

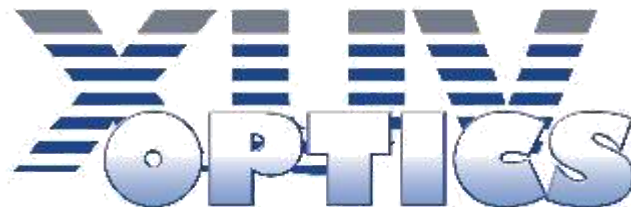
# Normal- and grazing incidence mirrors for 6.x nm wavelength

Dmitry Kuznetsov, Andrey Yakshin, Marko Sturm,  
Robbert van de Kruijs, Eric Louis and Fred Bijkerk  
(*XUV Optics Group, MESA+, University of Twente, the Netherlands*)

PXRNMS Workshop, Enschede, the Netherlands

10-11 November 2016

[d.kuznetsov@utwente.nl](mailto:d.kuznetsov@utwente.nl)



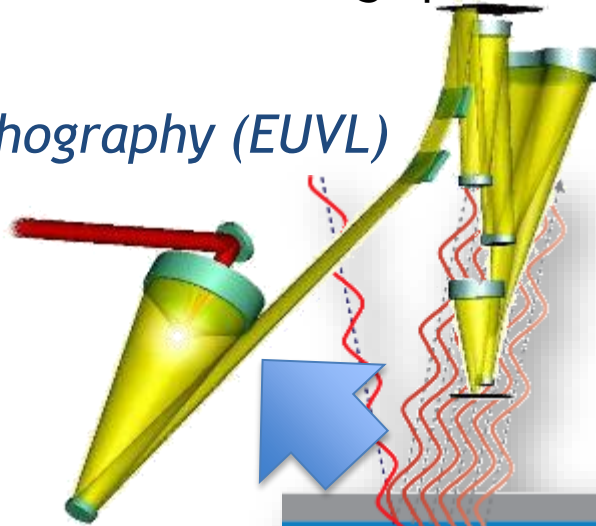
# Motivations for 6.x nm multilayers

General trend: extend the high performance of 13 nm to shorter wavelengths

**EUV Photolithography (EUVL)**  
Specific case



**ASML**

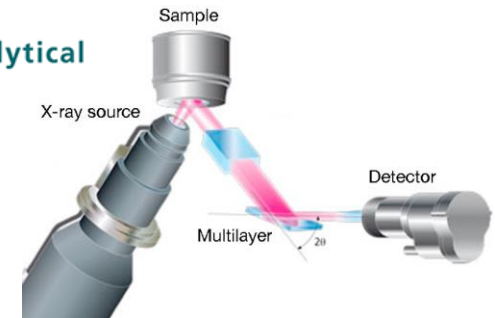


**XRF Materialanalysis**

Ultrasensitive detection using X-ray Fluorescentation



**PANalytical**

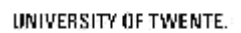
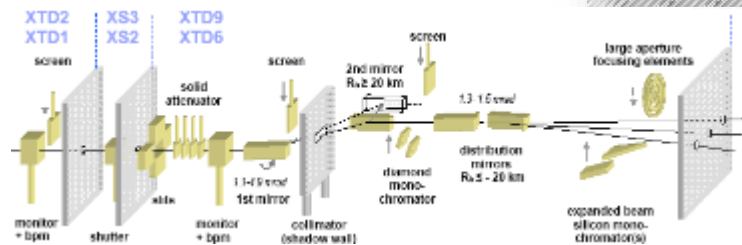


**Space research**  
XUV telescopes



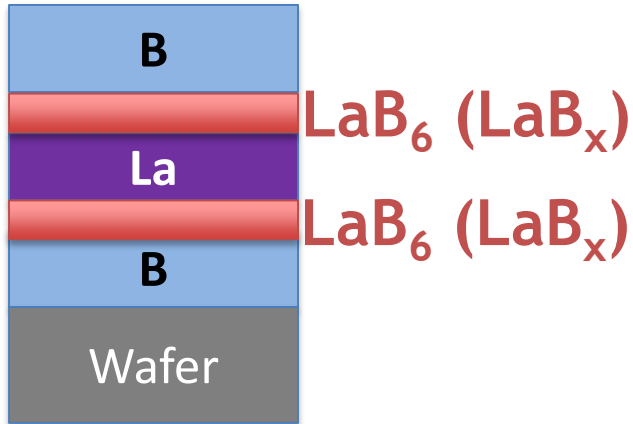
**Optics for high intensity light sources**

