High-reflective coatings for next generation lithography

Sergiy Yulin*, Philipp Naujok and Norbert Kaiser

Fraunhofer-Institut für Angewandte Optik und Feinmechanik, Albert-Einstein-Str. 7, 07745 Jena, Germany

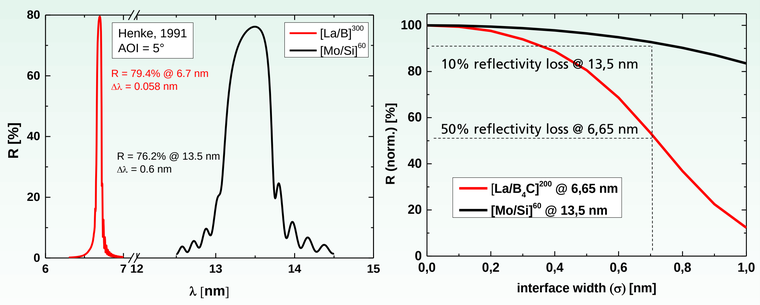
Abstract

The development of 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 La/B multilayer mirrors with theoretical reflectivity up to 80% @ 6.5 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 57.3% @ 6.66 nm was recently achieved on LaN/B multilayer coatings designed for near-normal incidence [1].

In this study we focused our interest on La/B_4C, LaN/B_4C and C/B_4C multilayer systems. The multilayer mirrors were deposited by industrial sputtering system and characterized by X-ray scattering and EUV-reflectometry at the PTB. Maximum peak reflectivities of 58.1% and 66.2% at the wavelength of 6.65 nm have been achieved by LaN/B_4C multilayer mirrors designed at incidence angles of 10 degrees and 45 degrees respectively. Finally, a different B-based multilayer systems will be compared in terms of reflective properties, temporal and thermal stabilities as well as prospects for reflectivity improvement up to level more than 60%.

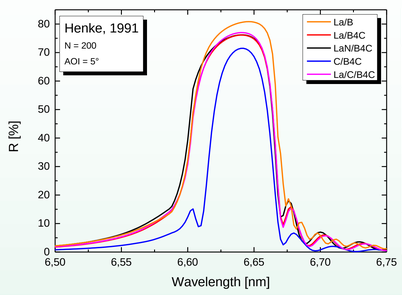
[1] Igor A. Makhotkin et al. Short period La/B and LaN/B multilayer mirrors for ~6.8 nm wavelength: Optics Express, v. 21, 24, p. 29894, 2013.

Theory: 13.5 nm vs 6.x nm



- Peak reflectivities of La/B and Mo/Si mirrors are comparable
- Reflectivity of La/B multilayer is extremely narrowband (FWHM = 0.06 nm)
- Higher reflectivity losses can be predicted at 6.X nm due to:
  - interface defects and
  - long deposition process

Theory: Reflectivity vs. Materials

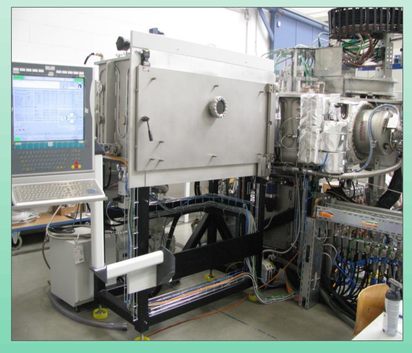


Materials	R_{peak} [%]	FWHM [nm]
La/B	80,9	0,066
La/B_4C	76,1	0,064
LaN/B_4C	76,2	0,066
C/B_4C	71,5	0,047
La/C/B_4C/C	76,4	0,064

- Highest reflectivity of 80.9% @ 6.65 nm by La/B multilayer mirrors
- Transition from B to B_4C results in reflectivity loss about 5.0%
- There no noticeable reflectivity loss due to application of:
  - other absorber materials (LaN, C…) and
  - different diffusion barriers (C, Mo….)

