Reflective optics for next generation lithography

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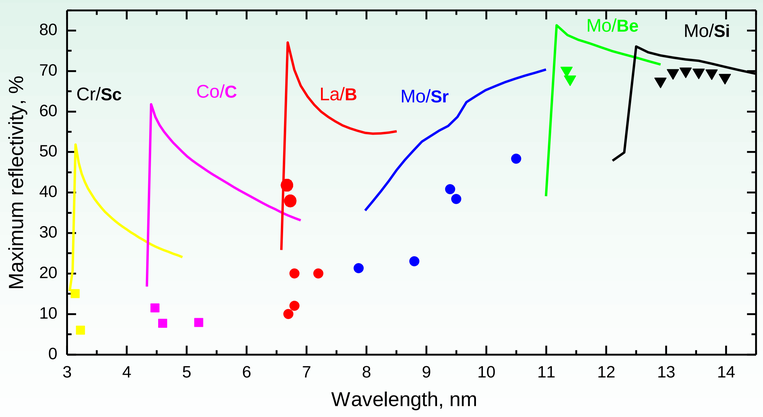
Abstract

The development of stable Mo/Si multilayer coatings designed for the wavelength of 13.5 nm with high reflective optical performance up to 70% is close to saturation. It was shown, that B-based multilayer mirrors with theoretical reflectivity up to 76% @ 6.64 nm are the most promising reflective coatings for the next generation of EUV lithography in terms of maximizing throughput of an optical system. The highest reported experimental reflectivity of 49%@6.63 nm [1] was recently achieved on La/B_4C multilayer coatings designed for near-normal incidence.

In this study we focused our interest on a comparative study of different B-based systems: La/B_4C, Ru/B_4C and Mo/B_4C. The multilayer mirrors were deposited by conventional magnetron sputtering and characterized by X-ray scattering, transmission electron microscopy and EUV-reflectometry at the PTB. Maximum normal incidence reflectivities of 32.1%, 26.0% and 18% at the wavelength 6.67 nm for La-B_4C, Mo/B_4C and Ru/B_4C multilayer mirrors have been achieved without full optimization of multilayer design and deposition parameters. Finally, the different multilayer systems will be compared in terms of spectral selectivity, temporal and thermal stabilities.

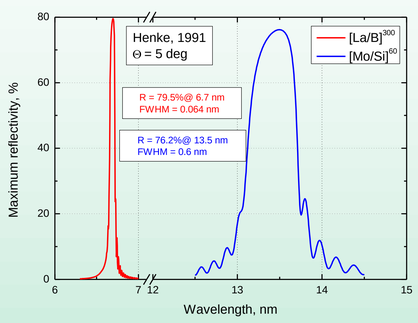
[1] Yuriy Platonov et al. Multilayers for next generation EUVL at 6.X nm, Proc. SPIE 8076, 2011.

Wavelength selection



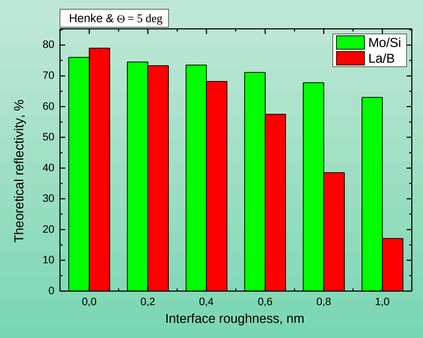
Multilayer	Wavelength nm	Period, nm	Bilayer number	Theory, %	Experiment, %
Mo/Si	> 12.4	7.0	60	76.1	70
La/B	> 6.7	3.4	200	79.5	41
Co/C	> 4.4	2.3	300	63	15
Cr/Sc	> 3.1	1.6	500	55	21

Reflectivity of La/B and Mo/Si multilayers (theory)



