Structural and reflective characteristics of Mo/Be multilayer with barrier layers

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Outline

- Motivation
- Experimental methods
- Methods for reconstruction of MLF's inner structure using X-ray reflectometry
- Experimental results on Mo/Be, Mo/Be/B_4C, Mo/Be/C and Mo/Be/Si MLM
- Summary and Discussion

Motivation

1. Shorter wavelength for the Next Generation (BEUV) Lithography

N. I. Chkhalo, N. N. Salashchenko. BEUV nanolithography: 6.7 or 11 nm? 2013 International Workshop on EUV and Soft X-Ray Dublin · Ireland · November 3-7 · 2013 (N.I. Chkhalo, N.N. Salashchenko. Next generation nanolithography based on Ru/Be and Rh/Sr multilayer optics // AIP Advances. 2013. Vol.3, Issue 8. P. 082130.)

2. Improving efficiency of optical systems for Lithography

2.1 $\Pr oductivity \sim R_m^N \times CE \ldots N = 10 - 11$

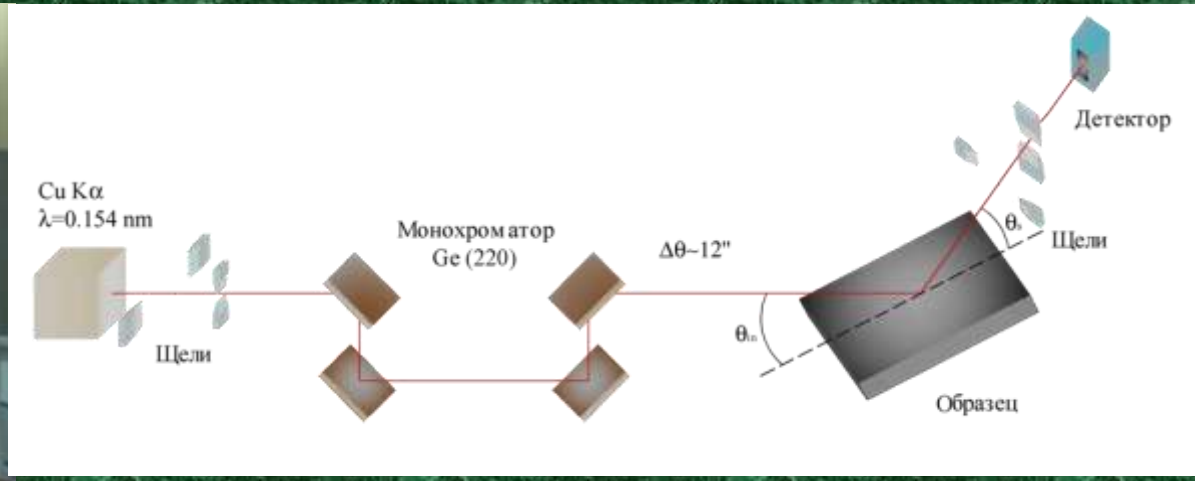
2.2 Why reflectivity of Mo/Be MLM 70% when theory predict 76%

2.3 Impact of Be to reflectivity of Mo/Si at 13.5 nm?

Experimental methods

1. Deposition: magnetron sputtering in Ar on Si wafers

2. Small-angle X-ray diffraction at 0.154 nm



$$\Delta\lambda_{nat} = 4.4 \cdot 10^{-5}\ \text{nm}$$

$$\Delta\theta_H \leq 0.0036°$$

3. Reflectometry in XEUV spectral range (λ=0.6-200 nm)

λ=0.6-25 nm
X-ray tube, lines

λ=30-200 nm
Low pressure discharge, lines

λ=4-70 nm
Laser plasma, continuous

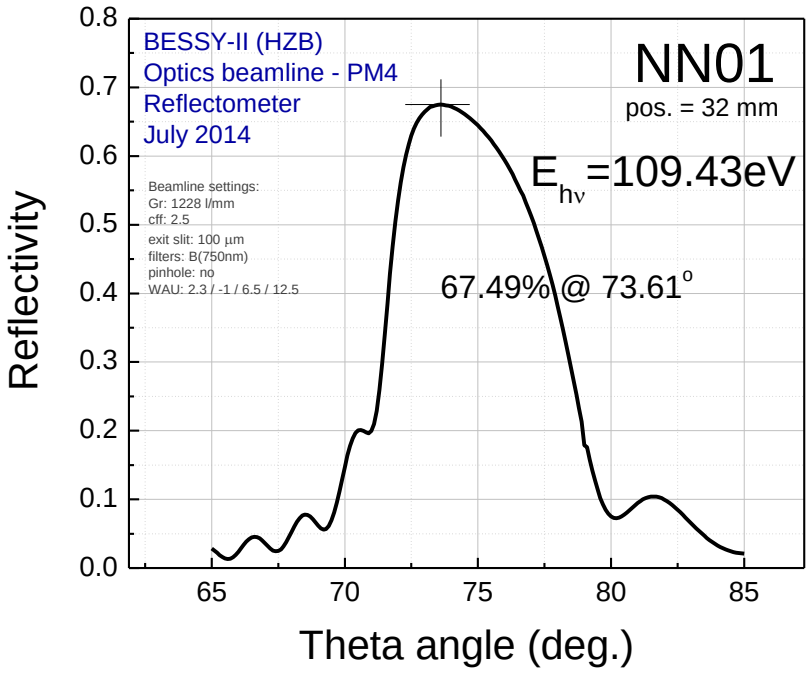
RSF-DFG 16-42-01034
Infrastructure of BESSY-II

