Carbon/Boron Multilayer for Beyond EUV Lithography

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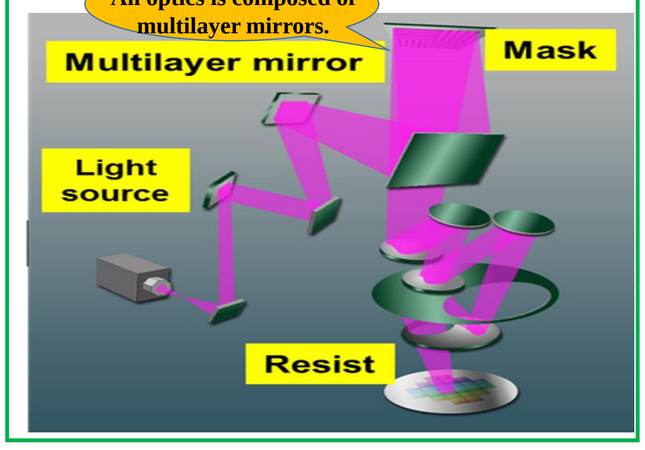
Introduction

In 2019, EUV lithography technology with a wavelength of 13.5 nm was first applied to the mass production of 7 nm node semiconductor devices. In the future, semiconductor devices with higher-density electronic circuits will be required. Beyond EUV (BEUV) lithography technology with exposure wavelengths around 6.7 nm is expected as next generation lithography. The development of multilayer with high reflectivity is a critical issue for BEUV lithography.

La/B-based multilayers have been mainly studied as BEUV multilayers. In a previous study of La/B-based multilayers, a reflectance of 64.1% was reported. However, the active chemical properties of La makes it challenging to maintain the reflectivity of La-based multilayers over the long term. For this reason, we propose Carbon/Boron (C/B) multilayer as a new BEUV multilayer.

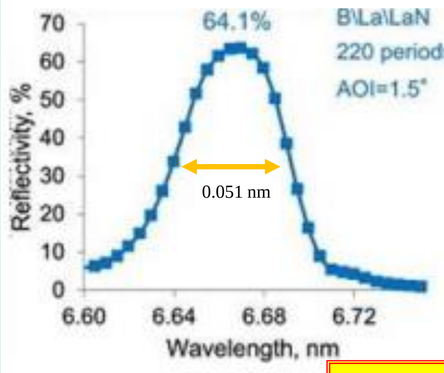
Schematic view of EUVL



Multilayer for BEUVL

Reported study of La/B multilayer

La/B-based multilayers have been developed.

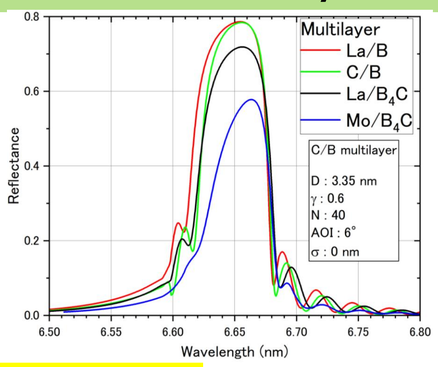


Despite high expectations, La/B multilayers showed a low reflectivity due to the intermixing of the layers and the high interface roughness[1].

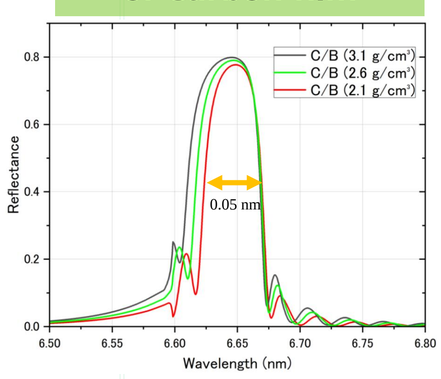
However, high reflectance of 64.1% was reported[2].

The problem of time stability of La-based multilayers has not yet been solved!

Calculated reflection spectra of BEUV multilayers



Density dependence of Carbon film



C/B Multilayer

- C/B multilayers have the same performance as La/B multilayers, which have been expected to have high reflectivity.
- Use C instead of La to solve stability problems.

- The optical constants of C films vary greatly with density.
  (3.1 g/cm³ is the highest density of ta-C film.)
- C/B multilayers can improve both peak reflectance and FWHM by increasing the density of the C film

Required high density Carbon !