X-ray Free Electron lasers

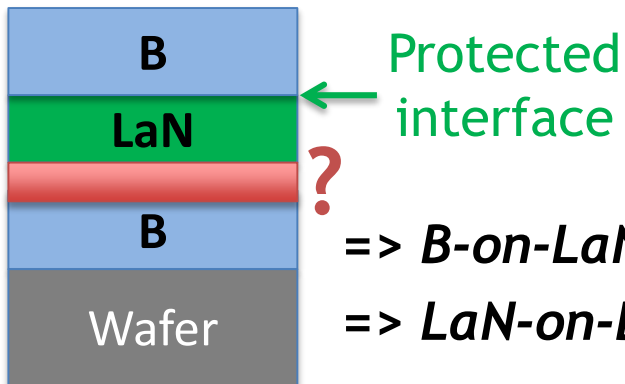


# 6.x nm normal-incidence

La/B

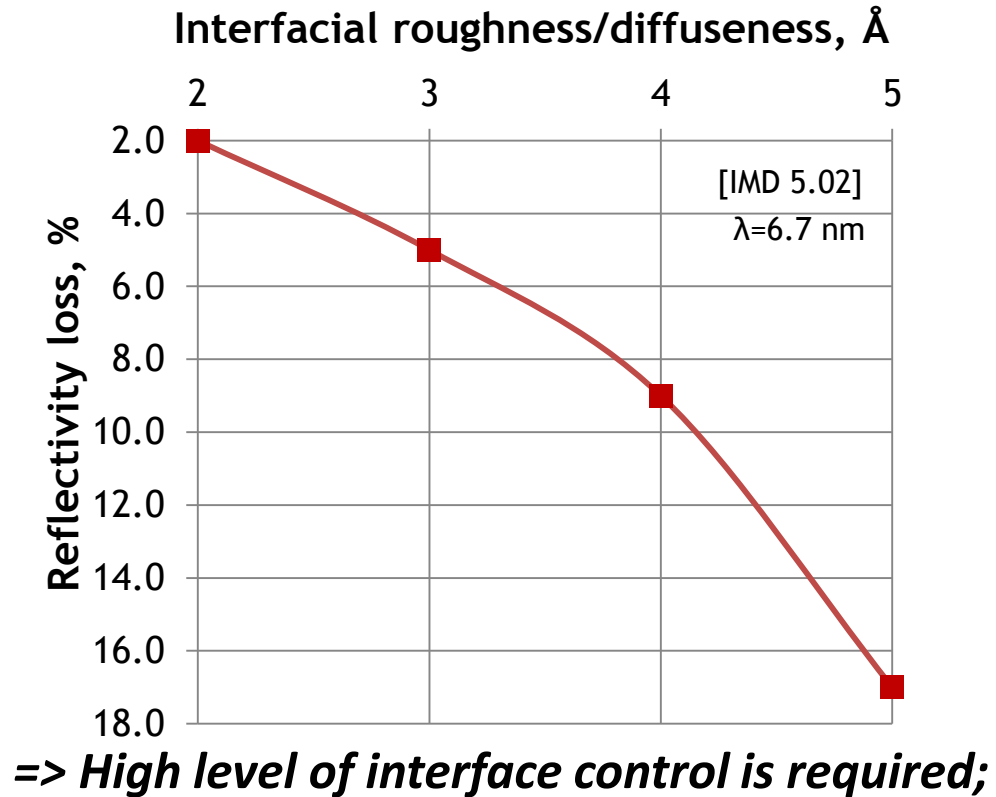


La nitridation (LaN/B) [1]



=> B-on-LaN interface protected

=> LaN-on-B needs further investigation

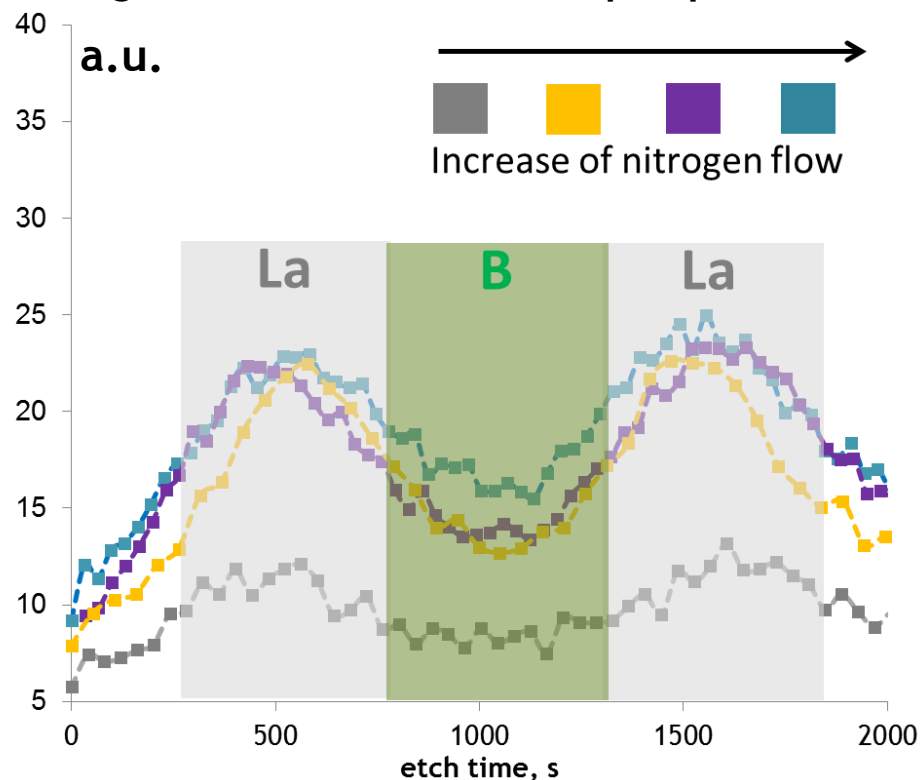


[1] I.A. Makhotkin et al., Optics Express 21, 29894 (2013)