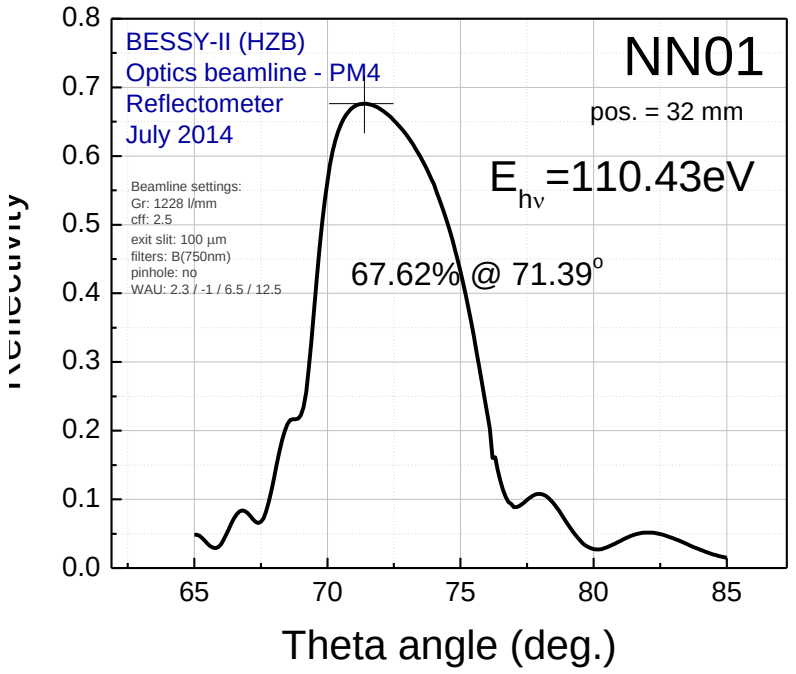
Methods for reconstruction of MLM's inner structure using X-ray reflectometry

Details of our approach

- Fitting is carried out simultaneously in Soft and Hard X-rays
- Fitting is carried out using interlayer regions as linear combination of erf, linear and exponential functions
- The result of the fitting procedure are distributions of MLM's inner parameters over realizations
- Comparing the average parameters of layers and interfaces with model-less approach

