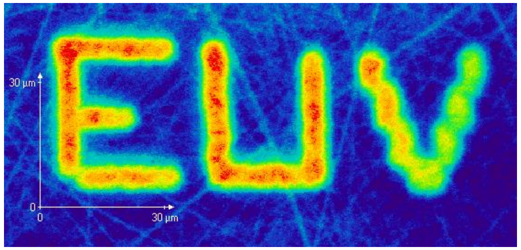

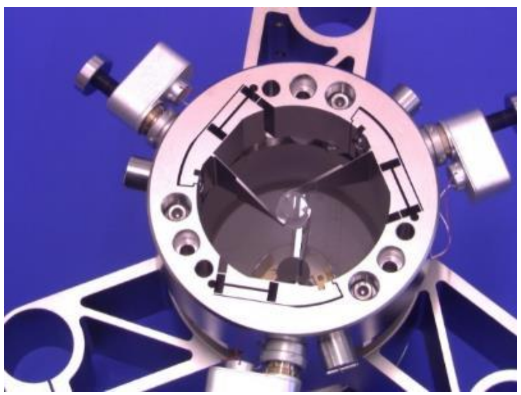

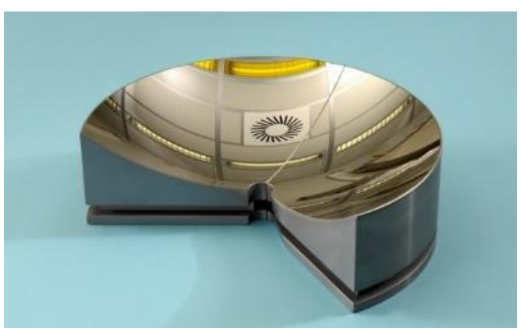

B-based ML coatings for Blue-X

Philipp Naujok, Tobias Fiedler, Marco Perske, Hagen Pauer, Torsten Feigl
optiX fab GmbH, Jena, Germany

Sergiy Yulin, Sven Schröder
Fraunhofer IOF, Jena, Germany

Fraunhofer IOF

optiX fab.

optiX fab.

- *History*

1997: Start of EUV multilayer development @ Fraunhofer IOF
2013: August 1st: Operations start @ **optiX fab.**
TODAY: Delivery of **14,258 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

optiX fab.

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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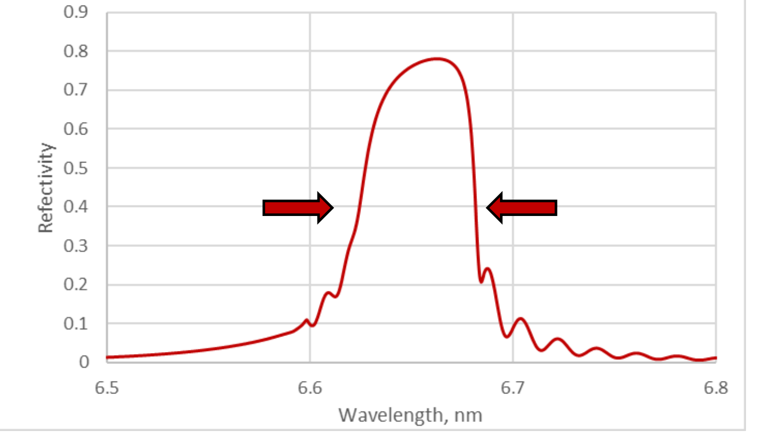
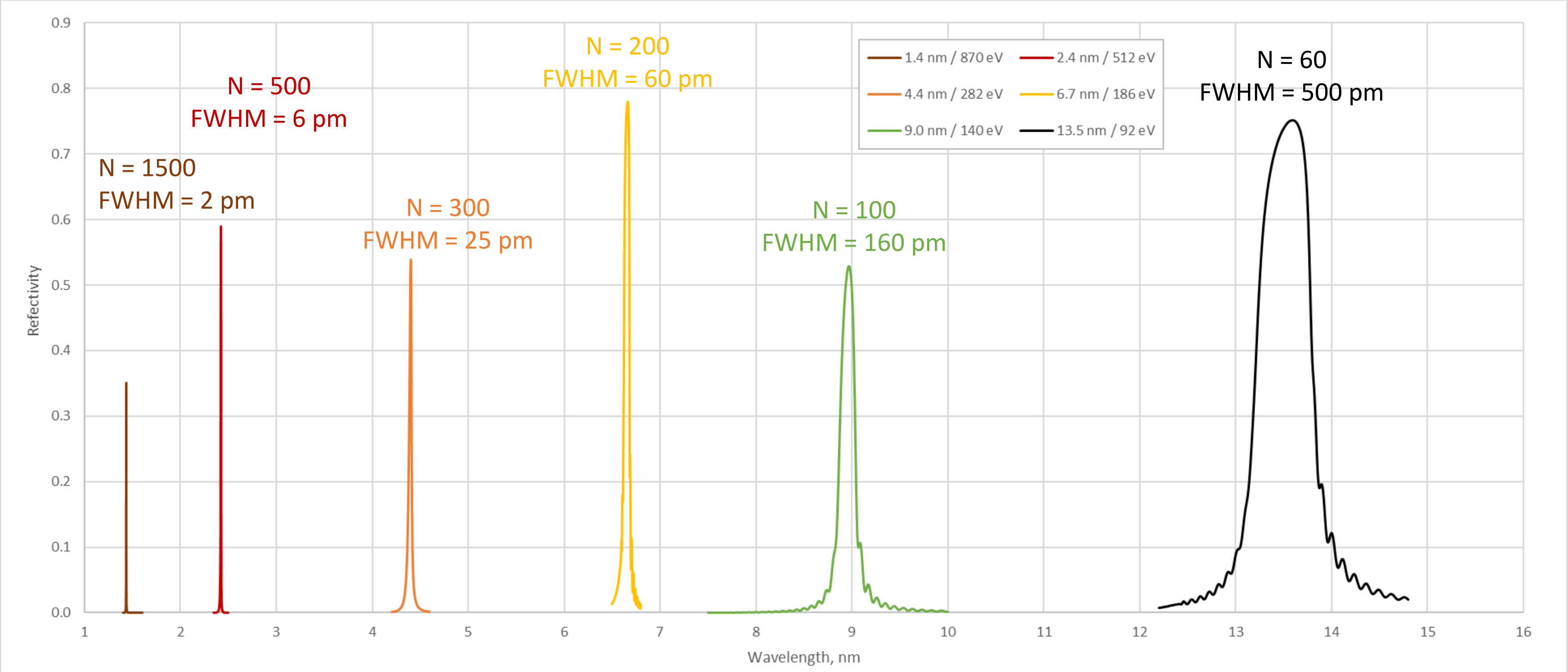
2nd: lower bandwidth