Multilayer deposition

Sputtering system NESSY-3

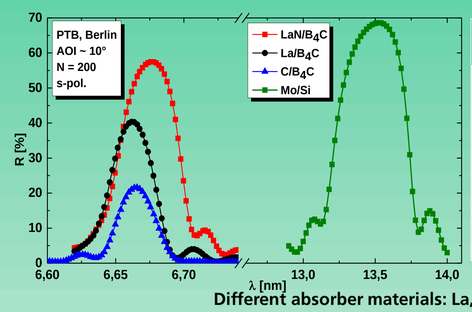


Sputtering system :

- Base pressure: $1*10^{-9}$ Torr
- Work pressure: $6 * 10^{-4}$ mTorr
- Optics size: D < 200 mm
- Optics size: D < 200 mm
- 6- magnetrons dif. Barriers
- Thickness uniformity : 0.1% on 200 mm
- Reflectivity uniformity: ± 0.3 % on 200 mm
- Load / unload system

BEUV reflectivity (AOI = 10°)

Different absorber materials: La, LaN and C



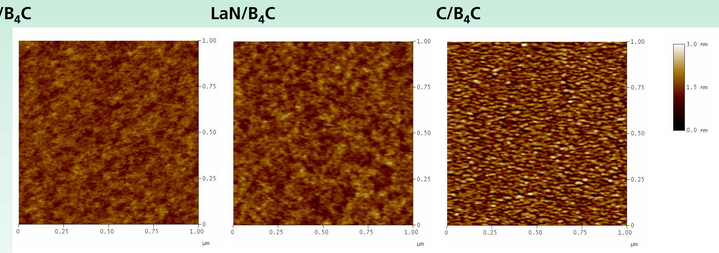
Design	R_{peak} [%]	FWHM [nm]	σ [nm]
$[LaN/B_4C]^{200}$	58.1	0.047	0.52
$[La/B_4C]^{200}$	40.4	0.036	0.75
$[C/B_4C]^{200}$	21.6	0.031	0.80
$[Mo/Si]^{60}$	69.0	0,500	0.70

Different absorber materials: La, LaN and C

- A maximum peak reflectivity of 58.1% @ 6.66 nm was experimentally achieved
- LaN/B_4C multilayer mirrors have a maximum measured spectral bandwidth of 0.047 nm
- LaN/B_4C mirrors have higher interface quality (σ = 0.52 nm) than Mo/Si ones (σ = 0.70 nm)

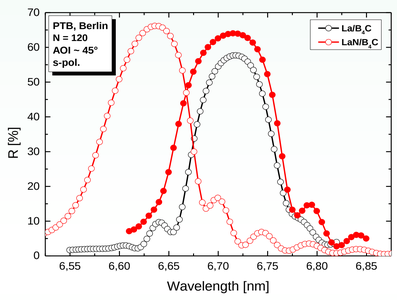
Surface roughness (AFM)

La/B_4C LaN/B_4C C/B_4C



RMS = 0.19 nm RMS = 0.17 nm RMS = 0.42 nm

BEUV reflectivity (AOI = 45°)

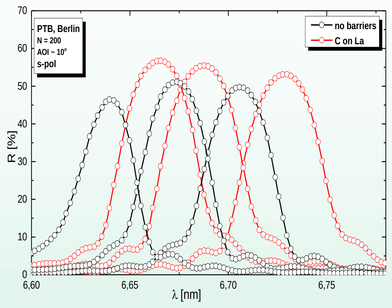


Design	R_{peak} [%]	FWHM [nm]	λ [nm]
$[La/B_4C]^{120}$	58.4	0.079	6.72
$[LaN/B_4C]^{120}$	64.0	0.107	6.72
	66.6	0.094	6.63

- Maximum peak reflectivity of 66.6% @ 6.63 nm was experimentally demonstrated

Interface-engineered mirrors (AOI = 10°)

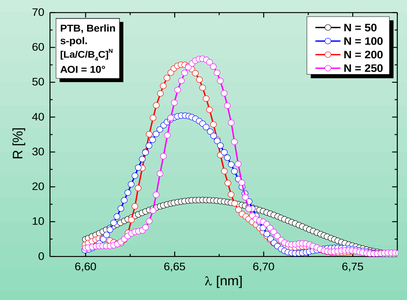
Carbon barriers



Design	R_{peak} [%]	FWHM [nm]	λ [nm]
$[La/B_4C]^{200}$	51.1	0.036	6.673
$[La/C/B_4C]^{200}$	56.8	0.042	6.664
$[LaN/B_4C]^{200}$	58.1	0.047	6.665

- Interface-engineering is powerful approach in reflectivity improvement at 6.X nm
- Optical performances of LaN/B_4C and La/C/B_4C multilayers are comparable at 6.X nm

BEUV reflectivity vs. number of bilayers (AOI = 10°)