First experimental results with Mo/Be, Mo/Be/B4C and Mo/Be/C

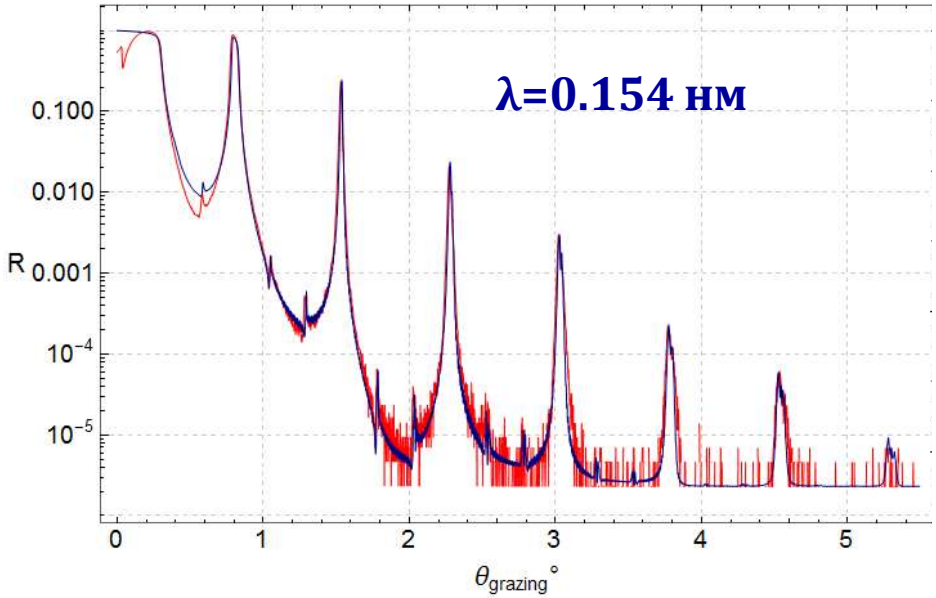


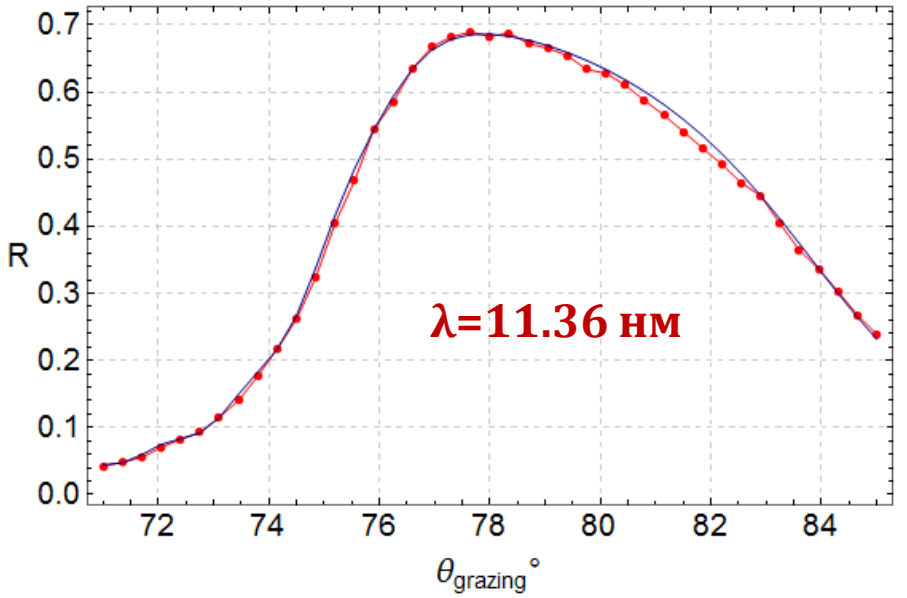


MLS	Thickness, nm	R,%
Mo/Be	2.5/3.4	67.0
Mo/Be/B4C	2.6/3/0.3	68.5
Mo/Be/C	2.6/3/0.3	69.2

Comparing the reflectance of Mo/Be, Mo/Be/B4C and Mo/Be/C MLM at λ=11.4 nm

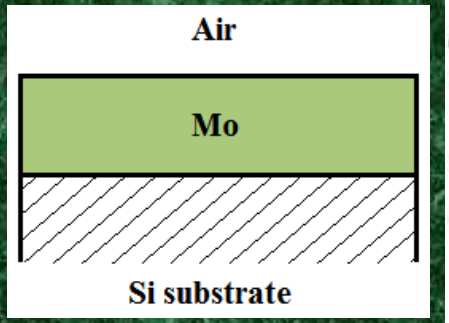
Experimental results: Mo/Be MLM inner structure (sample D307)

