BL-12A/2024G112

Test Measurements of La/B_4C Multilayer Reflectances in 6.x nm Wavelength Region

Takeo EJIMA[1,2,*], Ryosuke NAKAMURA[3] and Tadashi HATANO[1,2]
[1] SRIS, [2]IMRAM, and [3]Dept. Appl. Physics, Tohoku University
2-1-1 Katahira, Aoba-ku, Sendai, Miyagi 980-8577, Japan

1 Introduction

The Beyond Extreme Ultraviolet (BEUV) region, with a wavelength of 6.x nm, has been proposed as the operating range for next-generation semiconductor lithography systems. Since light in this region does not penetrate matter, a reflective projection optical system incorporating a multilayer mirror is employed. This multilayer mirror typically consists of two materials with low absorption and a large refractive index contrast, periodically stacked to form the structure. As the periodic thickness is approximately half the operating wavelength—around 3 nm in the BEUV region—the influence of the interface structure becomes increasingly significant at shorter wavelengths.

In November 2024, a new soft X-ray beamline BL-12A was opened in the Photon Factory [1]. A reflectometer with an in-vacuum precision goniometer was installed. For the purpose of evaluation of BEUV reflective multilayers, we expect this beamline to make an enormous contribution. This report shows the test runs of BEUV multilayer reflectance measurements.

2 Design and Fabrication of Reflective Multilayer

The material combination that currently exhibits the highest reflectance in the BEUV region is boron (B) and lanthanum nitride (LaN) [2]. While this pair is an ideal combination that meets the aforementioned criteria, it is fabricated via reactive sputtering, during which BN_x forms at the LaN/B interface and reduces reflectance. In this study, lanthanum (La) and boron carbide (B_4C) were selected as an alternative material pair that does not require reactive sputtering and is expected to exhibit high reflectance. B_4C has a negative standard formation enthalpy and is stable as a compound [3], while elemental La exists in its most stable phase under standard conditions [4]. The stability of both materials is well documented, and the interface between them is expected to be steep.

A reflective multilayer was designed with equal thicknesses of La and B_4C layers, achieving a reflectance of 0.63 at an incident angle of 10 degrees and a wavelength of 6.72 nm, and of 0.63 at an incident angle of 15 degrees and a wavelength of 6.62 nm.

The films were deposited using ion beam sputtering at acceleration voltages of 1.0 kV, 1.5 kV, and 2.0 kV. The resulting period lengths were 3.63 nm, 3.52 nm, and 3.80 nm, respectively. X-ray reflectivity (XRR) measurements showed that the positions and intensities of the interference peaks were similar among the samples, with structural differences appearing primarily between the peaks. These results suggest that variations in the multilayer films are attributable to differences in the interface structure.

3 Results and Summary

Our first reflectance measurements of the multilayer samples at BL-12A were carried out in December 2025. A photodiode (SXUV100, Opto Diode Corp.) was used as a detector. No multilayer reflection peak was obtained at normal incidence geometry at BEUV wavelength region, possibly due to the beamline condition at that time. On the other hand, at an incident angle of 78° a multilayer reflection peak was observed at 820 eV just below La M_5 absorption edge (Fig. 1), which would be a good evidence of successful deposition of La/B_4C multilayer samples. As the incident angle remained at 78°, the reflection peak was observed when the monochromator wavelength was scanned around 205 eV, which means the fourth order light of the monochromator was detected. It also implies that quite high proportion of the second and third order lights might be contained and disturb measurements in BEUV wavelength region.

To suppress second and third order lights, a photodiode SXUV100 coated with Mo (200 nm)/C (20 nm) was used in the measurements in March 2025. The transmittance of the coating in the 3–4 nm wavelength range is less than 0.01. As a result, a clear reflectance signal was successfully obtained (Fig. 2).

In the next phase of this study, we intend to investigate the interface structure in greater detail and aim to fabricate multilayer films with even higher reflection.

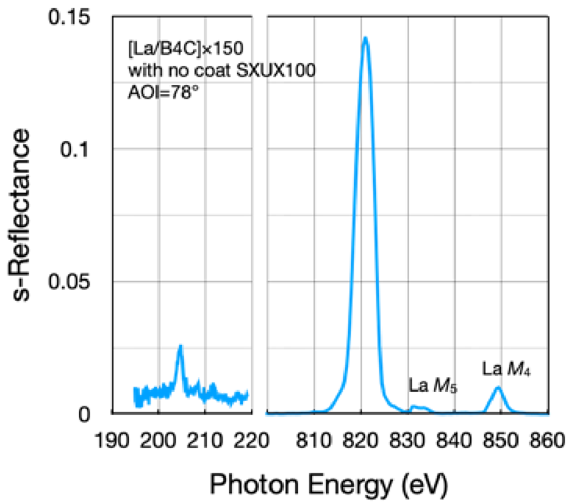

Fig. 1: S-polarized reflectance of the La/B_4C multilayer measured at an incidence angle of 78°.

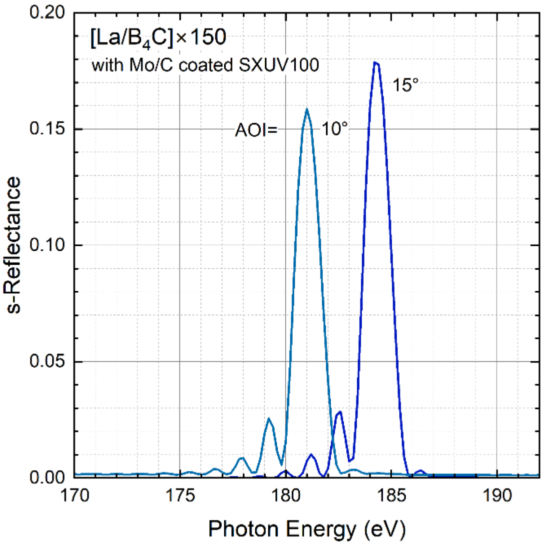

Fig. 2: S-polarized reflectance of the La/B_4C multilayer film measured at around normal incidence. A photodiode with a Mo (200 nm)/C (20 nm) coating was used as the detector.

References

[1] T. Ohigashi, D. Wakabayashi, H. Tanaka, R. Kataoka, H. Nitani, Y. Niwa, H. Miyauchi, T. Tahara, and N. Igarashi, 13th Asia Pacific Microscopy Congress Brisbane, Australia, February 2-7, 2025 (10.14293/APMC13-2025-0138).

[2] D. Kuznetsov, A. Yakshin, J. Sturm, R. van de Kruijs, E. Louis, and F. Bijkerk, Opt. Lett. **40**, 3778-3781 (2015).

[3] M. W. Chase Jr., J. Phys. Chem. Ref. Data, Monograph **9**, 1-1951 (1998).

[4] R. H. Schumm, D. D. Wagman, S. Bailey, W. H. Evans, and V.B. Parker in National Bureau of Standards (USA) Technical Notes, (1973) 270.

* takeo.ejima.e7@tohoku.ac.jp