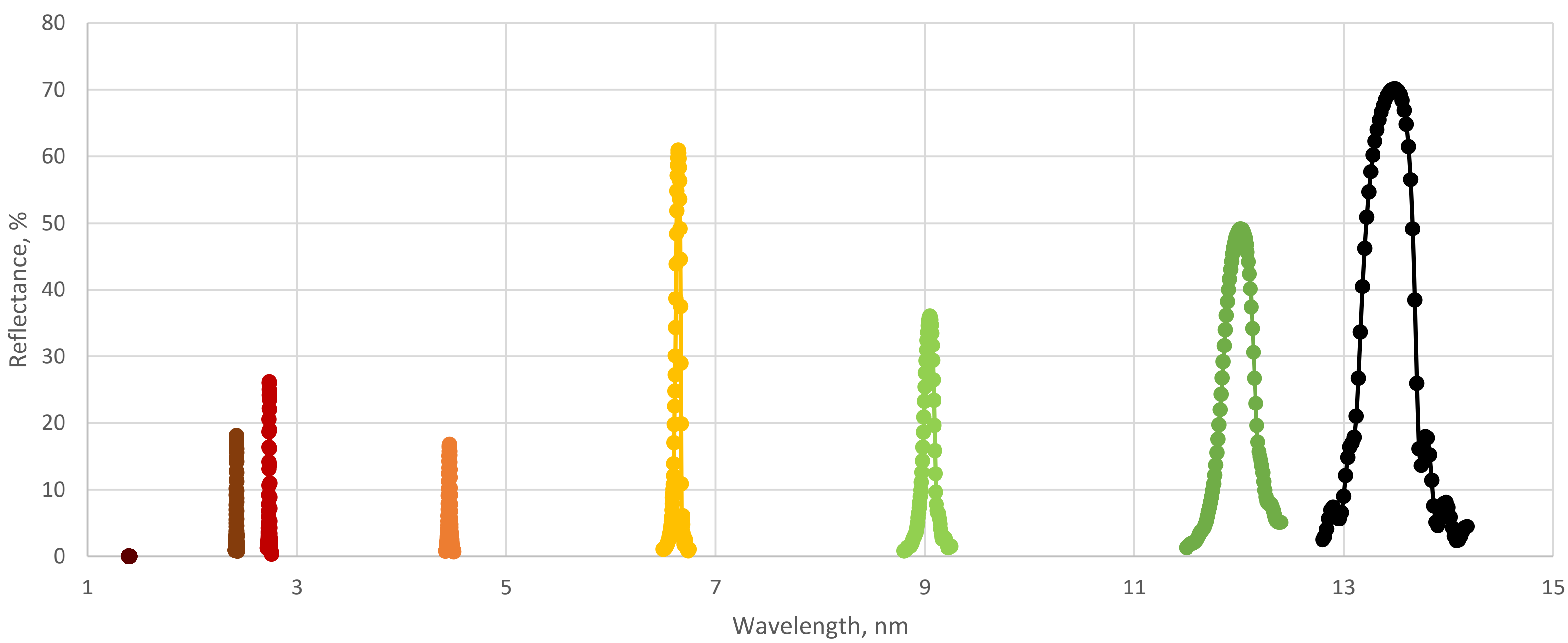
ML coatings for short wavelengths

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



ML coatings for short wavelengths

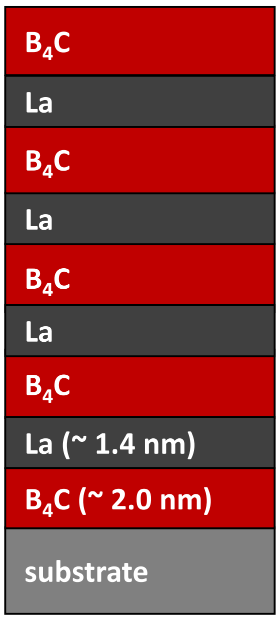
λ, nm	1.4	2.4	2.7	4.4	6.7	9.0	12.0	13.5
R, %	0.02	18.1	26.2	16.8	61.0	36.0	49.2	70.1
FWHM, nm	0.002	0.005	0.008	0.02	0.05	0.11	0.32	0.52