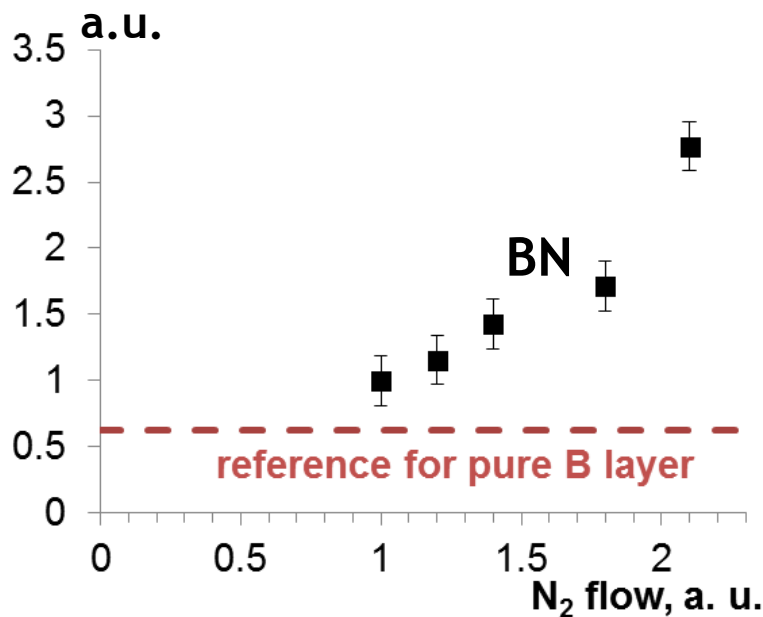
# Dealing with chemical interaction

Idea: minimize interaction of B with LaN => fully passivated LaN (saturated with N).

Nitrogen content from XPS depth-profile



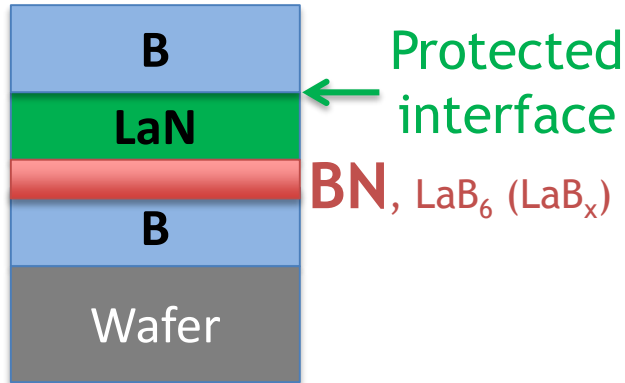
BN content from XPS without depth-profile



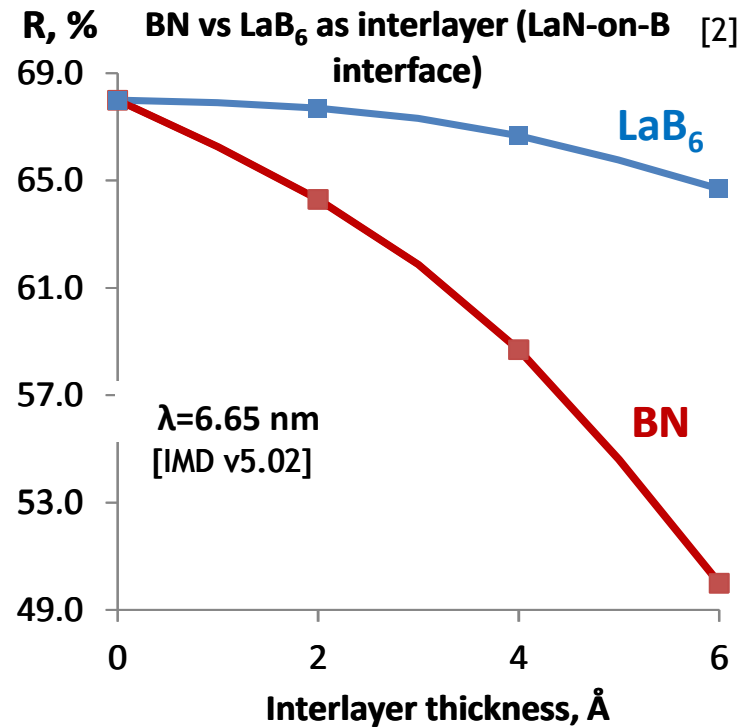
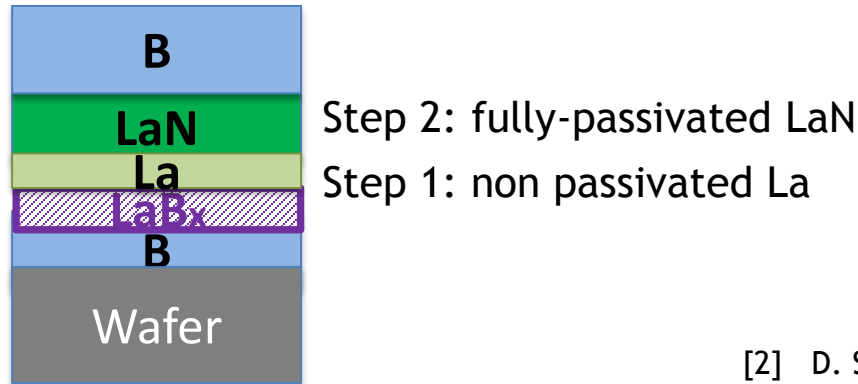
=> *Reactive deposition of LaN saturated with nitrogen is inevitably accompanied by formation of BN compound. Influence of BN - ?*

