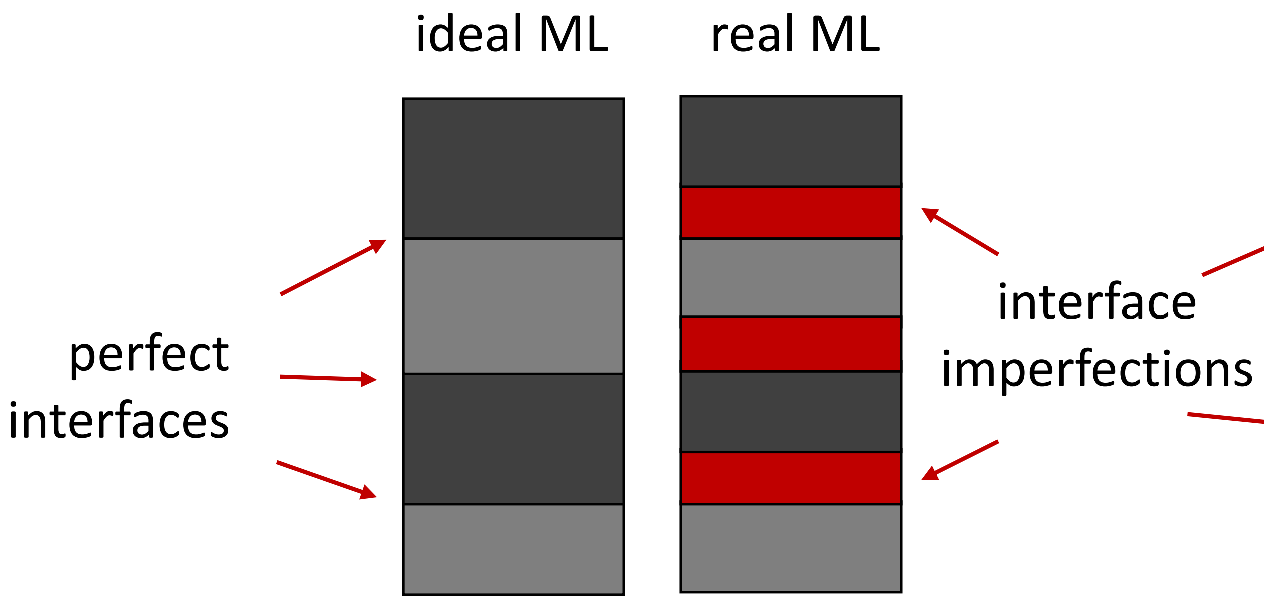
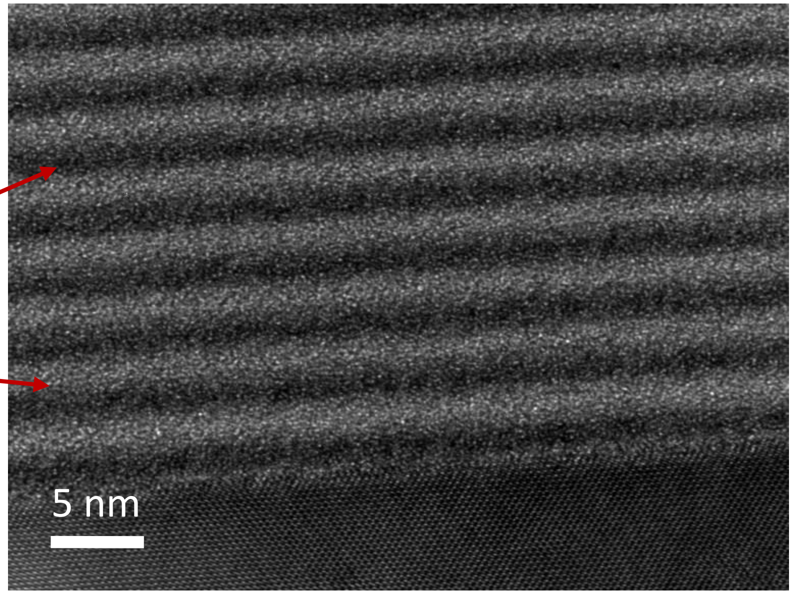
1st issue: lower reflectance at lower wavelengths

- real systems: reflection losses due to **imperfect** interfaces:
  - roughness
  - interdiffusion
  - formation of compounds