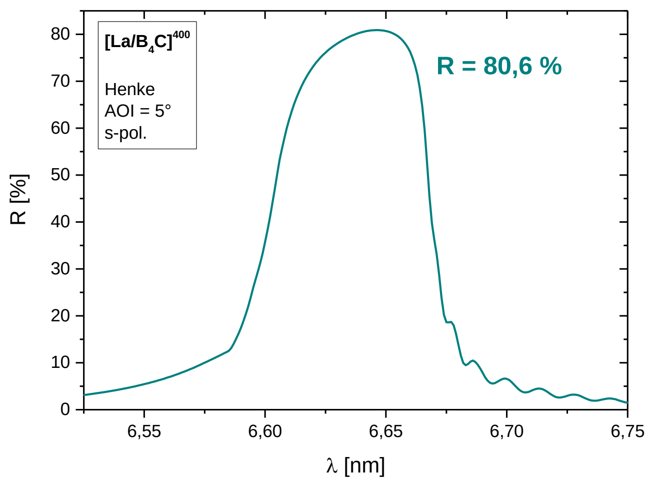


La/B_4C – simulation vs. experiment

<u>Simulation:</u>

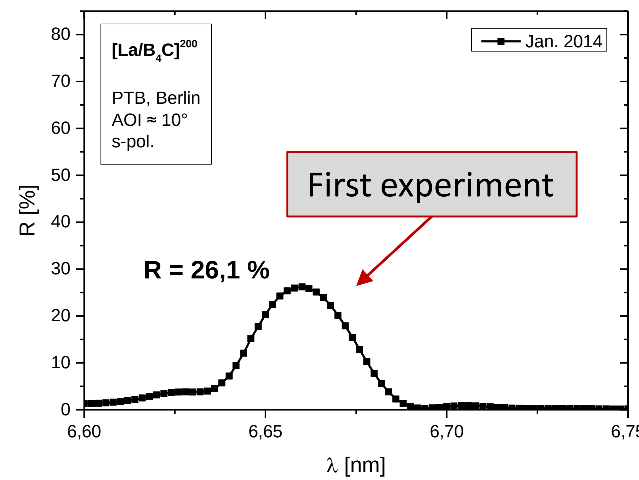
- > 250 bilayers of La and B_4C
- period thickness (La + B_4C): d = 3.4 nm
- ideal layers:





<u>First experiments:</u>

- very low reflectance
- huge difference between simulation and experiment



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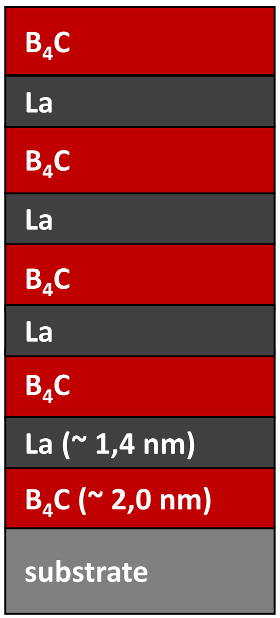
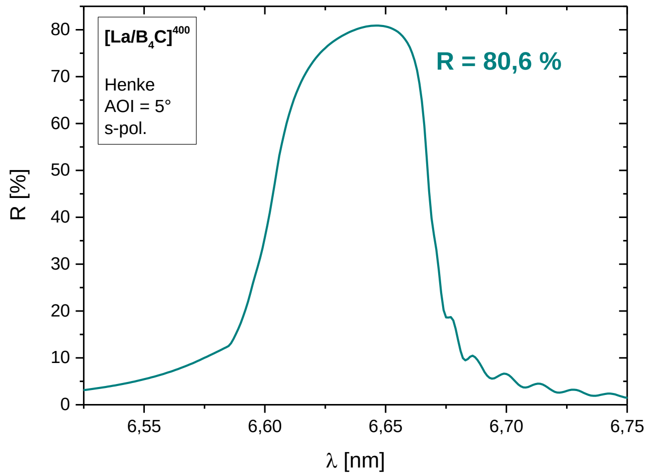
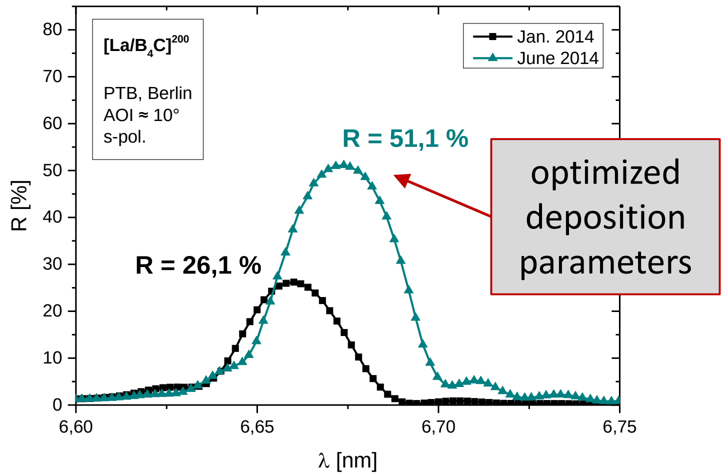