# Partial (delayed) nitridation

Initial system:  $\text{LaN}/\text{B}$



Partial nitridation [2]:  $\text{LaN}/\text{La}/\text{B}$

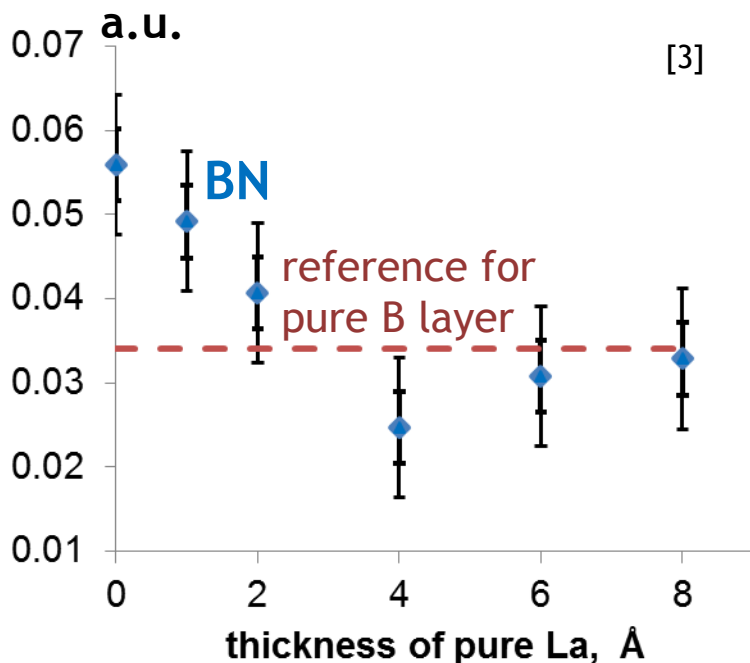


**=>  $\text{LaB}_x$  on LaN-on-B interface optically preferable over BN.**

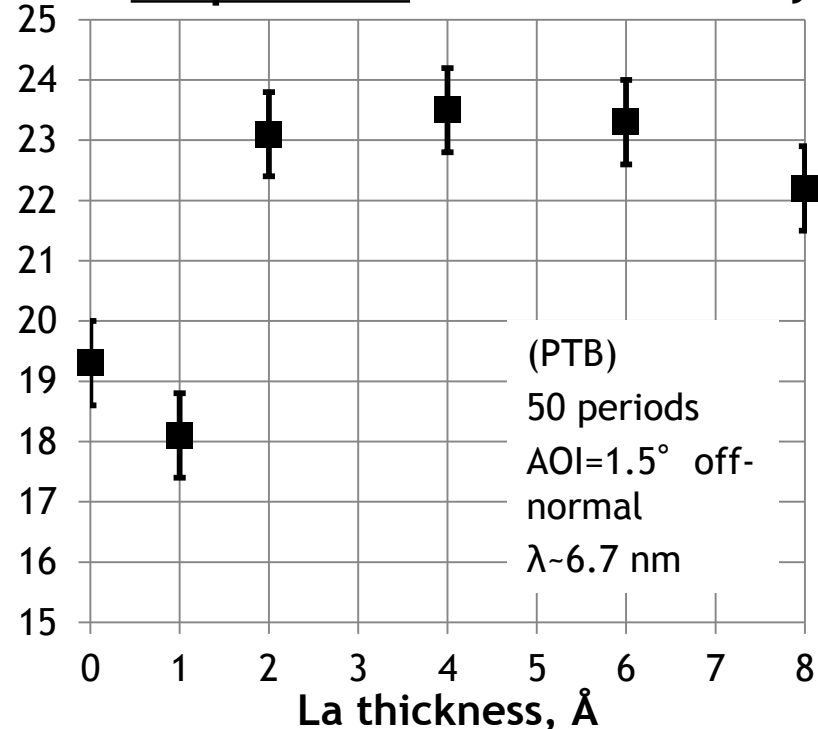
[2] D. S. Kuznetsov et al., Optics Letters, Vol. 40, No. 16 (2015)

# Partial (delayed) nitridation study

BN content (XPS)



R, % 50 periods 6.x nm reflectivity



**Reduction of BN => sharp increase of 6.x nm reflectivity;**

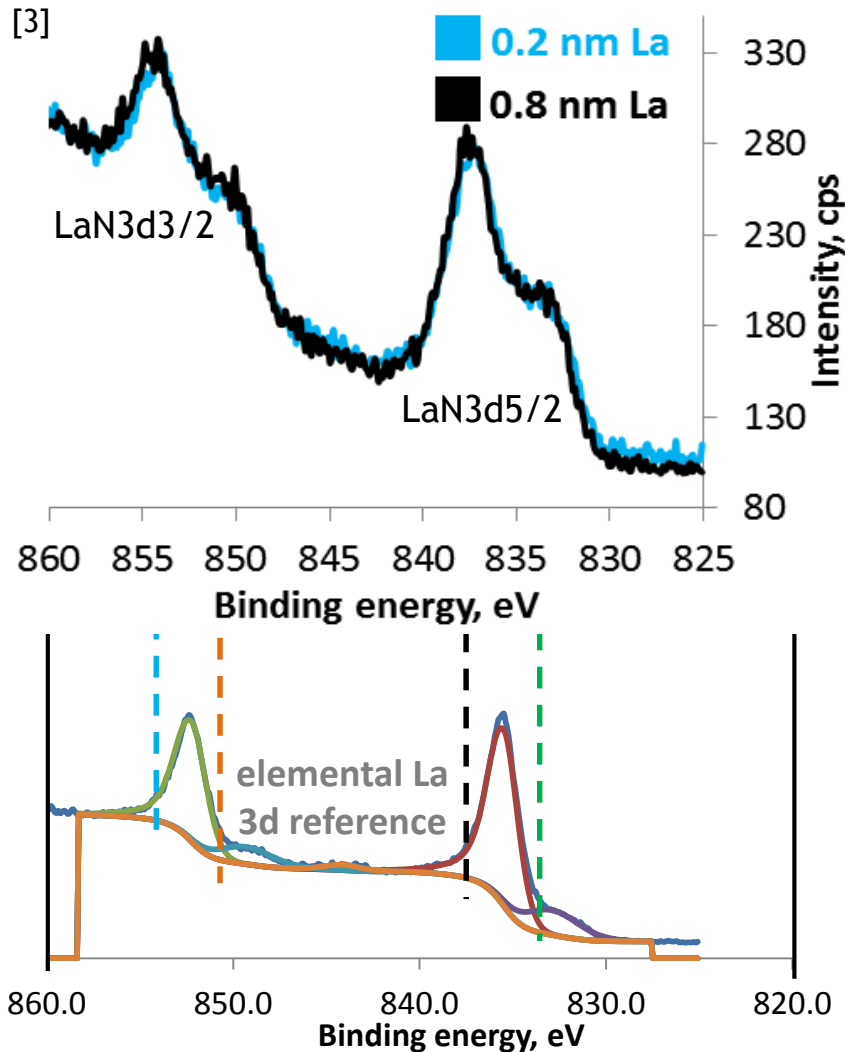
**To reduce BN, thick enough (closed) layer is needed.**