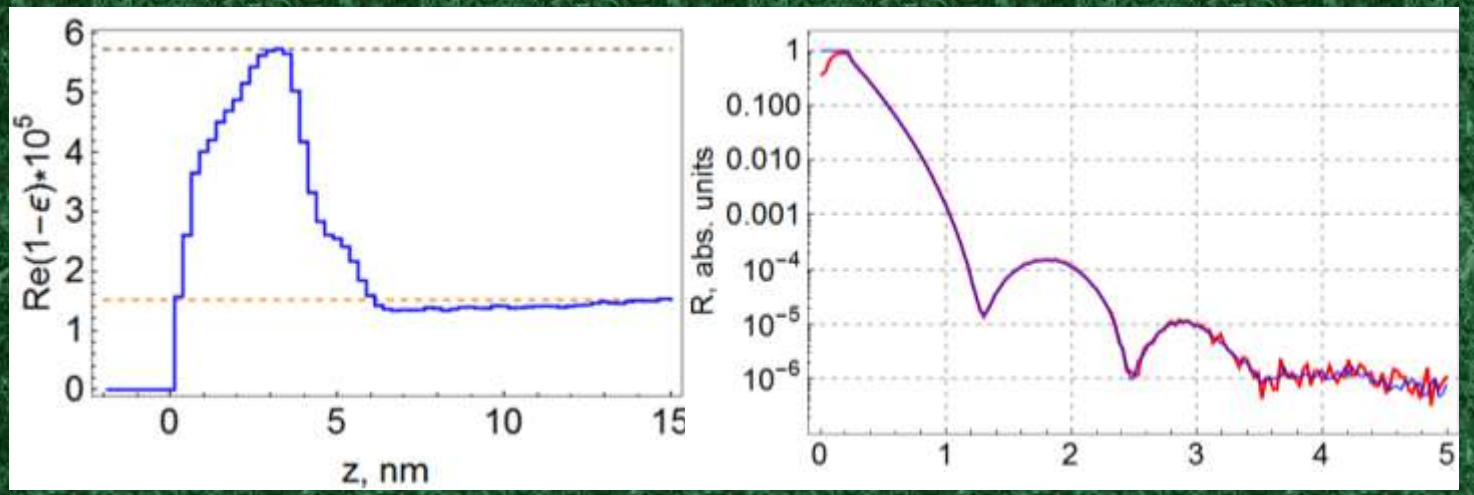


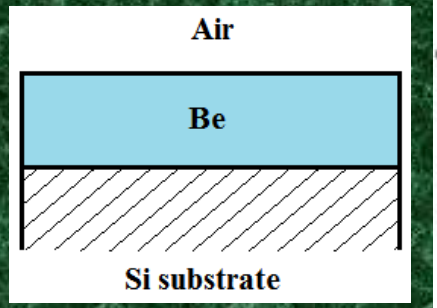


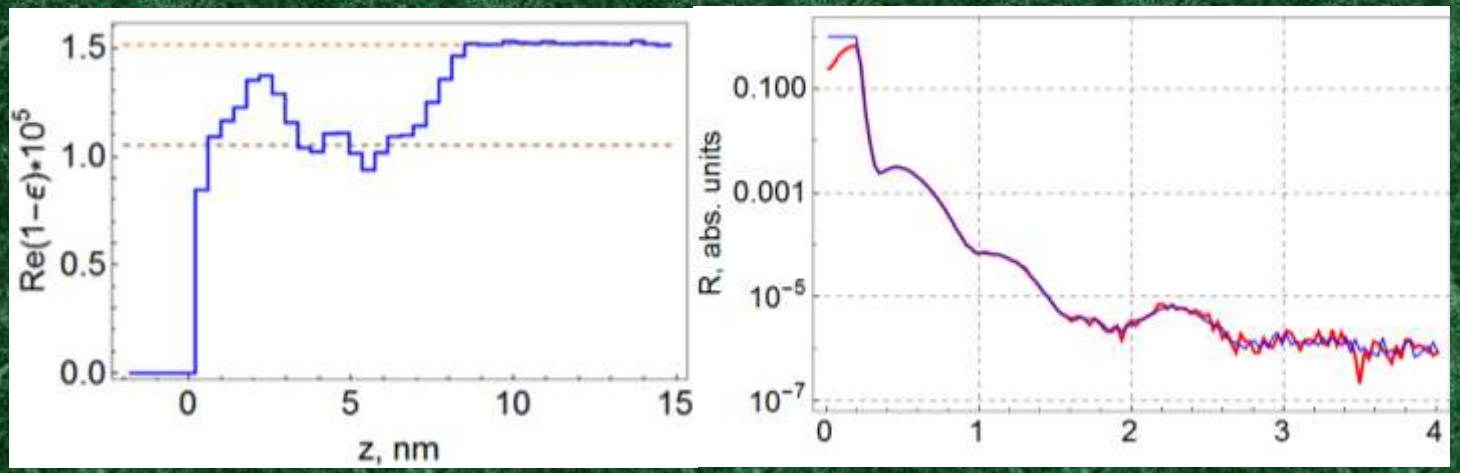
Number of periods	**N=110**
N_{th} period	**d_N=5.891 nm**
Thiskness	**h_{Be}=3.638 nm**
	h_{Mo}=2.253 nm
Gradient of period	**+0.013%×d**
Film density	**Be – solid**
	Mo - 97% of solid
Interface width	
Be-on-Mo	**0.36±0.02 nm**
Mo-on-Be	**0.71±0.04 nm**