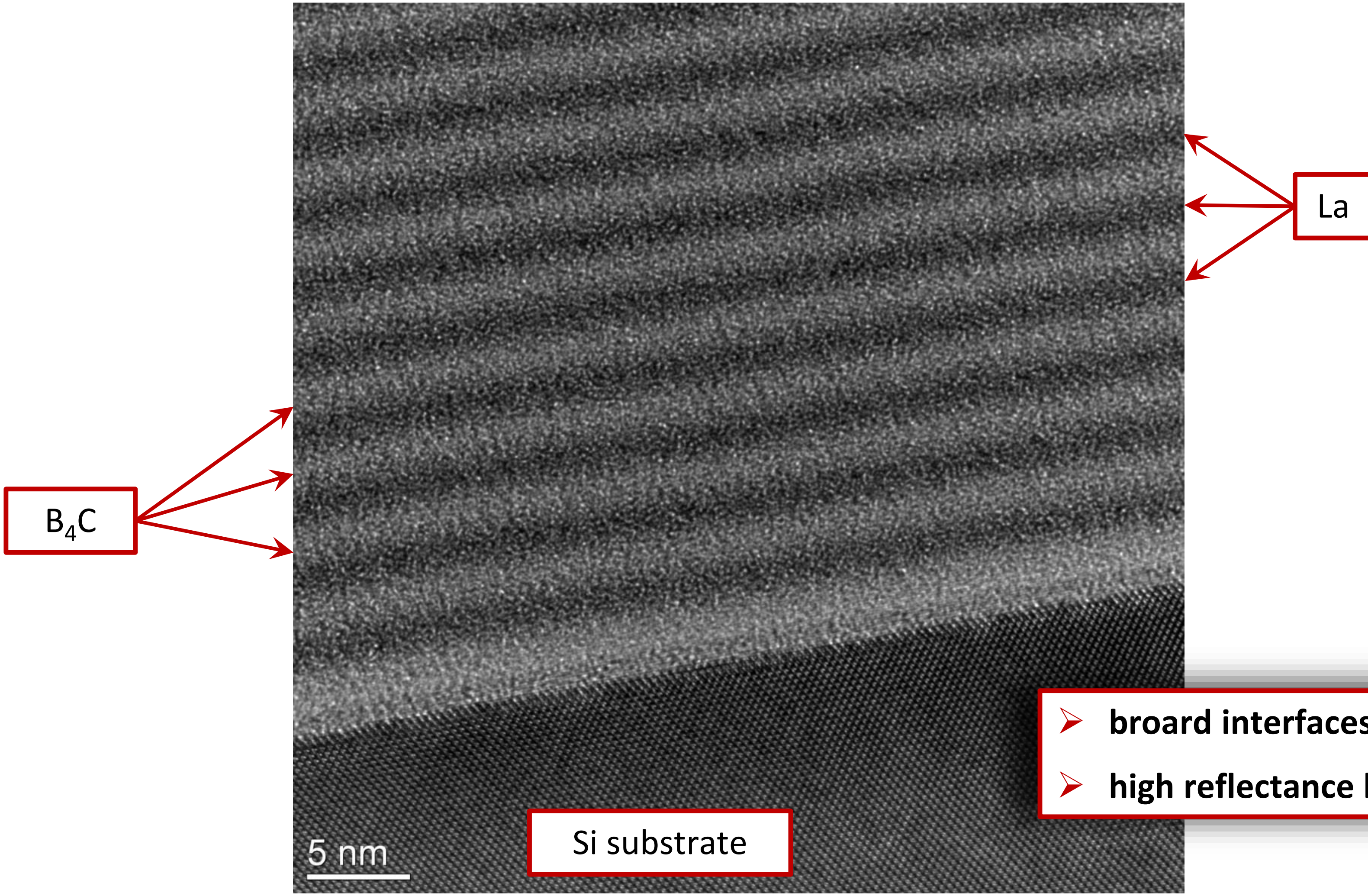
<u>Optimized experiments:</u>

- still low reflectance
- huge difference between simulation and experiment



➢ **R = 51,1 %** @ 6,65 nm after optimizing all deposition parameters

HR-TEM of La/B_4C-ML

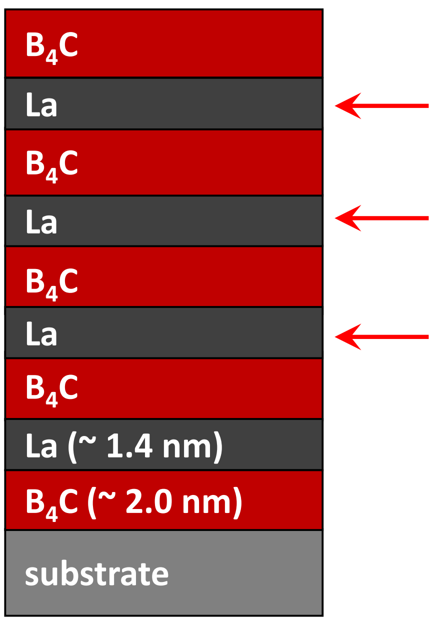


- broard interfaces
- high reflectance losses

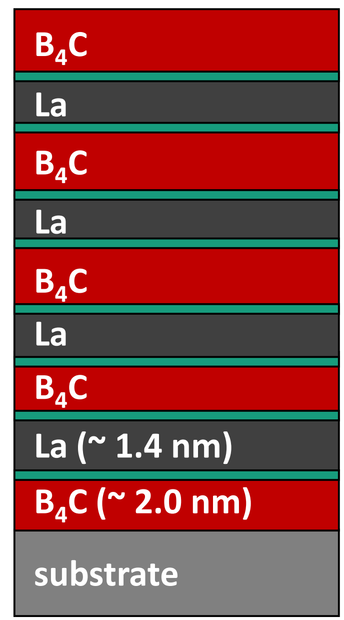
P. Naujok et al., Thin Solid Films 612, 414-418, 2016

Reducing the interface width

1. Utilizing chemically stable materials



2. Application of barrier layers



Reducing the interface width

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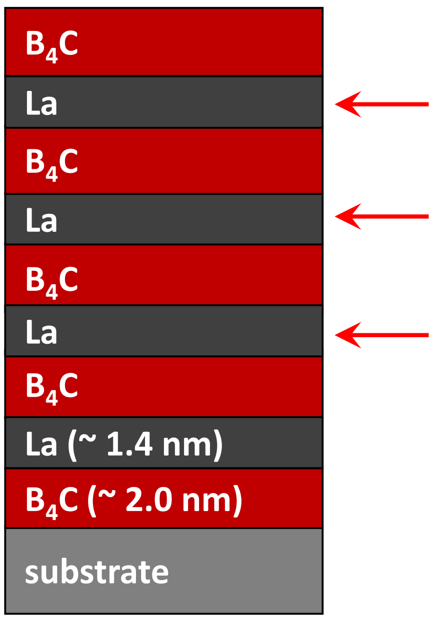

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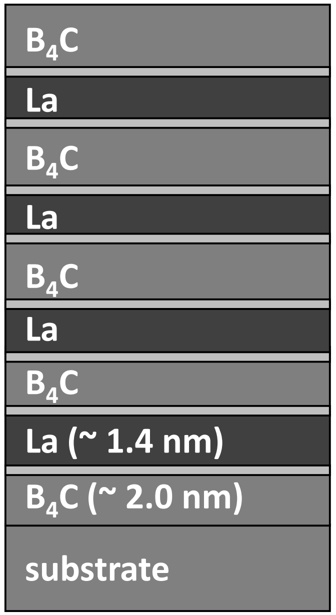
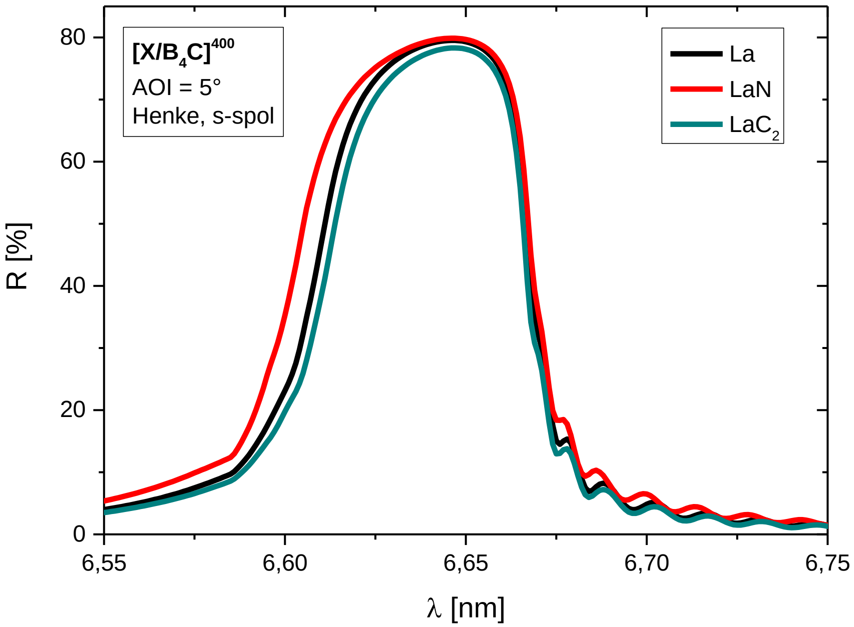