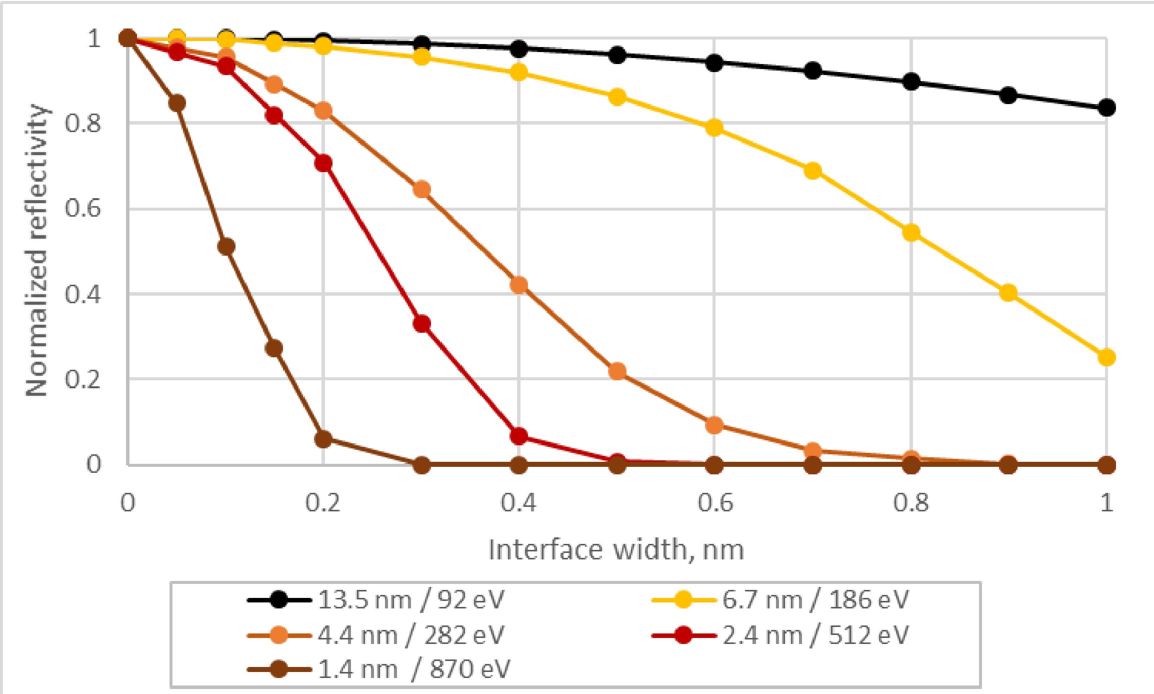
[1]

HR-TEM of a La/B-ML for 6.7 nm showing interdiffusion between La and B

[1] P. Naujok et al., Thin Solid Films 642 (2017) 252–257

1st issue: lower reflectance at lower wavelengths

- reflection losses due to imperfect interfaces
- **higher losses for shorter wavelengths** (stronger influence of interface regions)



d = 7.0 nm (λ = 13.5 nm)

d = 3.4 nm (λ = 6.7 nm)

d = 2.2 nm (λ = 4.4 nm)

d = 1.2 nm (λ = 2.4 nm)

d = 0.7 nm (λ = 1.4 nm)

- high near normal incidence reflectivity (R > 60%) impossible at short wavelengths (λ < 6.6 nm)

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ML coatings for short wavelengths

- main issues for ML coatings at shorter wavelengths (λ < 13.5 nm):

1st: lower reflectance

typical experimental values for near normal incidence:

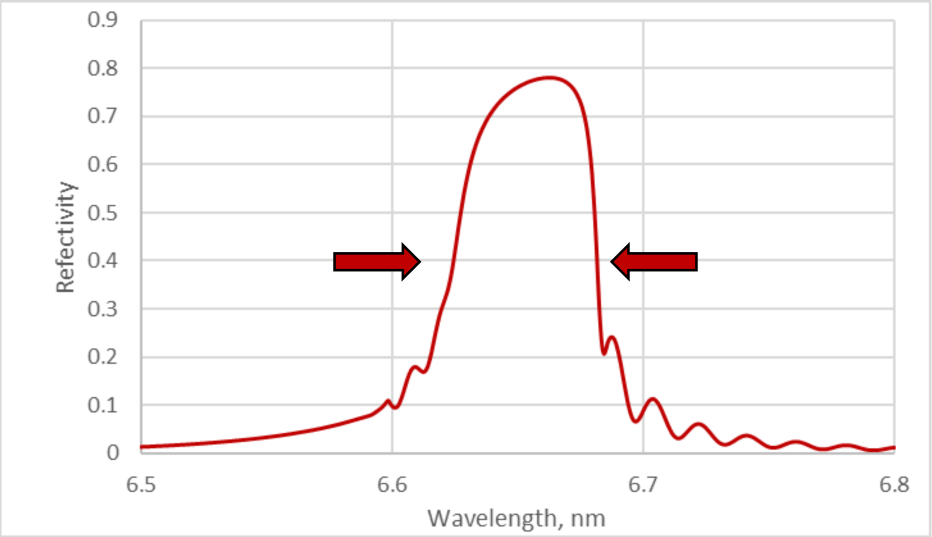
13.5 nm: R ≤ 70 %

6.7 nm: R ≤ 65 %

4.4 nm: R ≤ 15 %

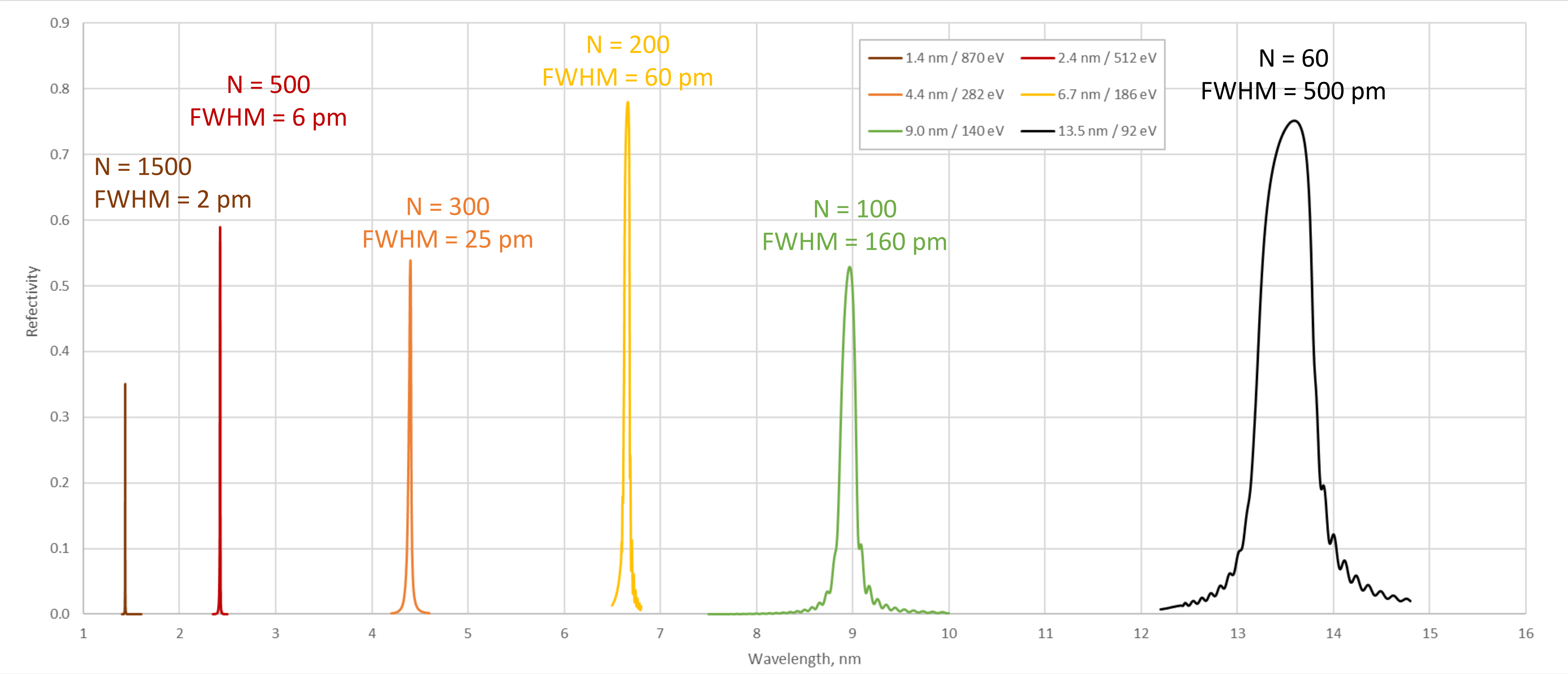
2.4 nm: R ≤ 20 %

2nd: lower bandwidth



2nd issue: lower bandwidth at lower wavelengths

- **strongly decreasing bandwidth** (FWHM) of the ML coating for shorter wavelengths
- reason: higher number of required contributing interfaces



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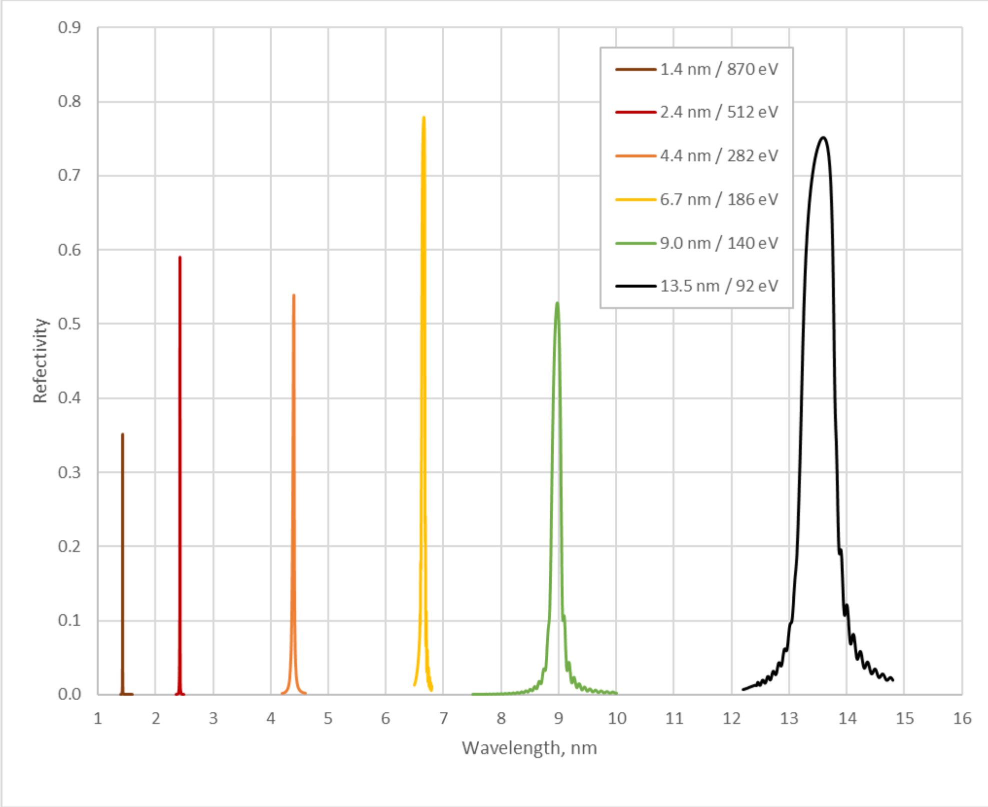
2nd issue: lower bandwidth at lower wavelengths