Reconstruction of MLF's inner structure using X-ray reflectometry



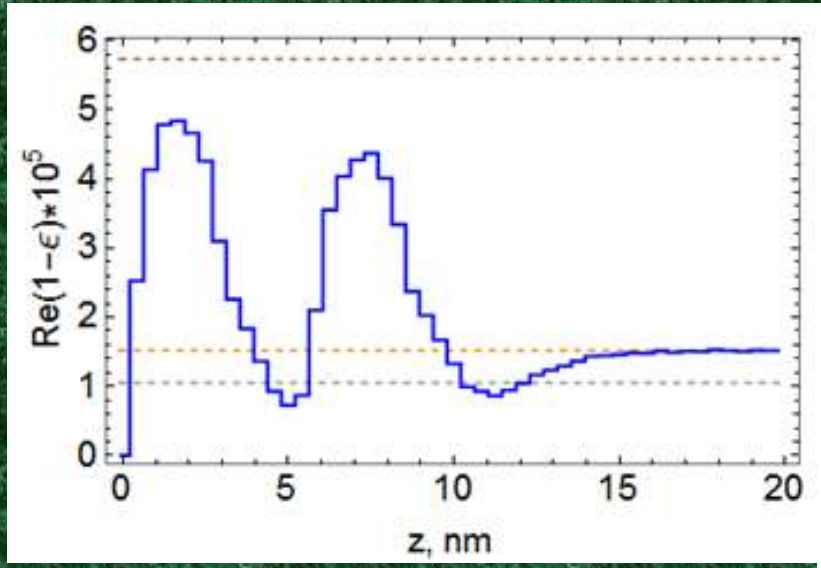


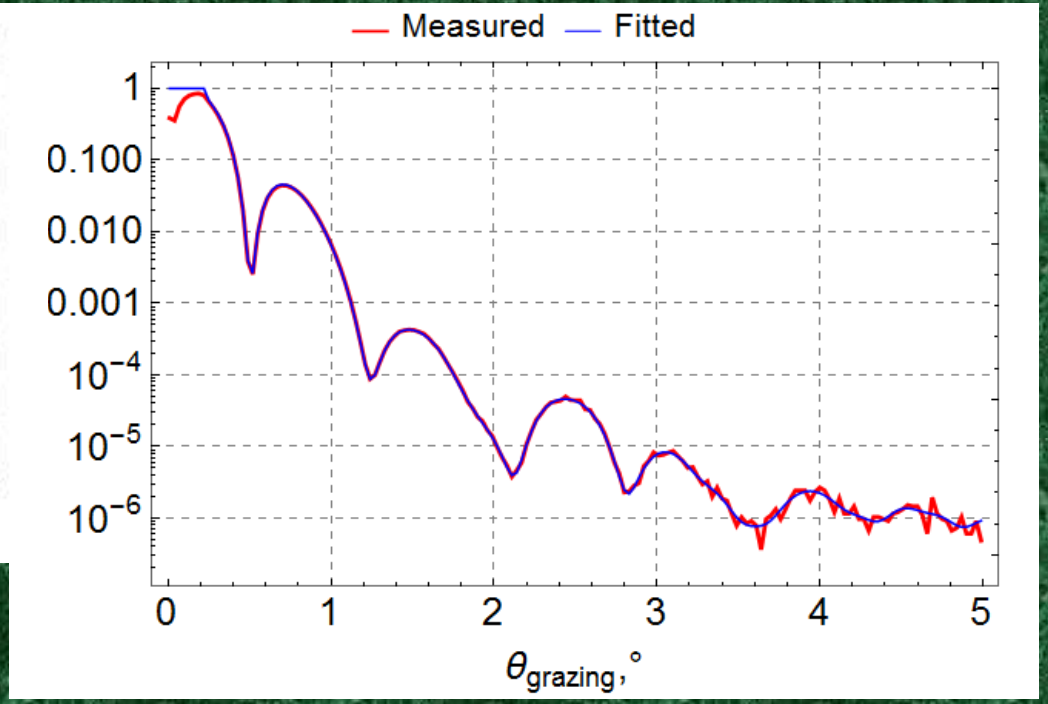


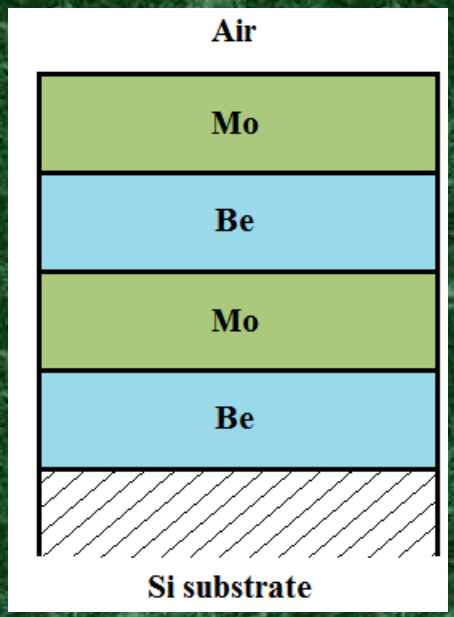


I. V. Kozhevnikov, NIM A **508**(3), 519–541 (2003)
I.V. Kozhevnikov, et al. Physical Review B 85, 125439 (2012)

