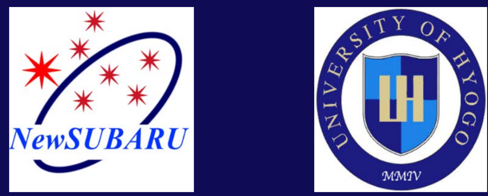
Large Collector Mirror Reflectometer for the High Power EUV Light Source Achievement



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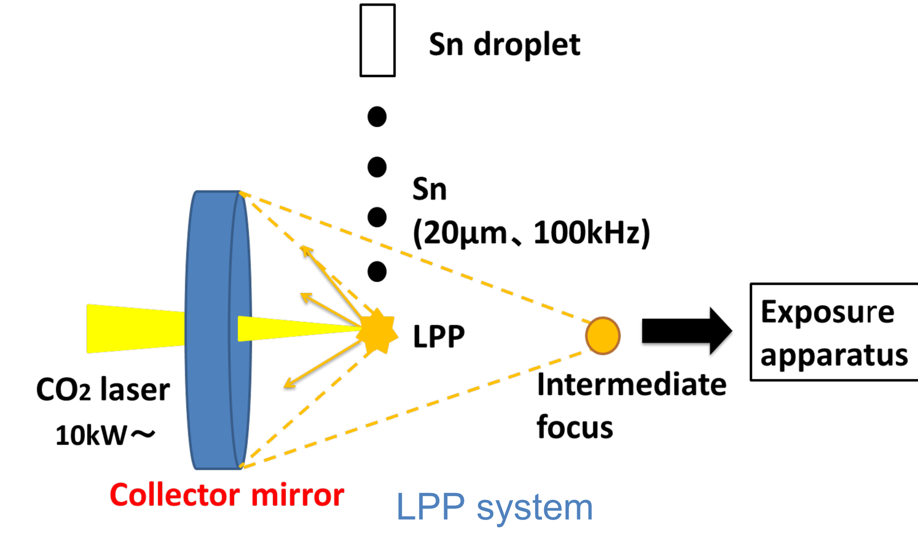
Introduction

Extreme ultraviolet (EUV) lithography is the promising candidate of the cost-effective lithography method for high-volume manufacturing of semiconductor devices. In EUV lithography, the development of high-power EUV sources is one of the critical issues. EUV light produced by the laser-produced plasma is focused at the intermediate focus position by a large collector mirror.



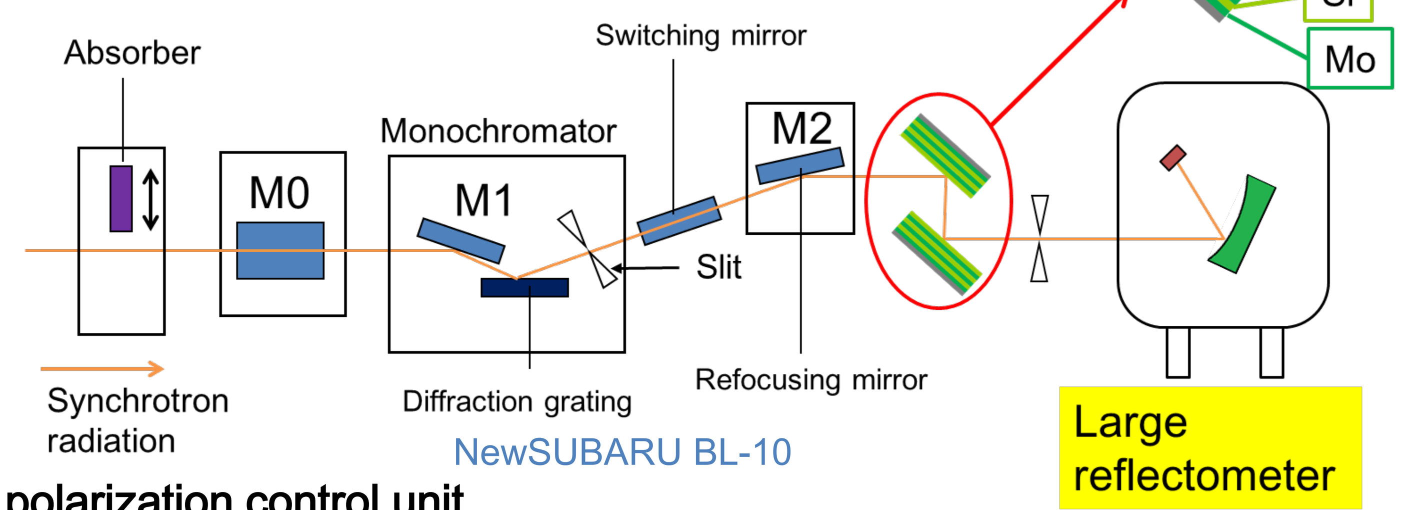
The EUV output power directly depends on the collection efficiency of the collector mirror.