1. Chemical passivation of La layers

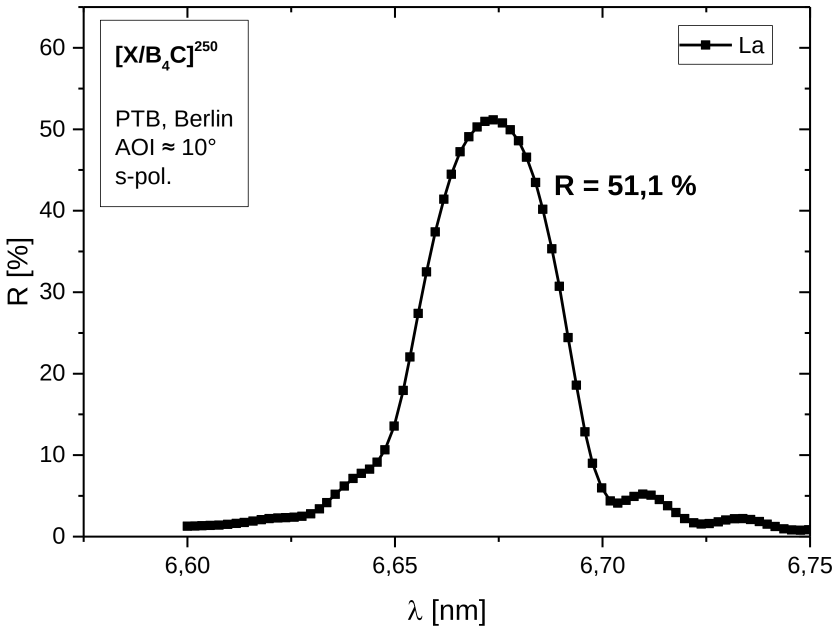
Theory:

- lowering chemical reactivity between B and La
- high peak reflectance achievable using La compounds
- expectation: higher experimental reflectance due to more narrow interfaces
- promising candidates:
  - LaN [1]
  - LaC_2



[1] T. Tsarfati et al., Thin Solid Films 518, 1365–1368 (2009)

1. Chemical passivation of La layers



System	EUVR @ 6,65 nm	
	R_{exp} [%]	$\Delta\lambda_{exp}$ [nm]
La/B_4C	51.1	0.036

P. Naujok et al., Thin Solid Films 612, 414-418, 2016

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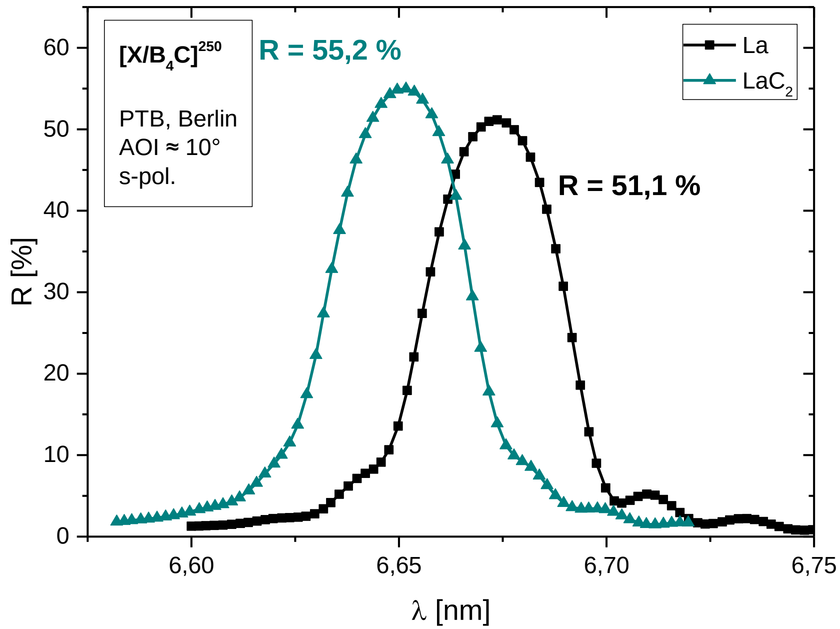

System	EUVR @ 6,65 nm	
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La/B_4C	51.1	0.036
LaC_2/B_4C	55.2	0.036

- increased reflectance due to less chemical rection between La and B_4C
  - R = 55,2 % @ 6,65 nm (LaC_2)