- **strongly decreased bandwidth** (FWHM) of the ML coating for shorter wavelengths

- consequences:
  - wavelength matching between mirrors more complicated
  - lower integrated reflection
    - ➢ lower photon throughput (assuming broad plasma sources)



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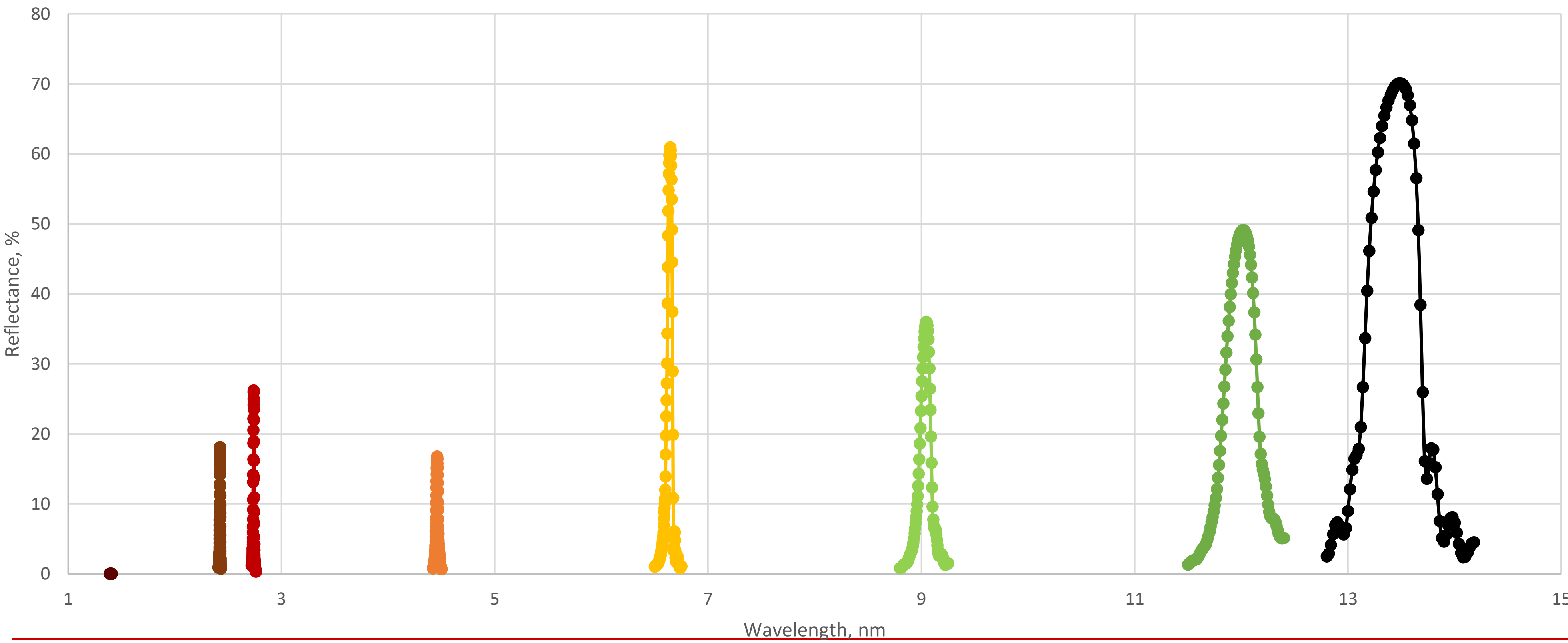
Experimental results

λ, nm	1.4	2.4	2.7	4.4	6.7	9.0	12.0	13.5
R, %	0.02	18.1	26.2	16.8	61.0	36.0	49.2	70.1
FWHM, nm	0.002	0.005	0.008	0.02	0.05	0.11	0.32	0.52