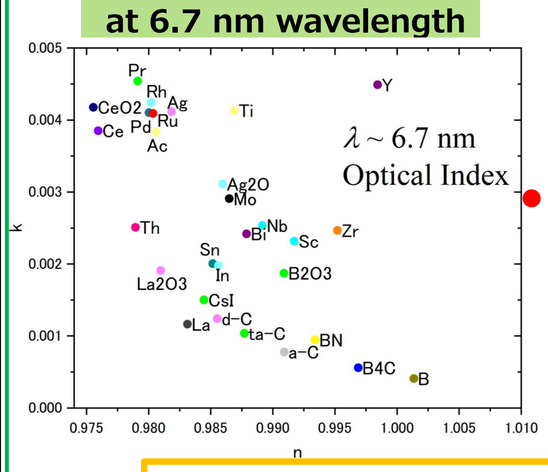
Purpose of research

Investigation of stable and highly reflective C/B multilayers for BEUVL

- Theoretical calculations for C/B multilayers will be performed and compared with other multilayers to study the usefulness of C/B multilayers.
- To measure the optical constants of monolayer materials and search optimal deposition conditions of C/B multilayers.

Material select

Optical index at 6.7 nm wavelength

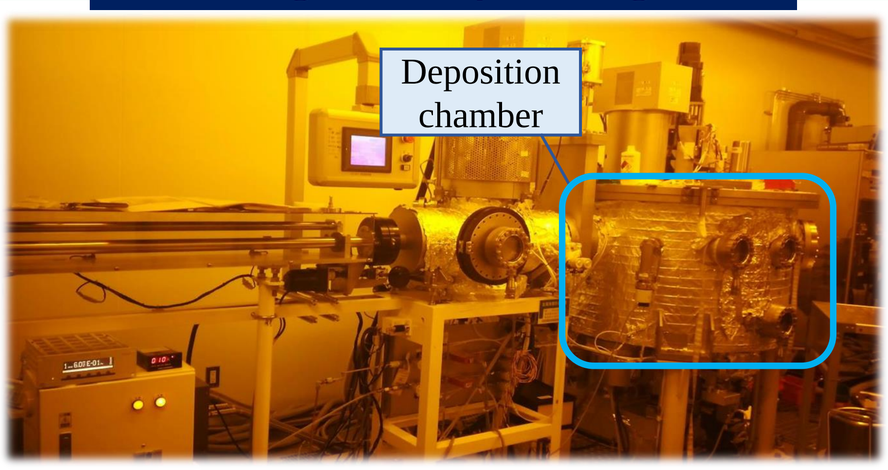


- We selected a material with a small extinction coefficient and an absorption edge at a wavelength slightly smaller than 6.7 nm
  →Boron
- We selected a material with a small extinction coefficient and a large refractive index difference from B
  →Conventionally selected highly reactive La

Select Boron and Carbon for stability !

Deposition process

Magnetron sputtering



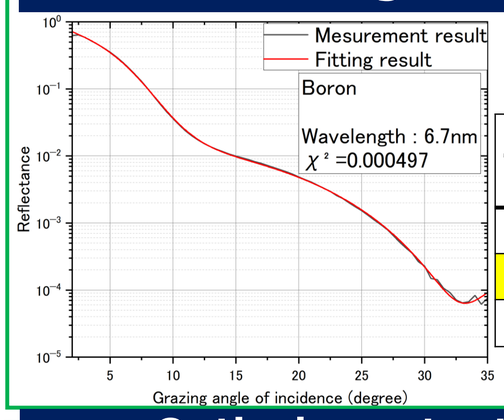
Deposition Conditions

- RF power ・・・ 500 [W]
- DC power ・・・ 250 [W]
- Substrate ・・・ Si substrate
- Back pressure ・・・ $8.0 \times 10^{-5} \sim 1.2 \times 10^{-4}$ [Pa]
- Ar gas pressure ・・・0.22 [Pa] or 0.60 [Pa]
- Deposition rate ・・・Carbon 0.29 [nm/min]
  Boron 0.22 [nm/min]

・Monolayers are deposited using RF cathode.
・In multilayer films, C was deposited using a DC cathode and B using an RF cathode.