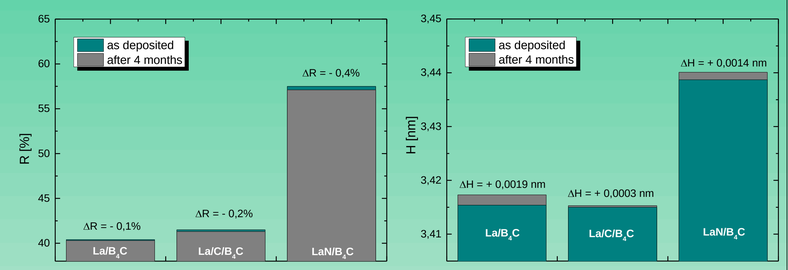


N	R_{peak} [%]	FWHM [nm]	σ [nm]
50	16,2	0,111	0,55
100	40,5	0,062	0,57
200	55,1	0,044	0,58
250	56,8	0,042	0,61

- Minor interface roughness development was found with growth of bilayer number
- The saturation of peak reflectivity takes place for N ≥ 250

Temporal stability

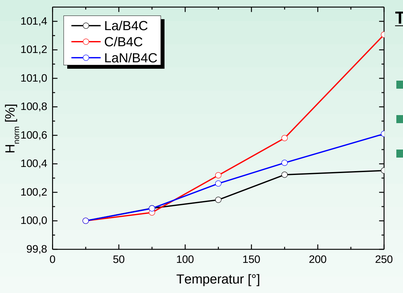
La/B_4C, LaN/B_4C and La/C/B_4C



4 months storage without any protection:

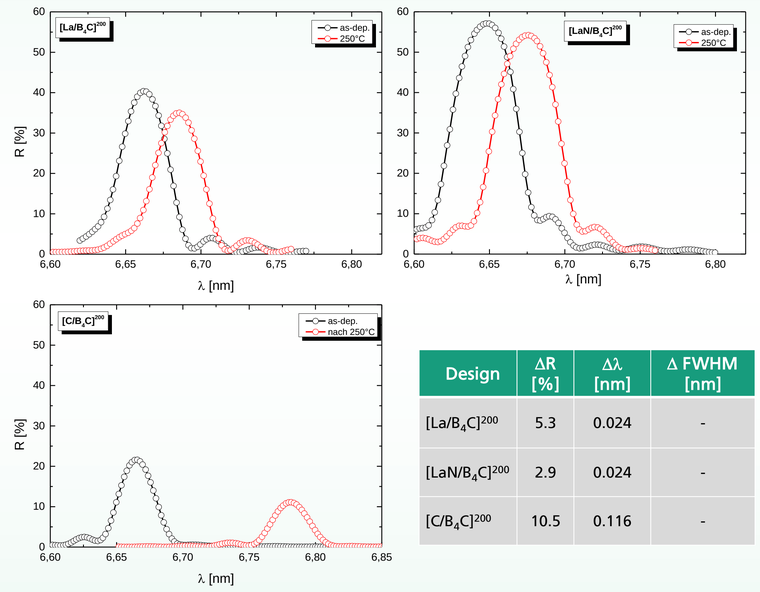
- Reflectivity losses of 0.1…0.4%
- Minor growth of bilayer thicknesses (0.0003…0.0019 nm)
- Minimum thickness changes are in interface-engineered La/C/B_4C multilayers

Thermal stability



T = 20 … 250°C & τ = 10 hours

- Maximum thickness changes of 1.4% (C/B_4C)
- Minimum thickness changes of 0.3% (La/B_4C)
- Good agreement between SAXR and EUVR



Design	ΔR [%]	Δλ [nm]	Δ FWHM [nm]
$[La/B_4C]^{200}$	5.3	0.024	-
$[LaN/B_4C]^{200}$	2.9	0.024	-
$[C/B_4C]^{200}$	10.5	0.116	-

Summary

- Different multilayer systems were designed at the wavelength of 6.7 nm and compared in terms of optical properties and thermal stability.
- It was shown that magnetron sputtering is a promising technology for preparation of high-reflective mirrors designed at the wavelength near 6.7nm and AOI=10 degrees:
  - LaN/B_4C R = 58.1% & FWHM = 0.047 nm
  - La/C/B_4C R = 56.8% & FWHM = 0.042 nm
  - La/B_4C R = 51.1% & FWHM = 0.036 nm
  - C/B_4C R = 21.6% & FWHM = 0.031 nm
- A maximum reflectance of R = 66.6% @ 6.63 nm with FWHM = 0.094 nm was achieved with LaN/B_4C mirrors designed at the AOI = 45 degrees.
- Annealing of B_4C-based multilayer mirrors up to a temperature of 250°C for 10 hours results in reflectivity losses and increasing of the resonance wavelength.
- Binary LaN/B_4C and interface-engineered La/C/B_4C multilayer systems have good prospects for further reflectivity enchantment of R > 60% @ 6.X nm.

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Fraunhofer IOF

* Contact: sergiy.yulin@iof.fraunhofer.de