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Experimental results

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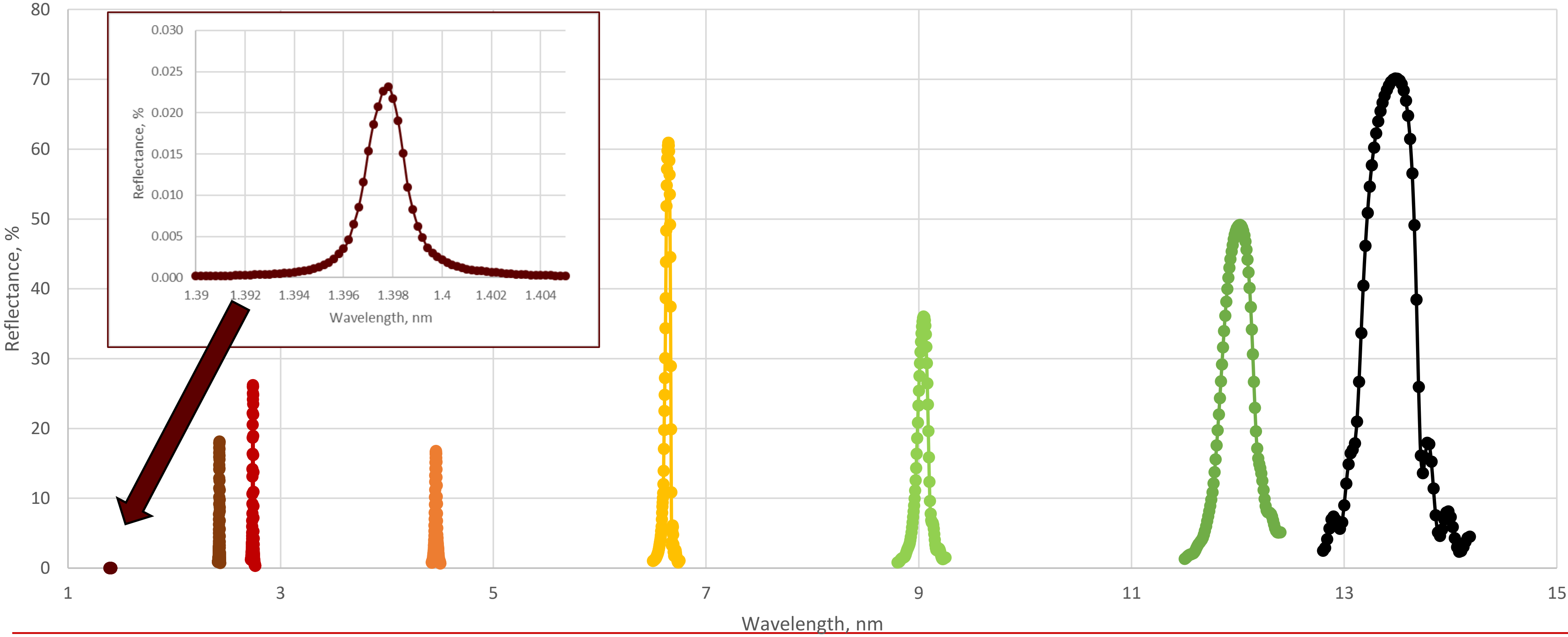