Reconstruction of Si-Be-Mo-Be-Mo structure using X-ray reflectometry

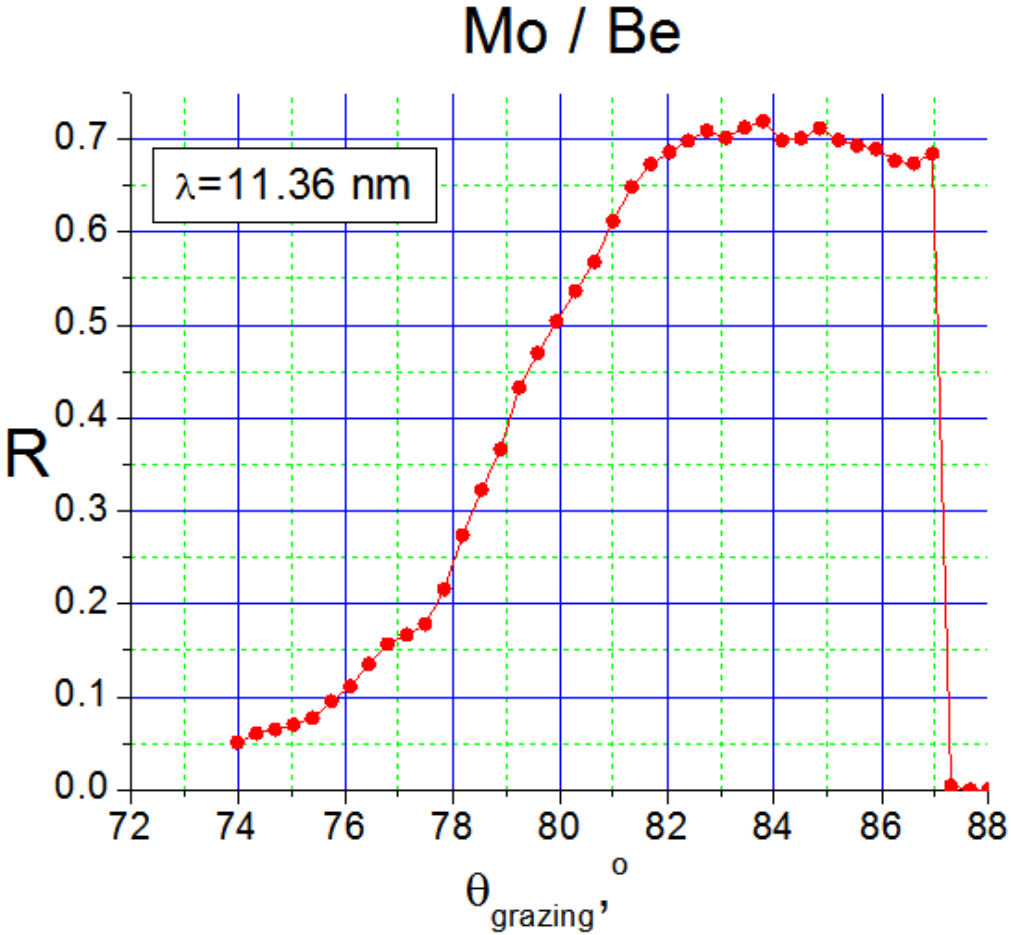






Asymmetry of the interfaces is clearly seen that proofs results of the fitting.

Experimental results: Mo/Be MLM reflectivity at normal incidence (sample D304)