The collection performance evaluation of the collector mirror is essential !

Mirrors with diameters larger than 660 mm are necessary to achieve the high collector mirror performance and take sufficient distance to prevent heat and debris in LPP system.
We developed a large reflectometer at BL-10 beamline of the NewSUBARU synchrotron radiation facility that can be used for mirrors diameters up to 800 mm.

NewSUBARU BL-10 Confuguration

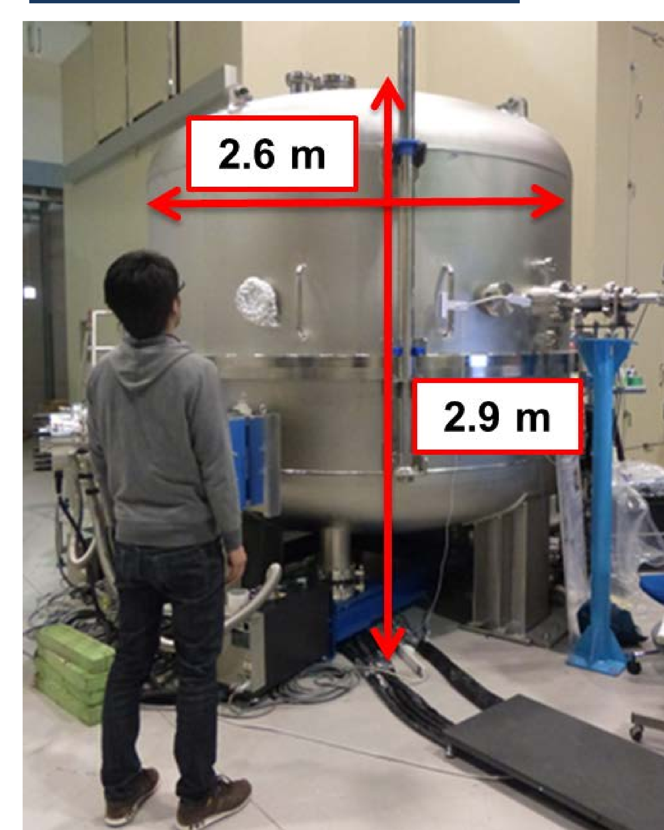
- Wavelength resolution : 1 / 1,300 (at 13.5 nm)
- Wavelength region : 1.1- 20 nm
- Beam size : 1.4(H) × 0.35(V) mm^2



The polarization control unit

- To control polarization and eliminate higher-order light from the monochromator, a polarization control unit was inserted upstream of the large reflectometer.
- This unit consists of two Mo/Si-multilayer mirrors settled at the Brewster angle of 42.5°, which can improve EUV-light polarization to be approximately 1.00.