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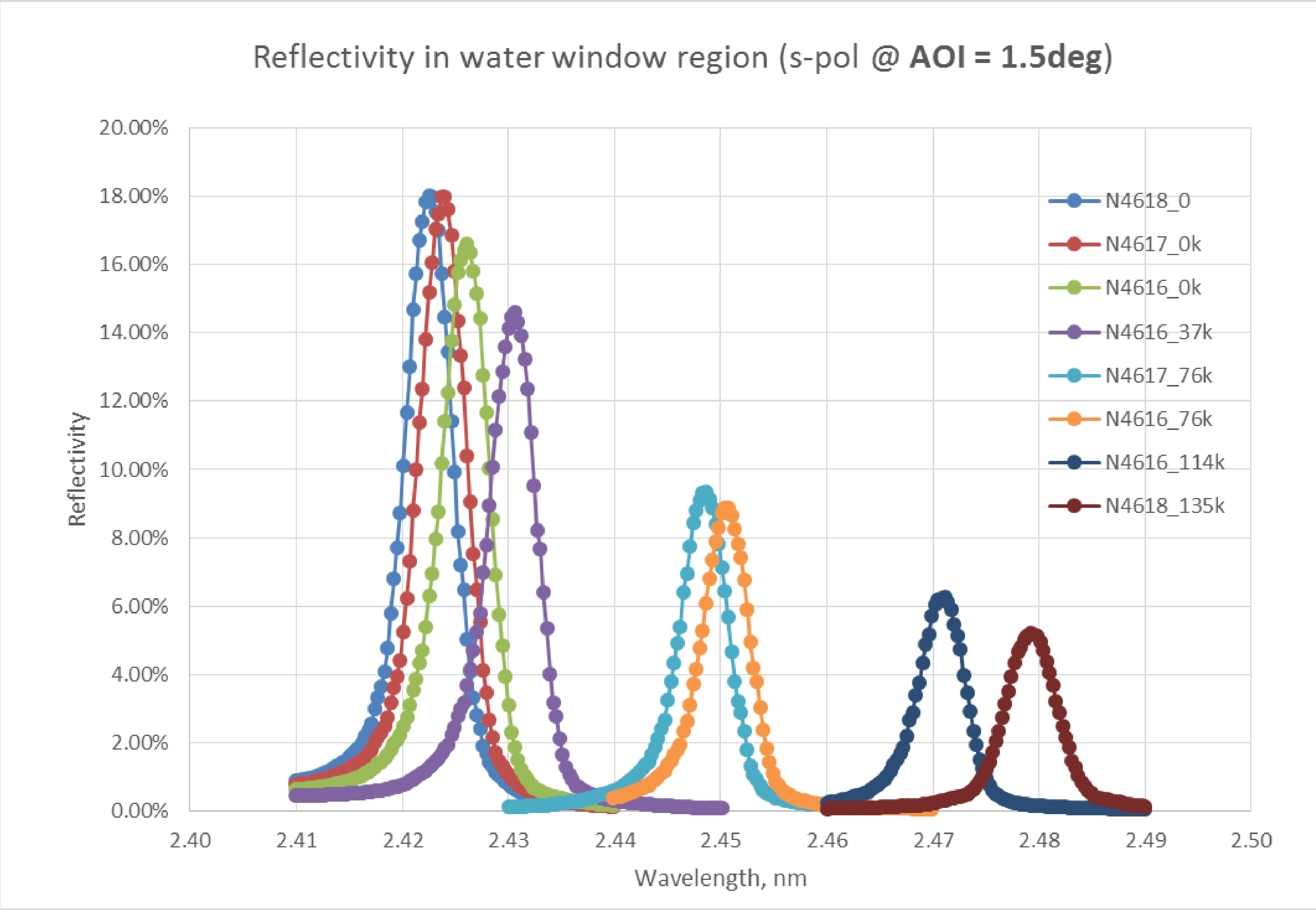
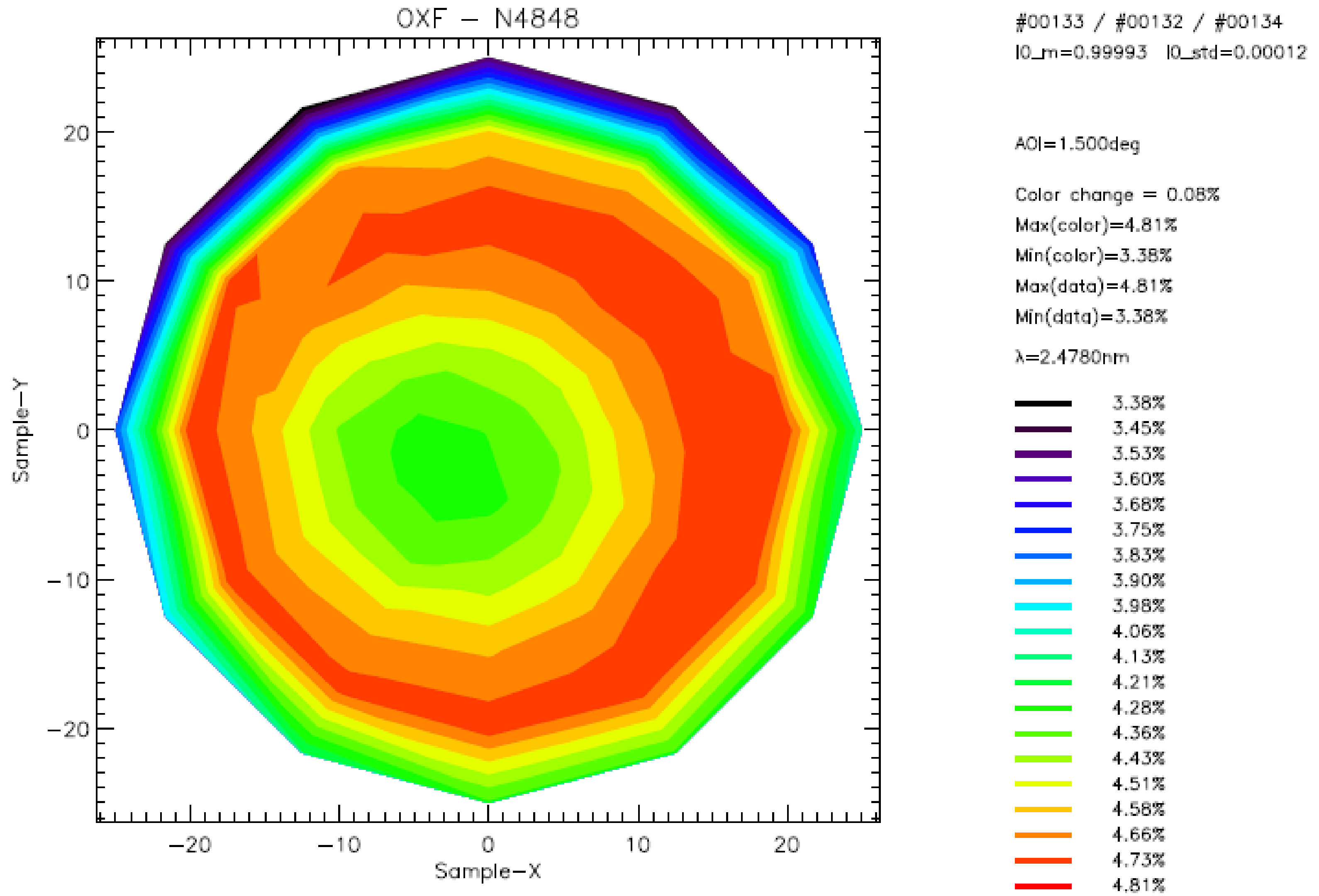
Multilayer development for water window collector