*What is this layer - ? (LaB<sub>x</sub> - ? La - ? ...)*

[3] D. S. Kuznetsov et al., accepted by AIP Advances (2016)

# Compound formation upon La on B growth?

(one example of analyzed XPS spectra)



**No difference in elemental La in LaN\La\B if La 0.2 or 0.8 nm.**

LaB<sub>x</sub> - ?

[IMD v5.02]: R drops by 3.0% @ 6.65 nm if LaB<sub>6</sub> interlayer 2 -> 6 Å.

Exp.: no difference in R (within reproducibility ~1%) even for 8 Å La.

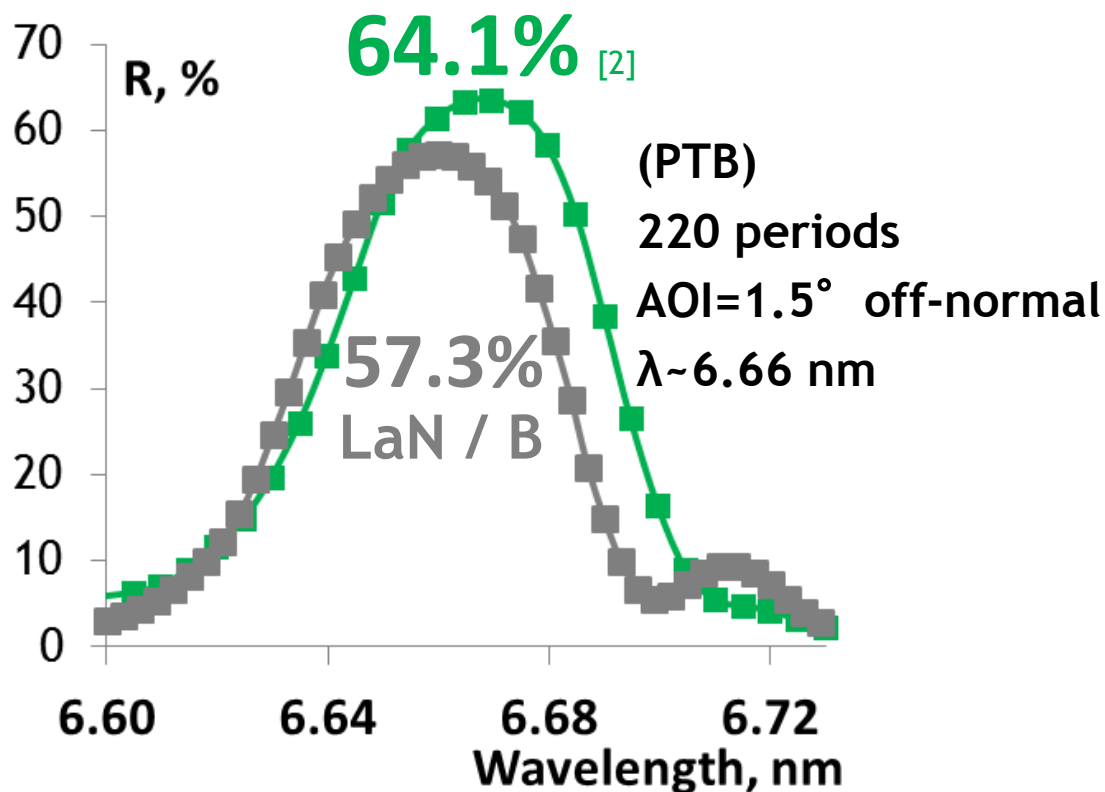
**=> Initial LaB<sub>x</sub> growth is followed by elemental (pure) La growth.**

**=> Remaining La is nitridized by subsequent reactive deposition of LaN.**

[3] D. S. Kuznetsov et al., accepted by AIP Advances (2016)

# Normal-incidence reflectivity

Partial (delayed) nitridation (LaN \ La \ B) [2]