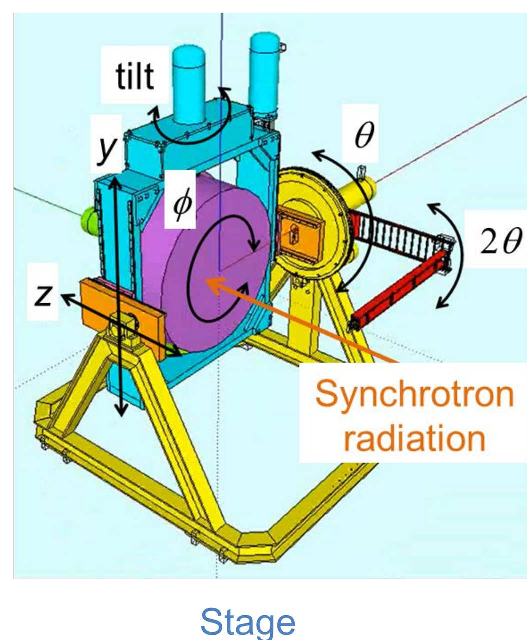
Large reflectometer



The large reflectometer

< Specification >

- Chamber volume (11 m^3)
  Diameter : 2.6 m
  Height : 2.9 m
- Cylindrical shape
- Ultimate vacuum pressure
  2×10^{-6} Pa



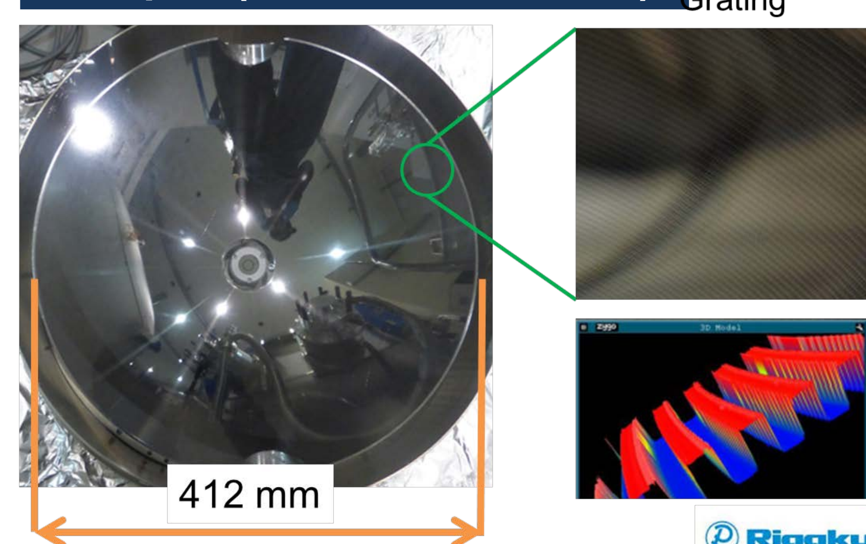
Stage

- Maximum sample size and weight
  - Diameter : 800 mm
  - Thickness : 250 mm
  - Weight : 50 kg

The world largest reflectometer !

- The incident angle of the EUV light to the mirror can be changed by θ-axis stage.
- The reflectance of the entire surface of a mirror can be measured in spherical coordinates by y- and ϕ-axes stages.
- The detector photodiode can be moved to measure the reflected light intensity by 2θ-axis stage.