P. Naujok et al., Thin Solid Films 612, 414-418, 2016

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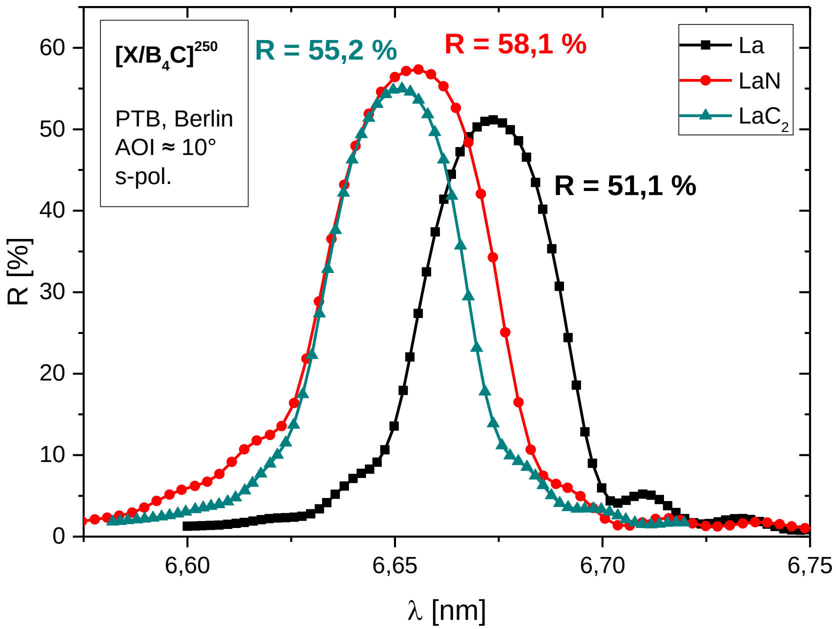

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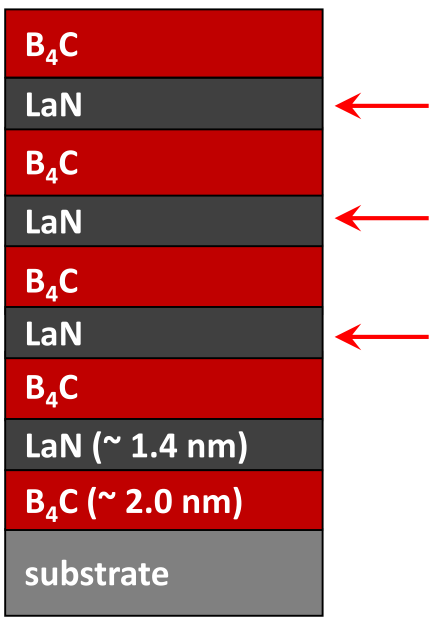
	R_{exp} [%]	$\Delta\lambda_{exp}$ [nm]
La/B_4C	51.1	0.036
LaC_2/B_4C	55.2	0.036
LaN/B_4C	58.1	0.046

- increased reflectance due to less chemical rection between La and B_4C
  - R = 55,2 % @ 6,65 nm (LaC_2)
  - R = 58,1 % @ 6,65 nm (LaN)

P. Naujok et al., Thin Solid Films 612, 414-418, 2016

Reducing the interface width

1. Utilizing chemically stable materials → LaN



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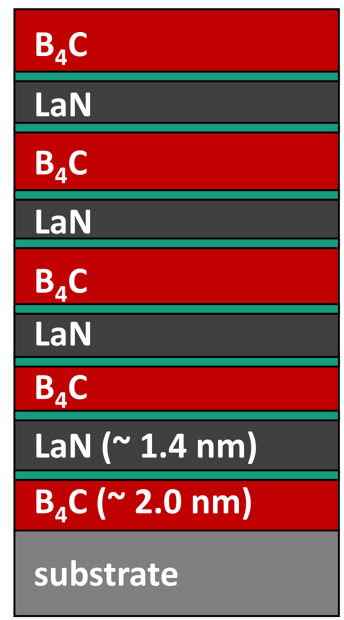
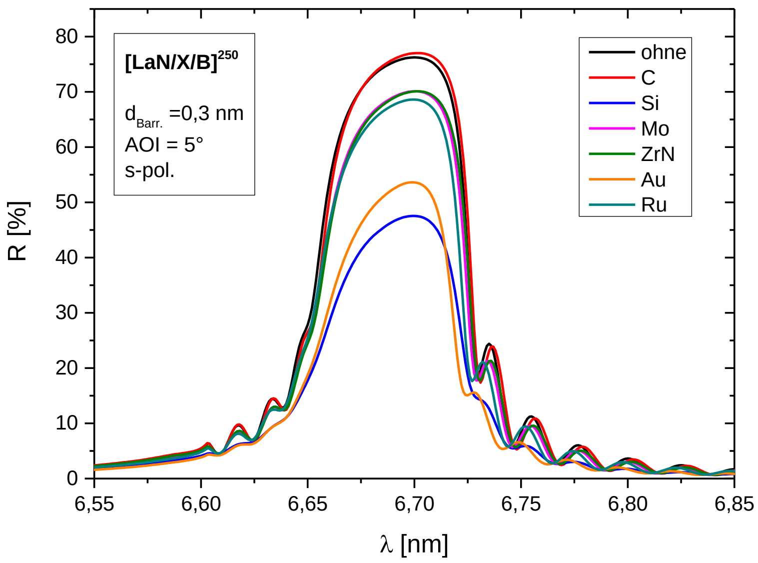
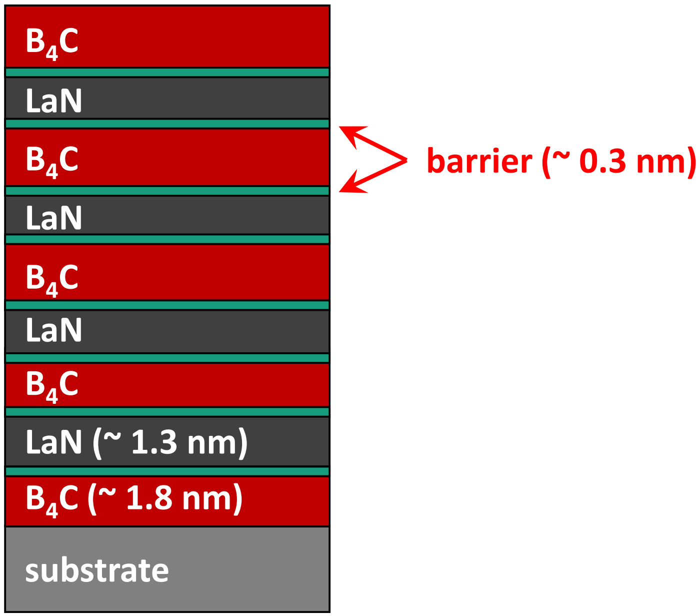