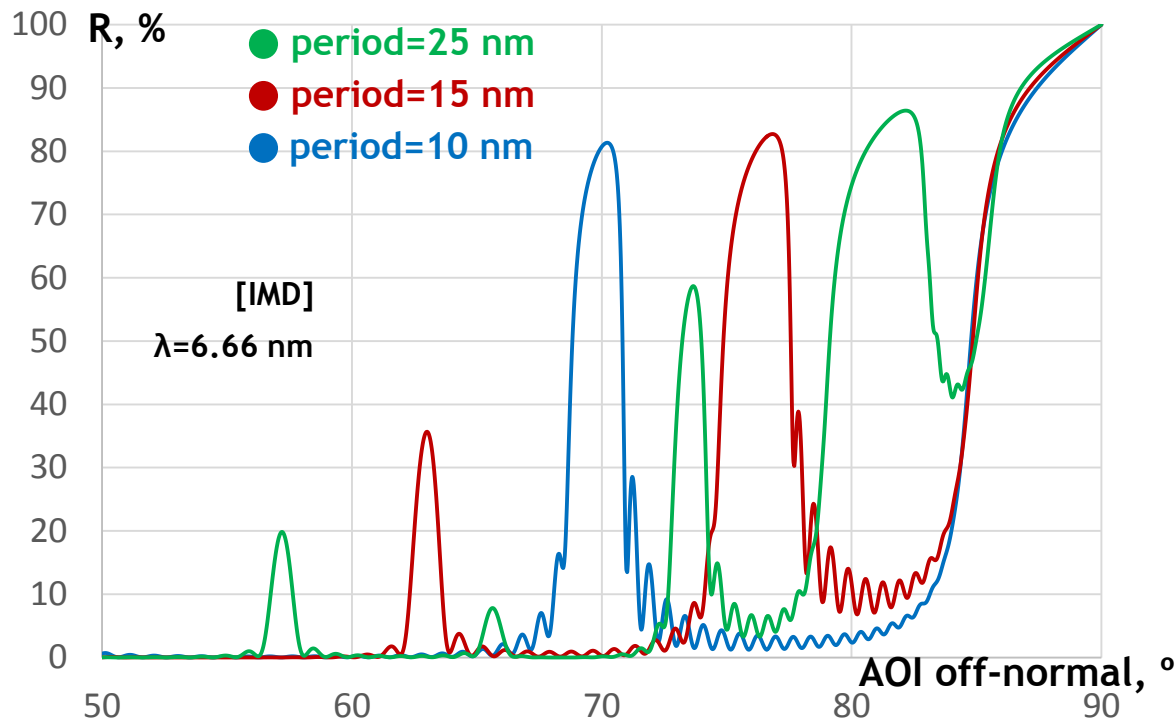
=> Partial nitridation of La results in significant increase of normal incidence reflectance

[2] D. S. Kuznetsov et al., Optics Letters, Vol. 40, No. 16 (2015)



# Grazing-incidence for 6.x nm

## Simulations



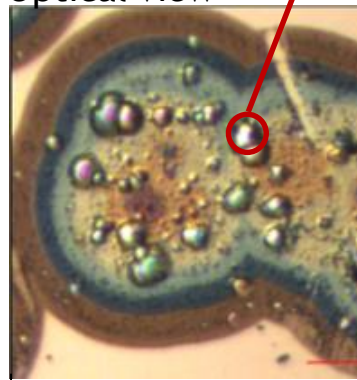
=> *Theoretically R > 80% achievable*

# GI LaN/B instable to storage

AFM cross-section

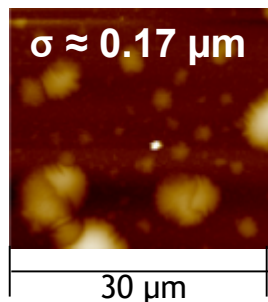


Optical view

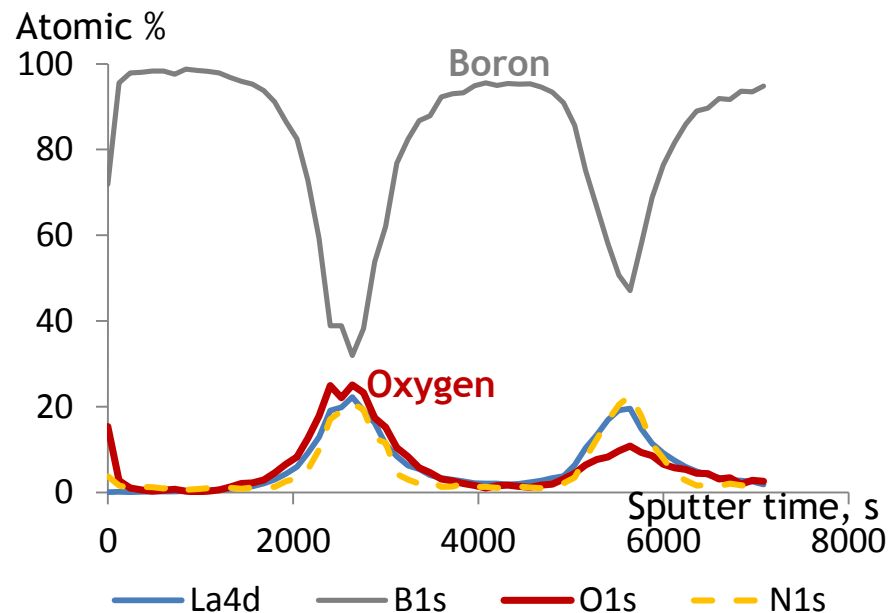


Typical ~100 μm

AFM 2D

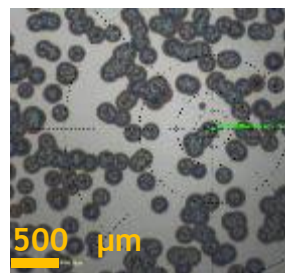


XPS depth-profile (DP)



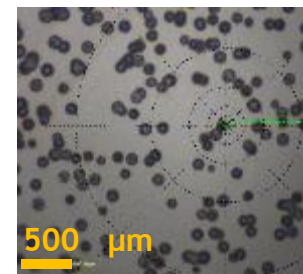
*~1 week after deposition:  
circular defects, roughening,  
blistering and complete  
oxidation of LaN.*