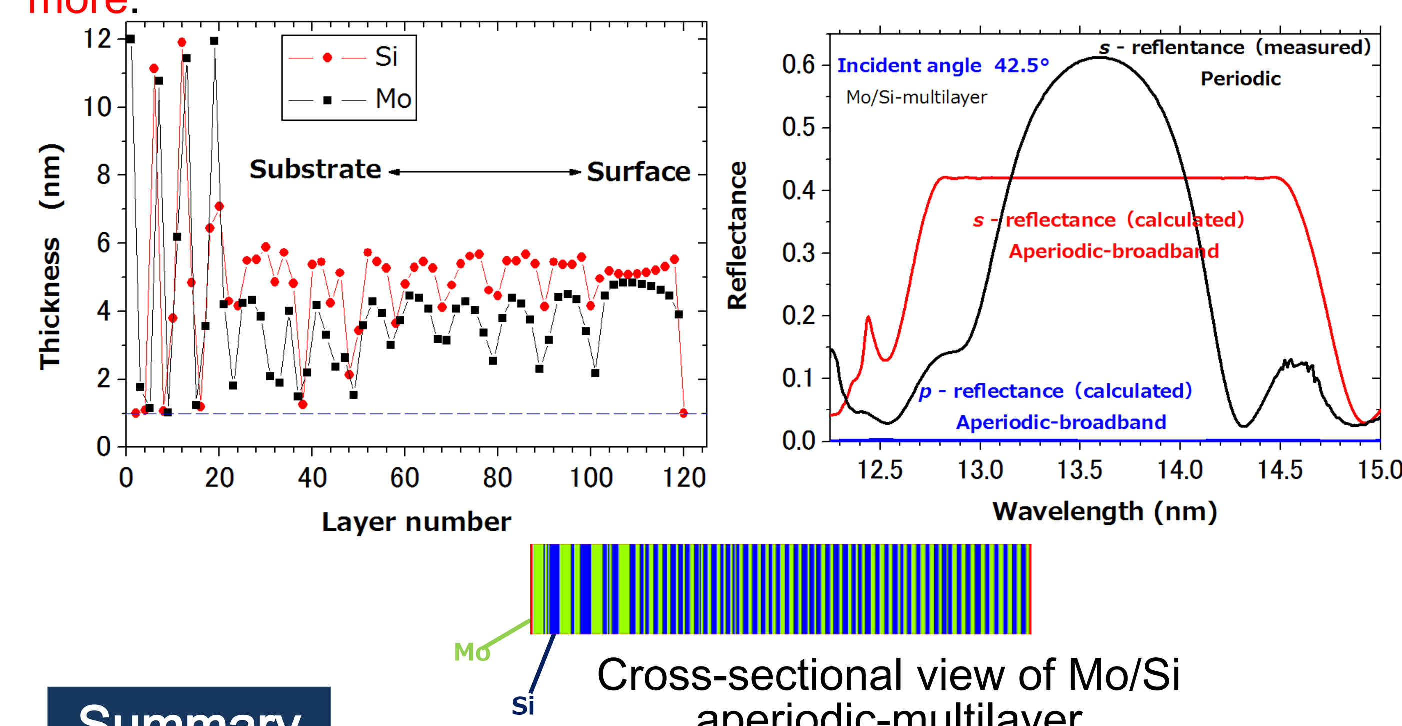
Sample (Collector mirror)



- This mirror was used as a sample to verify the large reflectometer performance.
- This mirror has 412 mm and 106 mm in diameter and thickness, respectively.
- The maximum angle of light incident is 36°.
- The periods of the grating and the depth are 1 mm and 2.7 μm, respectively.
- The reflectance of this mirror was already measured at Physikalisch-Technische Bundesanstalt (PTB).

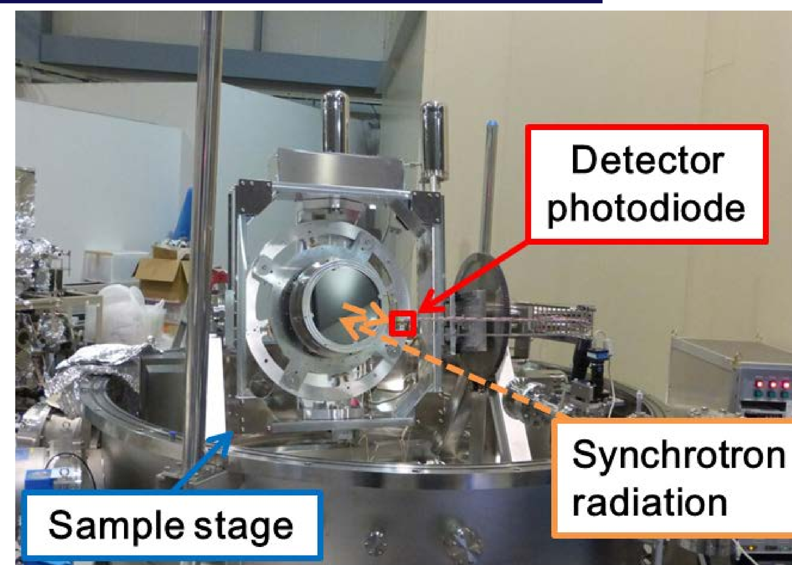
Design of aperiodic-broadband-multilayer