	Mo/Si	La/B
R, %	76.1	79.5
Δλ	0.60	0.07
N	60	≥ 200

Interface roughness in La/B and Mo/Si multilayers



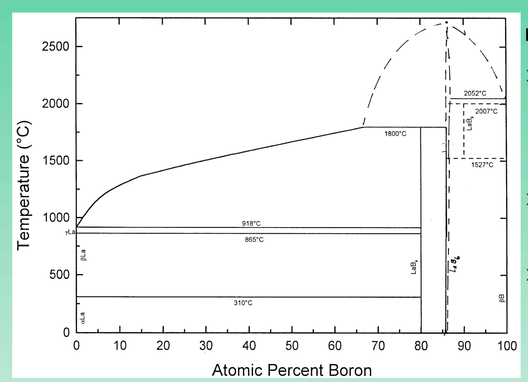
Debye-Waller Factor:

$$R_{exp} = R_{theor}\left[-\left(\frac{2\pi m\sigma}{H}\right)^2\right]$$

σ - interface roughness
H – multilayer period

R > 70 % @ σ < 0.25 nm

La and B are not the best materials for HR multilayers

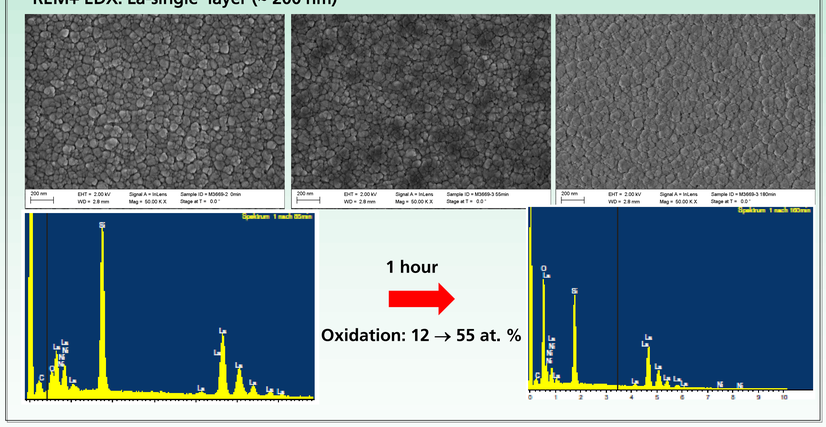


Disadvantages:

- La is not stable material
  - cubic
  - hexagonal
  - tetragonal
- High chemical interaction
  - LaB_4, LaB_6, LaB_9
- High oxidation of La and B

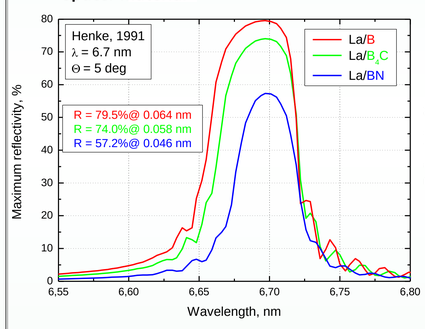
Lanthanum oxidation

REM+ EDX: La-single layer (~ 200 nm)



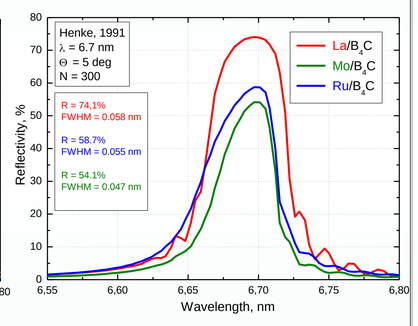
Material optimization of La/B multilayers (theory)

Spacer material



Multilayer	R, %	FWHM, nm
La/B	79.5	0.064
La/B_4C	74.1	0.058
La/BN	57.2	0.046

Absorber material



Multilayer	R, %	FWHM, nm
La/B_4C	74.1	0.058
Ru/B_4C	58.7	0.055
Mo/B_4C	54.1	0.047