Before DP



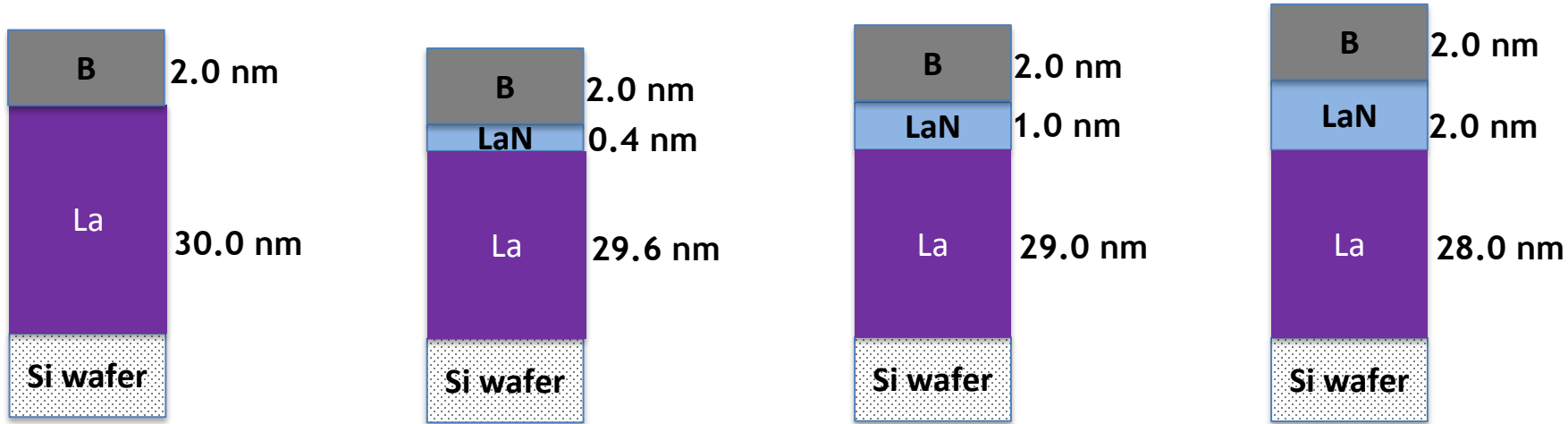
Ar<sup>+</sup>, 0.5 keV  
→

After DP

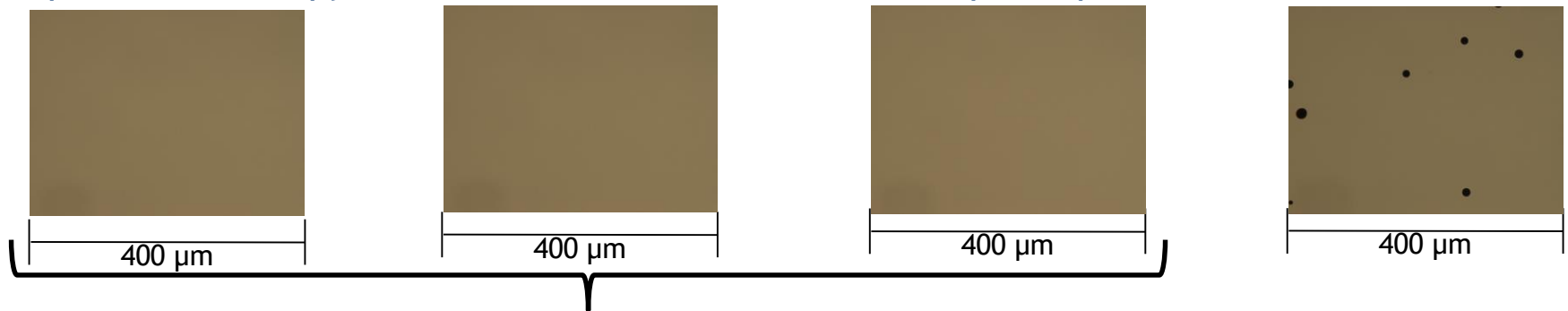


# Idea of “surface nitridation” of La

Test experiment based on single layers:



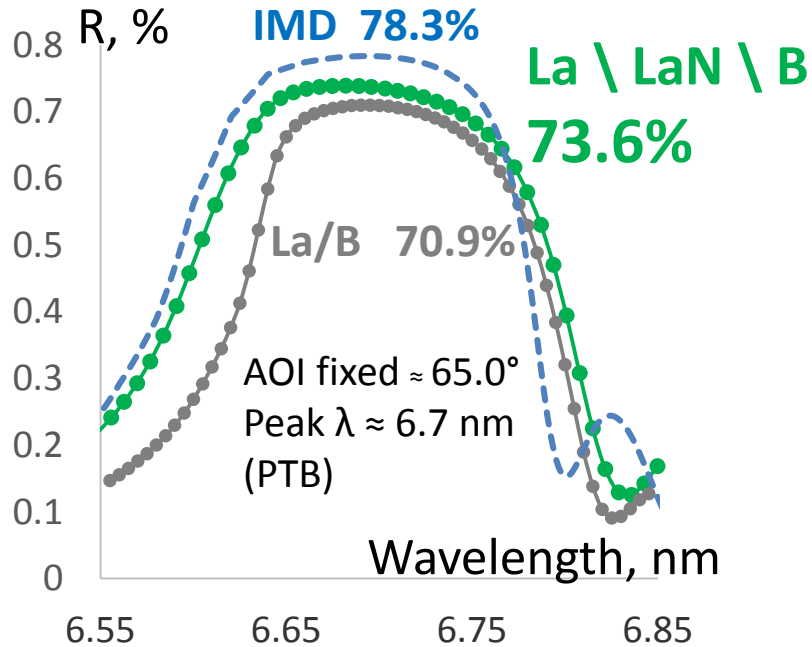
Optical microscopy taken in 1 week after the each sample deposition