Collector mirror – today: Reflectance mapping at λ = 2.478 nm



R = 4.58 %

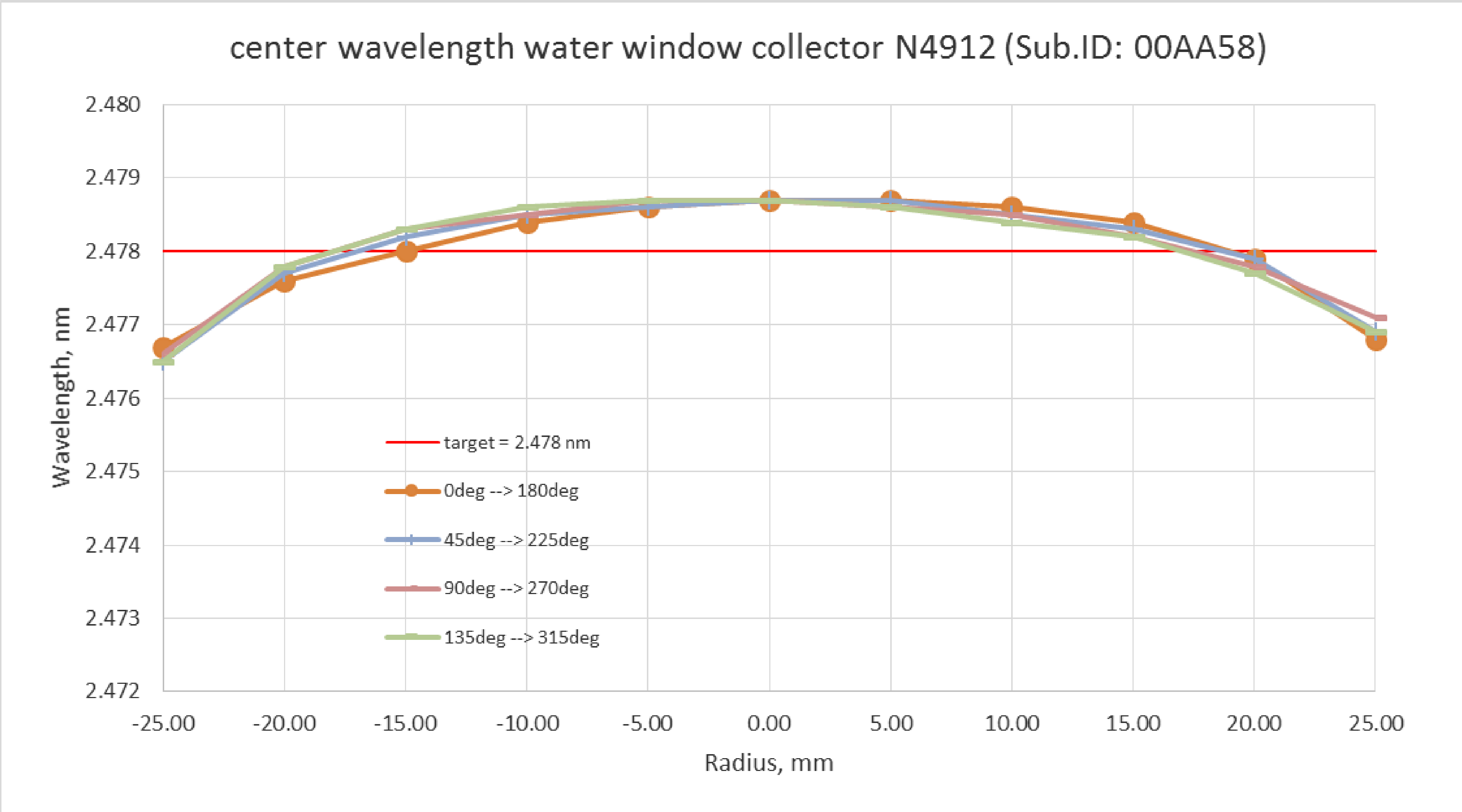
λ = 2.478 nm

FWHM = 0.005 nm

AOI = 1.5 deg.