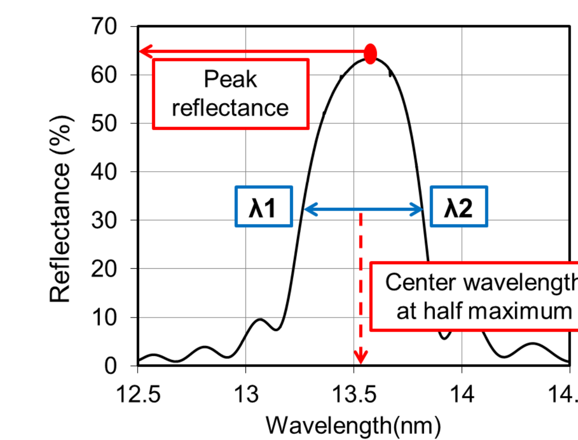
The aperiodic structure is optimized by iterative calculation in the optical property calculation software IMD so as to obtain the top-hat reflection spectrum at a wavelength of 12.8-14.5 nm. The multilayer pair is aperiodic 60 pairs of Mo/Si, the incident angle of 42.5°, the interface roughness of 0.8 nm, and each film thickness of 1.0 nm or more.



Cross-sectional view of Mo/Si aperiodic-multilayer

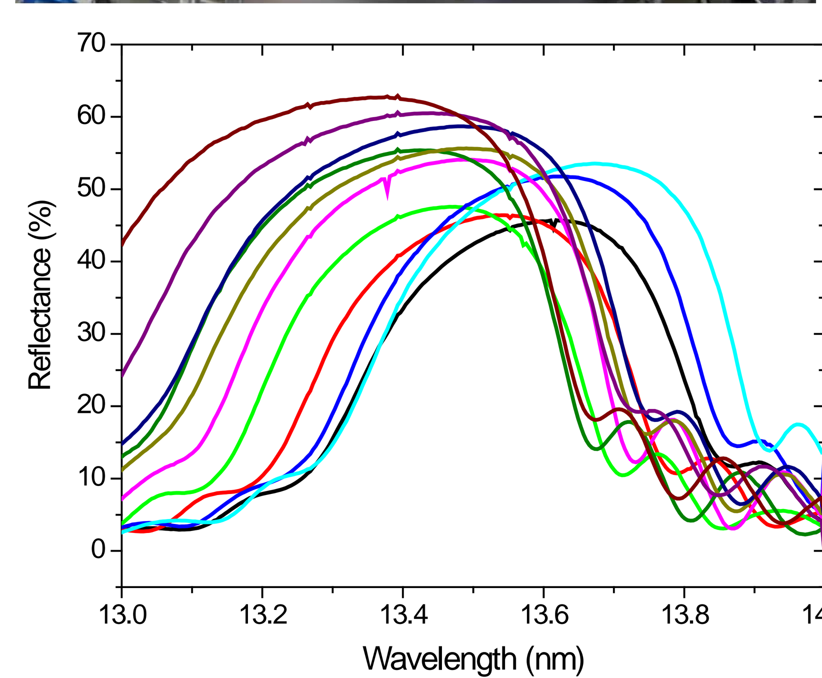
Experimental and results



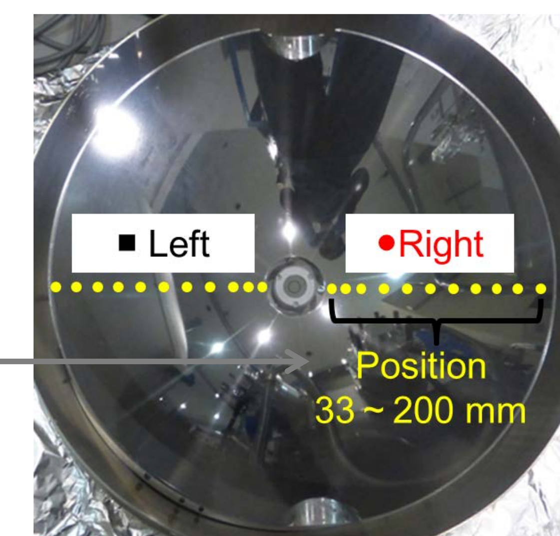