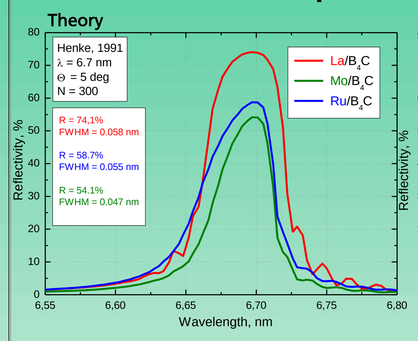
Multilayer deposition

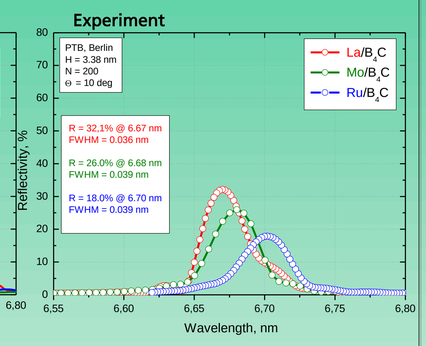
Sputtering system NESSY-1

Sputtering system Nessy 1

• base pressure:	$1*10^{-9}$ Torr
• Work pressure:	0.2 - 0.8 mTorr
• Optic size:	D < 650 mm
• 4- magnetrons	dif. barriers
• Thickness uniformity	0.2% on 300 mm
• Reflectivity uniformity	± 0.3 %
• Thickness gradient	± 50% on 300 mm
• Load / unload system	

Theoretical and experimental reflectivities

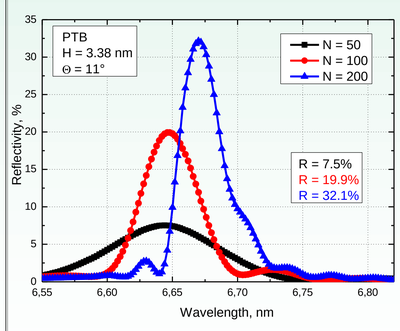




Multilayer	Theory R, %	Theory FWHM	Experiment R, %	Experiment FWHM	σ, nm
La/B_4C	74.1	0.058	32.1	0.036	0.81
Mo/B_4C	54.1	0.047	26.0	0.039	0.53
Ru/B_4C	58.7	0.055	18.0	0.036	0.75

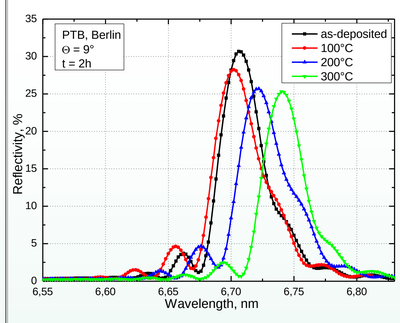
For R > 70 % @ σ < 0.25 nm

Interface roughness vs. number of bilayers



	Theory R, %	Exp. R, %	σ, nm
N = 50	39.8	7.5	0.72
N = 100	68.0	19.9	0.78
N = 200	74.1	32.1	0.81

Thermal stability of La/B_4C multilayers



	R, %	λ, nm	σ, nm
20°C	32.1	6.706	0.81
100°C	28.2	6.702	0.83
200°C	25.7	6.722	0.85
300°C	25.3	6.740	0.85

Summary

- The most promising wavelength for the next generation EUVL is ~ 6.7 nm due to highest expected peak reflectivity from La/B (La/B_4C) ML structures.
- Transition from 13.5 nm to 6.7 nm results in narrowing reflected peak by factor 10.
- Due to high oxidation and predicted high interdiffusivity, lanthanum and boron are complex materials for high-performance multilayer optics.
- It was shown that sputtering is promising technology for preparation of high reflective mirrors designed at the wavelength of 6.7 nm:
  - La/B_4C R = 32.1%
  - Mo/B_4C R = 26.0%
  - Ru/B_4C R = 18.0%
- Reflectivity drop of with increasing the resonance wavelength was found after annealing of La/B_4C ML mirrors up to temperature of 300°C.

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