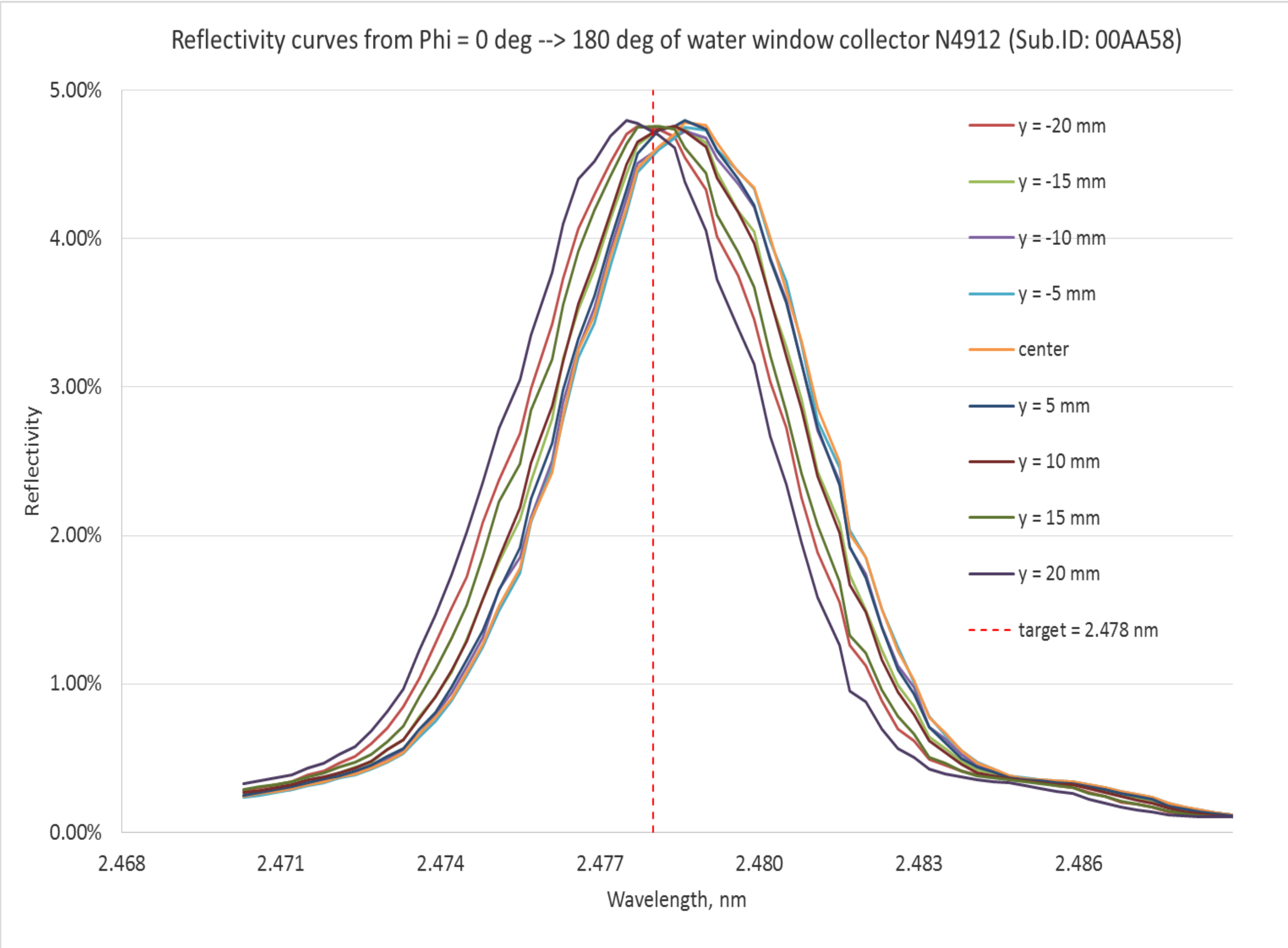
Measured @PTB Berlin

2018 multilayer collector mirror: Wavelength at different positions



Measured @PTB Berlin

2018 multilayer collector mirror: EUV reflectance at different radii

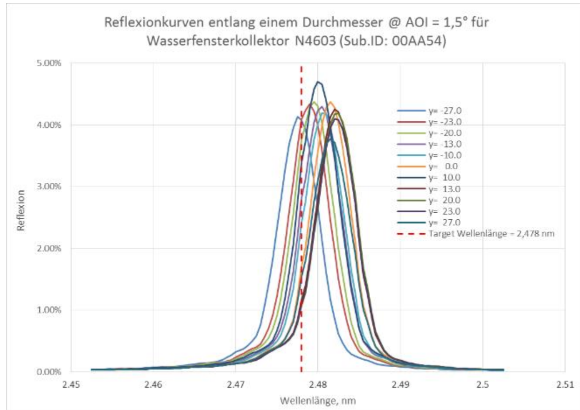


2015: R = 2.45 %

2018: **R = 4.58 %**

→ 2x more photons!

2015 status:



Measured @PTB Berlin

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Summary

- It‘s really hard to make high-reflective multilayers for wavelengths < 13.5 nm
- Challenges: low reflectance, narrow bandwidth
- Please match source emission with multilayer absorption edges…

Still a very long and steep way to go … but good to start now

Acknowledgements

- **KTH:**
  Hans Hertz and team
- **MBI:**
  Holger Stiel and team
- **PTB Berlin:**
  Frank Scholze, Christian Laubis and team
- **Fraunhofer IOF:**
  Thomas Müller, Michael Scheler, Steffen Schulze

Thank you.

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