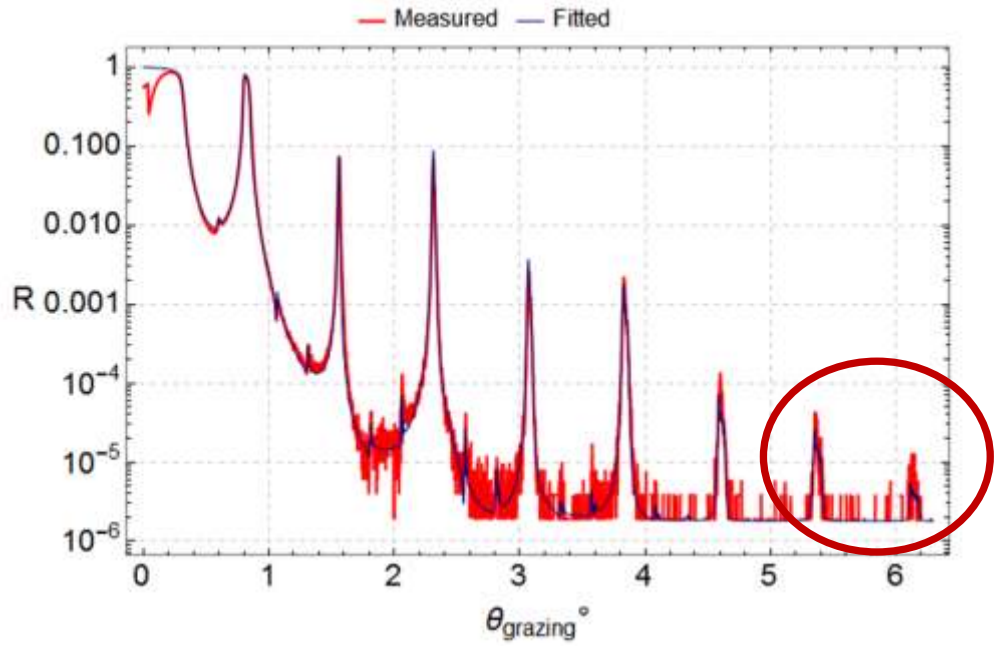
We obtain routinely reflection coefficients of Mo/Be MLM in the spectral range 11.3-11.4 nm at normal incidence reflection coefficients of 70 – 71%

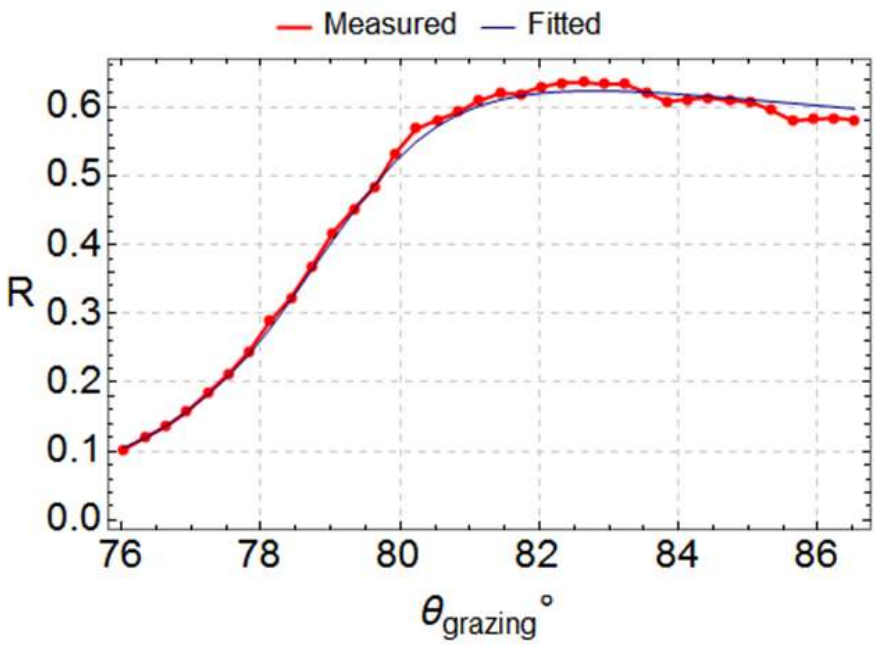
Problem

interface Mo-on-Be

σ=0.71 nm

Experimental results: Mo/Be/Si MLM (sample D324)