Measurement of optical constant

Fitting



➢ **Fitting Parameters**
- **Extinction coefficient**
- **Refractive index**
- Interface roughness
- Surface roughness
- Thickness

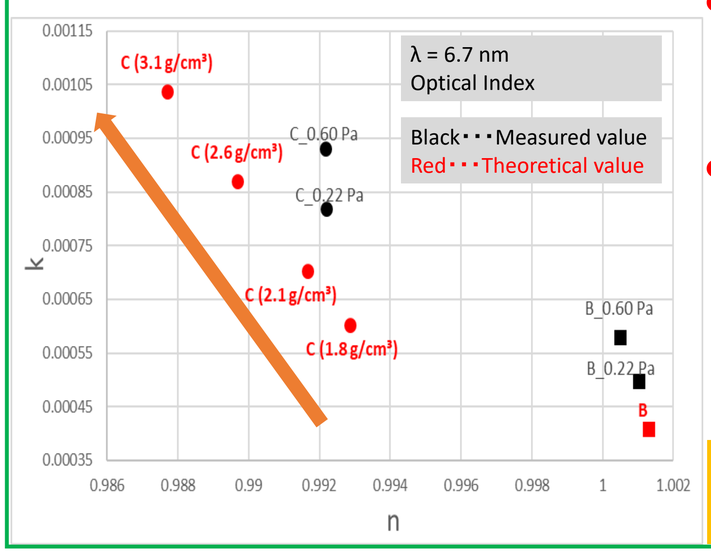
Type of layer	Thickness (nm)	*n*	*k*	Roughness (nm)
Top	1.10	1.00167	0.0001623	0.08(vacuum/top)
Main body	15.61	1.00049	0.0005791	0.16(top/main)
Bottom		1.00038	0.0003268	0.17(main/bottom)

Other monolayer samples were fitted in the same way to obtain optical constants!

Use main body results as optical constants!

Optical constant

・Measurement of optical constants of Carbon and Boron at 6.7 nm wavelength.
・Comparison of samples deposited at Ar gas pressure of 0.22 Pa and 0.60 Pa.
・Theoretical values are calculated by CXRO web site.



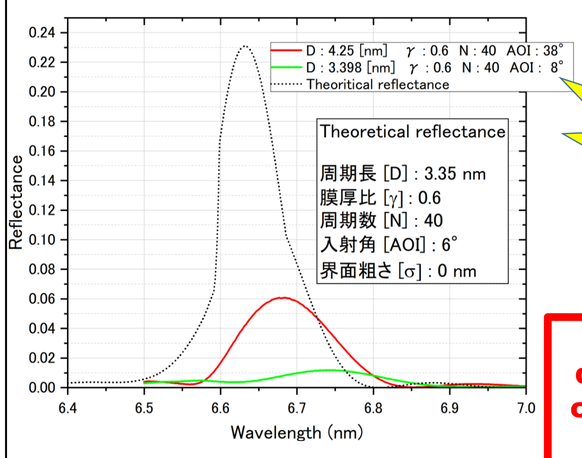
- From the theoretical values, it can be seen that the refractive index of the C film decreases with increasing density.
  →A high-density C film is required for high reflectance and wide FWMH.
- The B and C films deposited under high Ar gas pressure had larger extinction coefficients, however the refractive indices did not change significantly.
  →The extinction coefficient can be reduced by depositing the film at low Ar gas pressure.
  →The refractive index (density of C) does not change much at Ar gas pressure.

Deposition condition research is needed for achieve high density Carbon film!

C/B Multilayer

Reflectance measurement results

➢Causes of low reflectance
- Poor periodicity
- Large interface roughness



About 10 hours deposition!

Deterioration of deposition equipment conditions due to long deposition times

・Confirmation that C/B multilayers can be deposited.
・Deposited at 40 cycles to avoid loss of stability of deposition equipment.
・Measured with an incident angle larger than 6° due to the large period length
・The theoretical interface roughness was calculated at 0 nm.

summary

•Theoretical calculations of C/B multilayers, which are expected to be stable and highly reflective as multilayers for Beyond EUVL with a wavelength of 6.7nm, were performed.

•Deposition and measurement of optical constants of B and C monolayers for the development of C/B multilayers, and the change of optical constants with Ar gas pressure were investigated.

•Test deposition and reflectance measurement of C/B multilayers were conducted to confirm that C/B multilayers could indeed be deposited, and a reflectance of 6% was obtained.

Challenges and plans

For high reflectance C/B multilayer

1. High density carbon film.
2. Low interfacial roughness
3. Good periodic layer structure with high stable deposition rate.

New deposition tool is now under construction!!

Flexible parameter
- Target-Source distance
- Higher deposition rate
- 3 RF power source (1 pulsed DC source)
- 3 cathode
- Substrate RF power
- Unbalanced magnet source

References

[1] D.C..Kuznetsov, *et.al*, Opt. Lett. **2015**, 4, 3778-3781.
[2] Poul C. Uzoma, *et. al*, Nanomaterial **2021**, 11, 2782.