2. Application of barrier layers

- barrier thickness 0.3 … 0.5 nm
- important critera:
  - optical properties
  - film growth
  - chemical reactivity with La, B, C, N

simulation for ideal layers:





chosen candidates:

- C
- Mo
- ZrN

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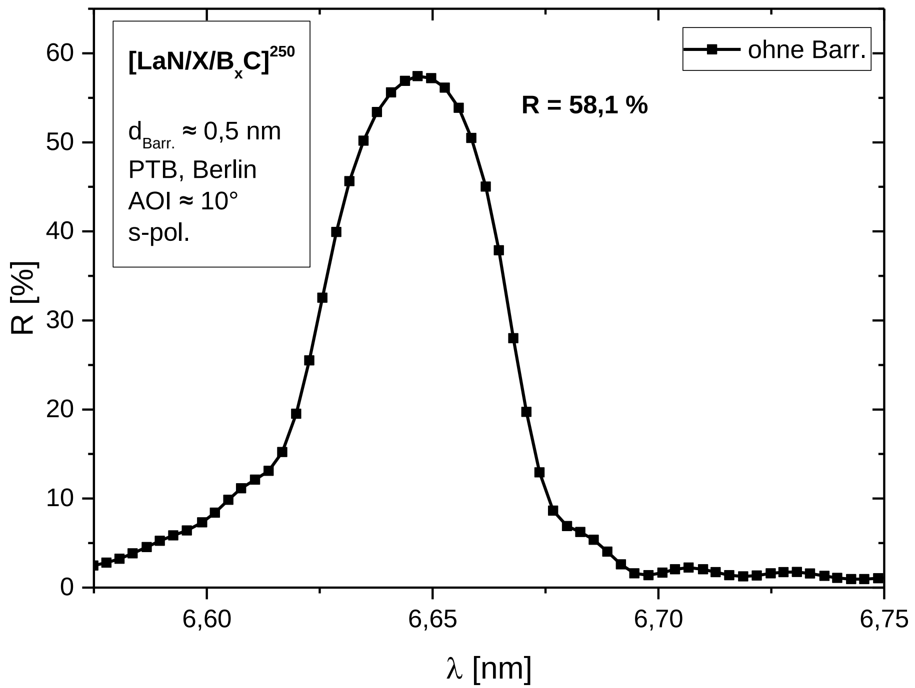

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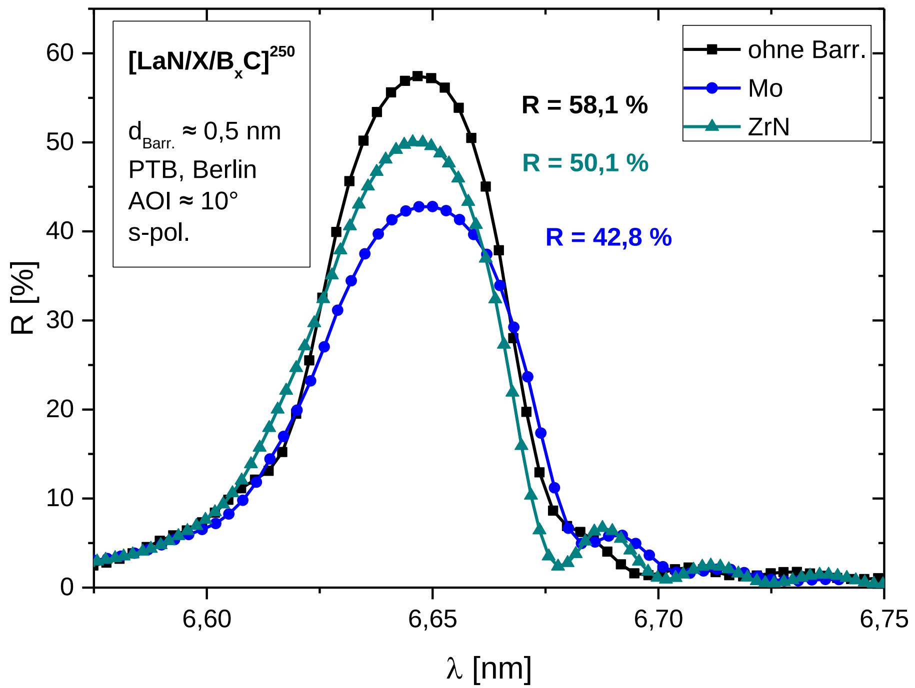

- **huge impact** on reflectance by extremly thin barriers
- no increased reflectane with

  Mo (ΔR = - 15.3 %)

  ZrN (ΔR = - 8.0 %)

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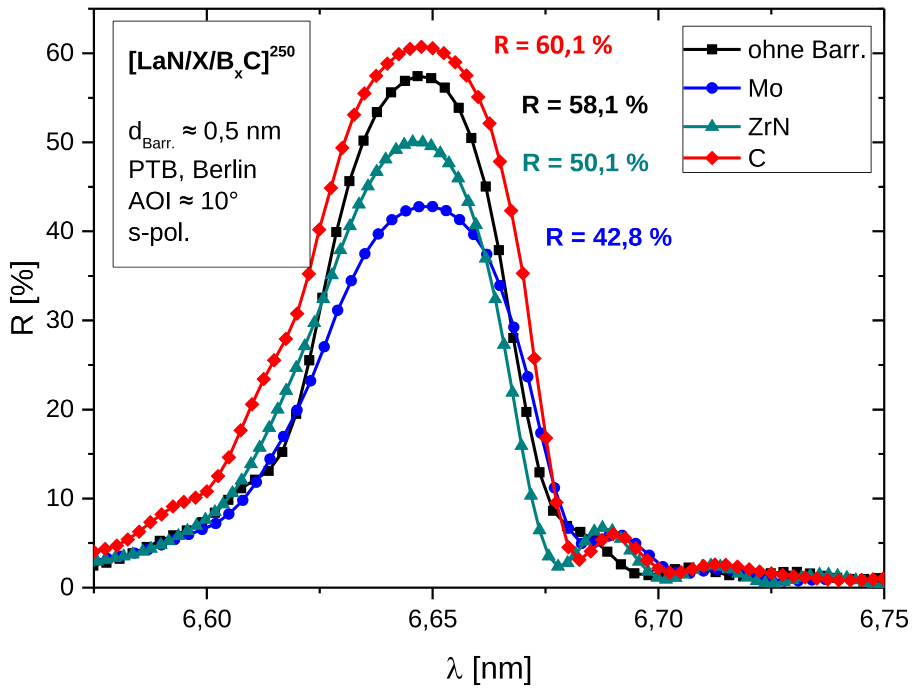