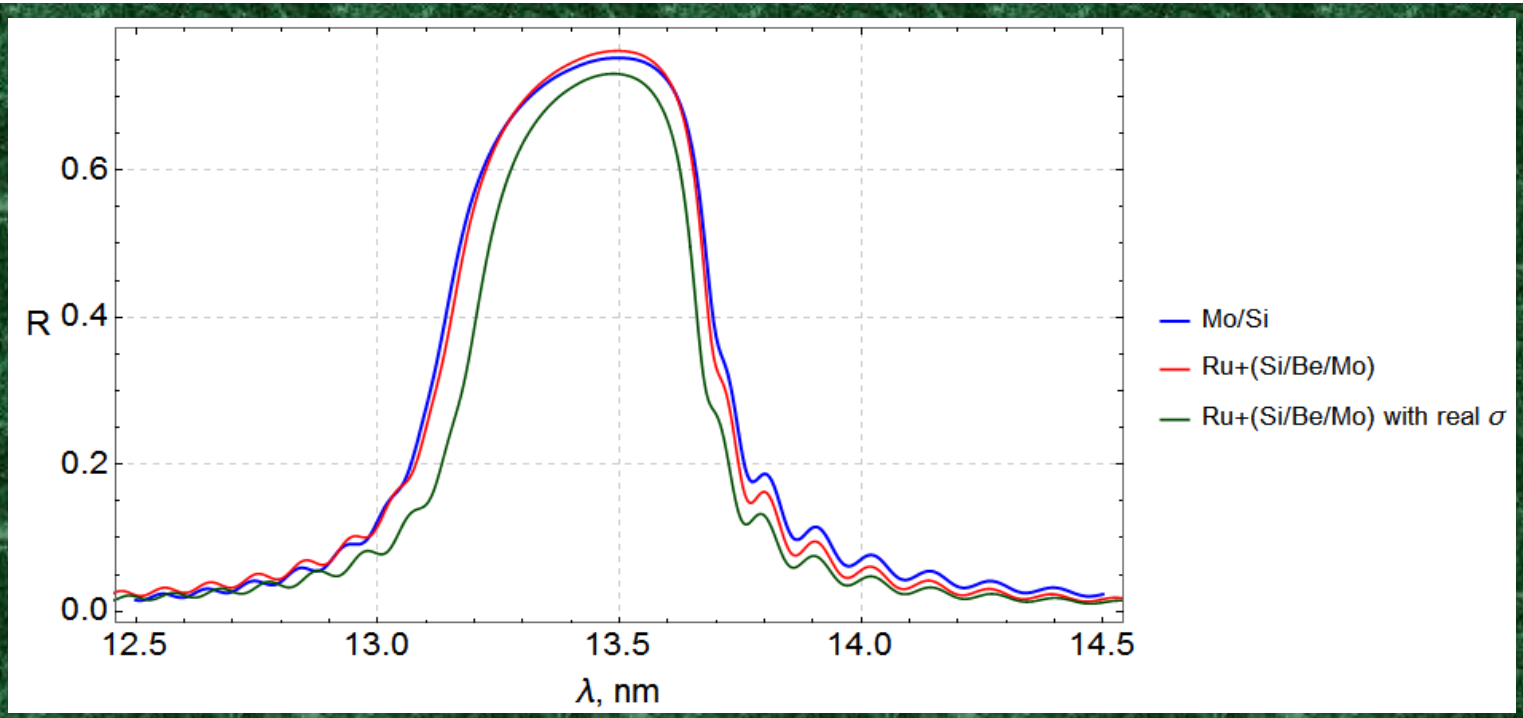


Number of periods	**N=150**
N_{th} period	**d_N=5.807 nm**
Thiskness	**h_{Be}=2.871 nm**
	h_{Mo}=2.665 nm
	h_{Si}=0.271 nm
Gradient of period	**+0.010%×d**
Film density	**Be – solid**
	Mo - 95% of solid
Interface width	
Be-on-Mo	**0.27±0.02 nm**
Mo-on-Be	**0.45±0.03 nm**

0.36±0.02 nm
0.71±0.04 nm

Optimized Mo/Be/Si +Ru MLM for 13.5 nm

(d_{Mo}=2.47nm, d_{Be}=1.534nm, d_{Si}=2.895nm, d_{Ru}=1.718nm)



— air/(Mo/Si)x100/sub ; R=0.753 ; FWHM=5.60 Å ; d(Mo)=26.25 Å ; d(Si)=42.58 Å ; D=68.93 Å

— air/Ru/(Si/Be/Mo)x100/sub ; R=0.762 ; FWHM=5.40 Å ; d(Ru)=17.18 Å ; d(Si)=28.95 Å ; d(Be)=15.34 Å ; d(Mo)=24.7 Å ; D=68.98 Å

— air/Ru/(Si/Be/Mo)x100/sub with real σ; R=0.731 ; FWHM=5.40 Å ; d(Ru)=17.18 Å ; d(Si)=28.95 Å ; d(Be)=15.34 Å ; d(Mo)=24.7 Å ; D=68.98 Å

73.1%

Summary and Discussion

1. We obtain routinely reflection coefficients of Mo/Be MLM of 70 – 71%
2. Interface Mo-on-Be of 0.71 nm width in Mo/Be are the main reason the reflectivity drop
3. Preliminary C and B4C interlayer improve the reflectance of Mo/Be by 1.5-2% (*should be investigated with 'high-end' MLM*)
4. Silicon interlayer smooth the interfaces in Mo/Be MLM down to 0.27 nm Be-on-Mo and 0.45 nm Mo-on-Be
5. Theoretically is shown that Mo/Be/Si MLM with optimized thickness of the films have higher as compared with Mo/Si reflectance at 13.5 nm. If put in calculation experimental data of Mo/Be/Si MLM one can expect record reflectivity ≈73% at 13.5 nm wavelength (*would be investigated experimentally*)

Thank you very much for your attention