Incident light — Photodiode — Synchrotron radiation — mirror — Reflected light

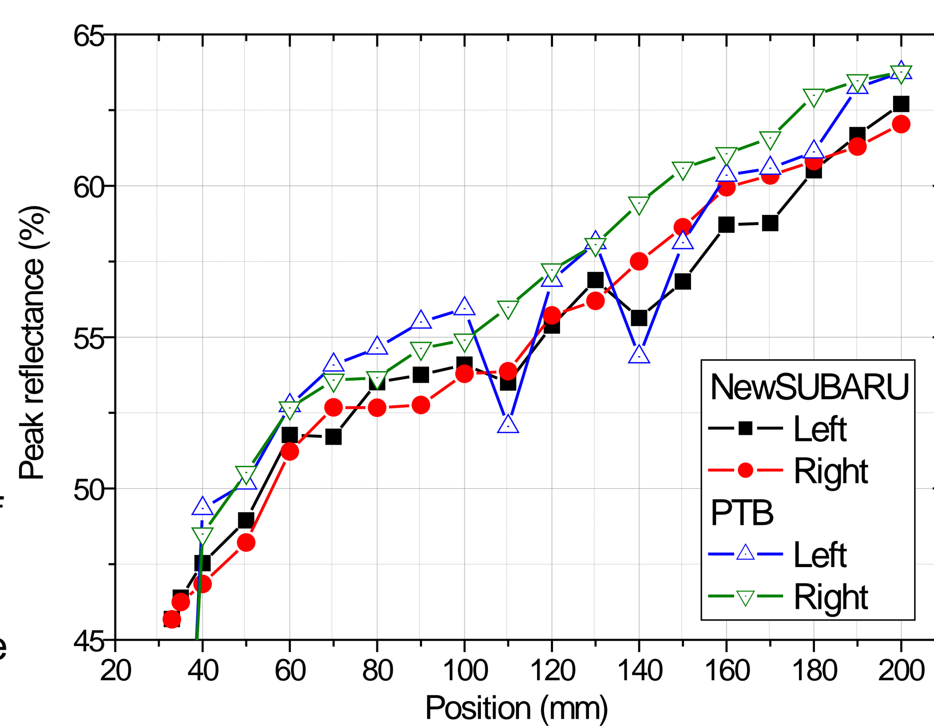
- $\text{Reflectance} = \dfrac{\text{Reflected light intensity}}{\text{Incident light intensity}}$
- $\text{Center wavelength at half maximum (CWHM)} = \dfrac{\lambda1+\lambda2}{2}$



Reflectance measurement results obtained at Left.



The reflectance spectra at 38 radial positions were measured within 3 hours.



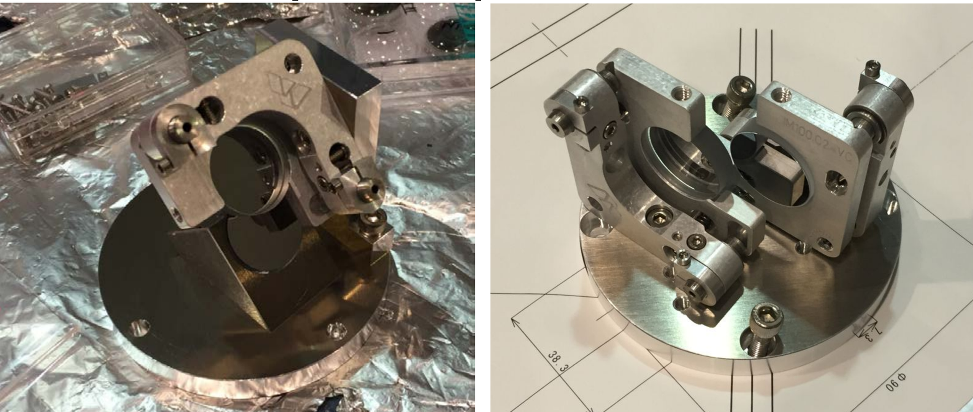
Peak reflectance results at NewSUBARU and PTB.