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- no increased reflectane with

  Mo (ΔR = - 15.3 %)

  ZrN (ΔR = - 8.0 %)
- **increased** reflectance with **C-barriers**

  C (ΔR = + 2.0 %)

Current best result using C-barriers

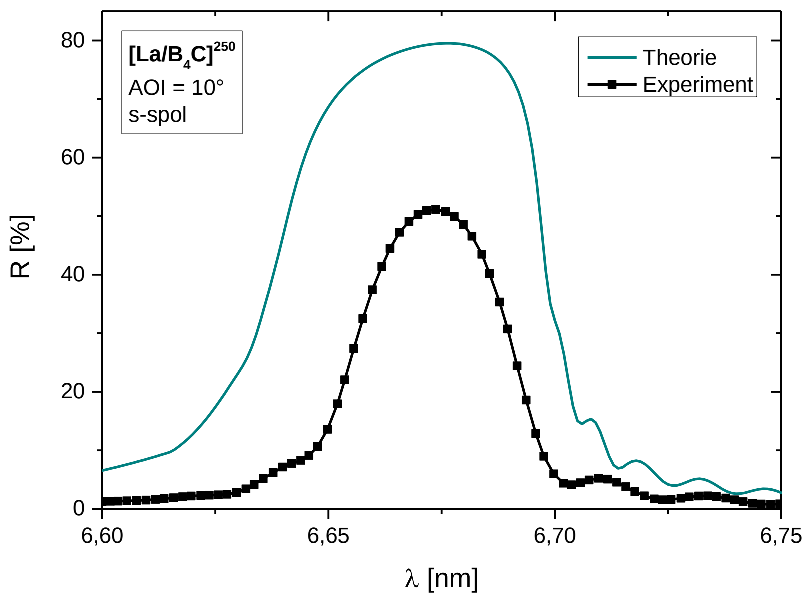
R = 60.1 % @ 6,65 nm (AOI = 10°)

Summary

- huge difference between ideal and experimental reflectance at 6.7 nm wavelength
- reflection losses due to roughness, intermixing and chemical reactions at the interfaces

<u>best results:</u>

- La/B_4C: R = 51.1 %



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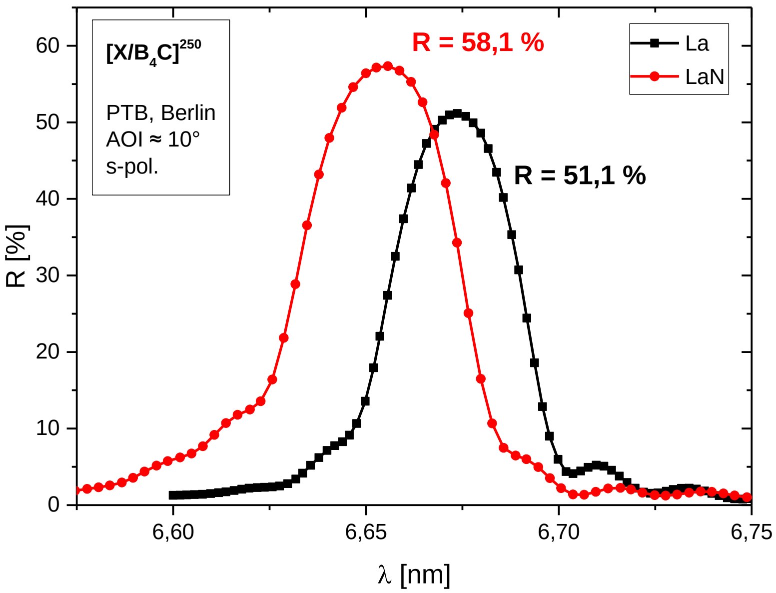

Fraunhofer IOF

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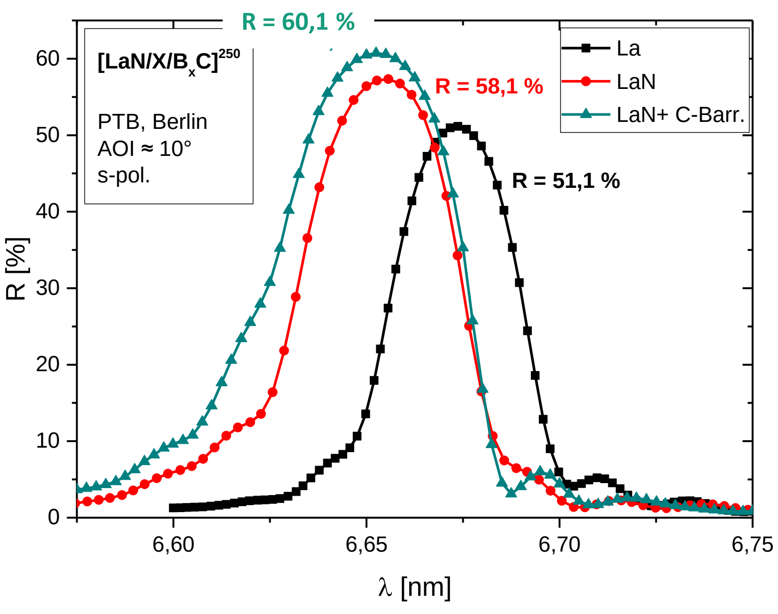

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next steps:

- current championship data: R = 64.1 % using La/LaN/B [2]
- target for HVM: R > 70 %
- therefore: lower chemical reactivity, optimize barrier layers needed

[2] D. Kuznetsov et al., Optics Letters 40 (16) (2015)

Thank you.