***LaN < 2 nm on top of La does not show oxidation (with 2nm B-cap) => try to use for GI multilayers.***

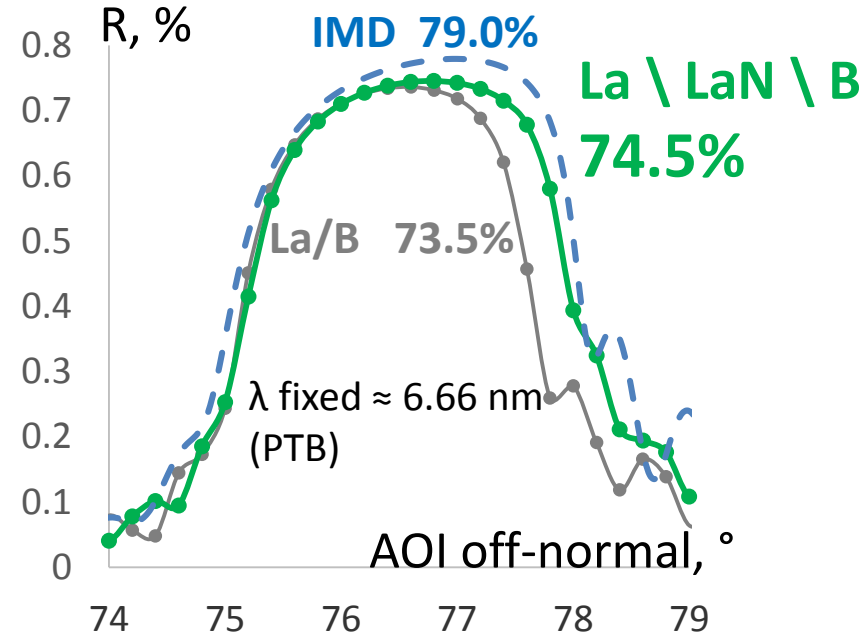
# GI reflectivity

8.x nm period.



➤ Gain by LaN interlayer: 2.7%

15.x nm period.



➤ Gain by LaN interlayer: 1.0%

=> Increase of GI reflectivity by La “surface nitridation”

# Summary

## Normal-incidence (NI)

- Partial (delayed) La nitridation applied to reduce BN,  $R=64.1\%$  at  $\sim 6.66$  nm,  $AOI=1.5^\circ$  off-normal achieved.
- $LaB_x$  formed during partial (delayed) nitridation of La;  
Further: deposition of elemental La;  
Nitridization by subsequent deposition of LaN.

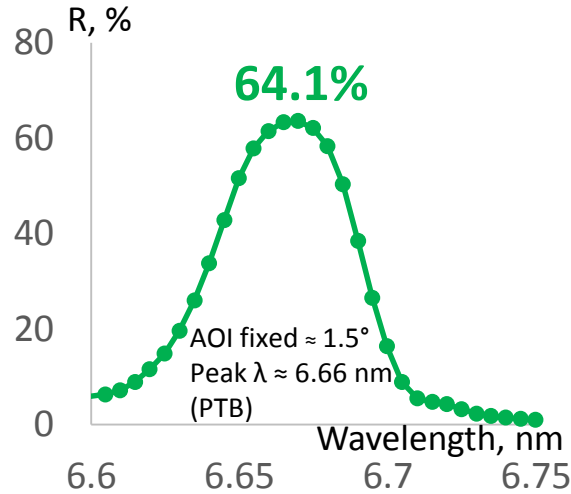
## Grazing-incidence (GI)

- GI (thick-period) LaN/B multilayer quickly oxidizes.
- Idea of La “surface nitridation” applied,  
improvement of R vs La/B achieved.

# Normal- and grazing-incidence 6.x

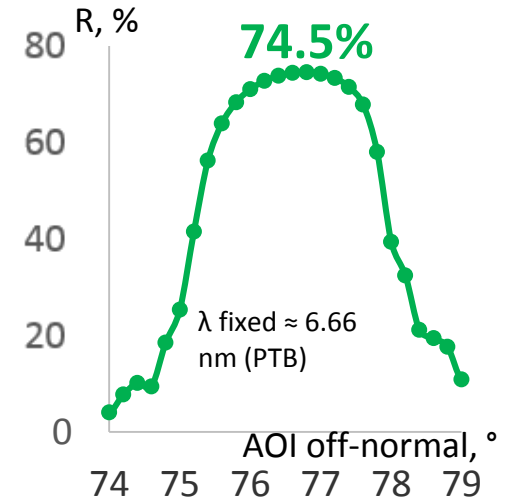
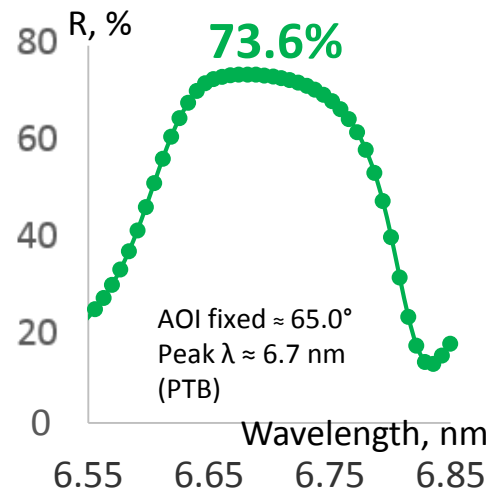
Normal-incidence

Partial (delayed) nitridation



Grazing-incidence

La surface nitridation



D. S. Kuznetsov et al., Optics Letters, Vol. 40, No. 16 (2015)

D. S. Kuznetsov et al., accepted by AIP Advances (2016)