- At NewSUBARU, the standard deviation of the peak reflectance difference from Left to Right was approximately within 0.9% (1σ).
- However, the peak reflectance at NewSUBARU was systematically1.4% lower than that at PTB Left. This difference might caused by temporal stability in the reflectivity measurement. In atmosphere, the reflectivity of the multilayer might be degraded with diffusion of the Mo-silicide interlayers.

The collector mirror reflectance was measured with a large reflectometer at NewSUBARU accurately.

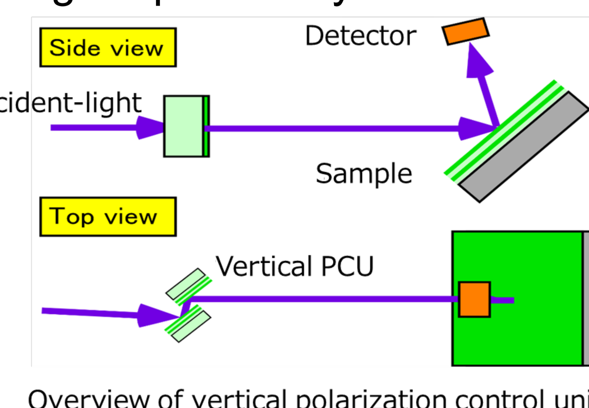
Polarization control unit (PCU)

1 inch synthetic quartz substrate



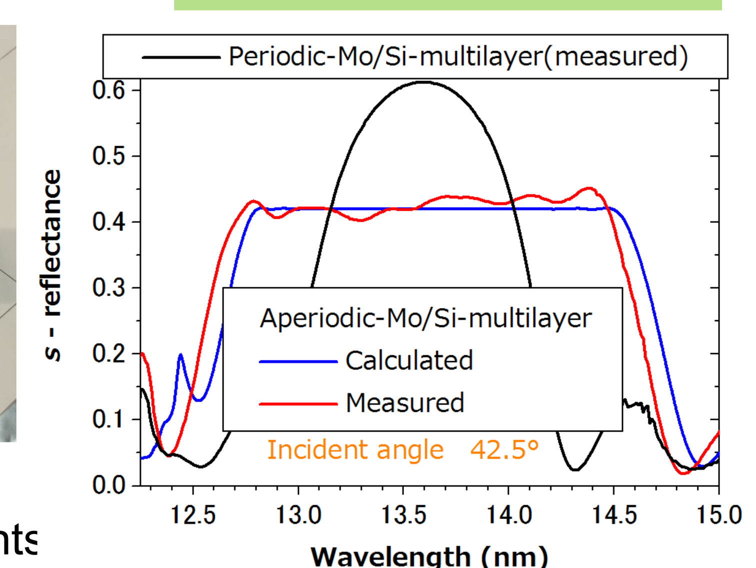
Horizontal PCU　　Vertical PCU

The polarizer was fixed by kinematic mirror mounts. This control unit is inserted into the optical path with high repeatability.



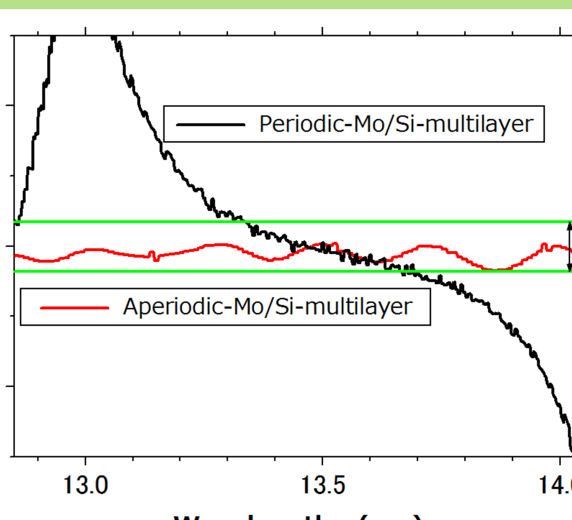
Overview of vertical polarization control unit

Reflectance of broadband multilayer



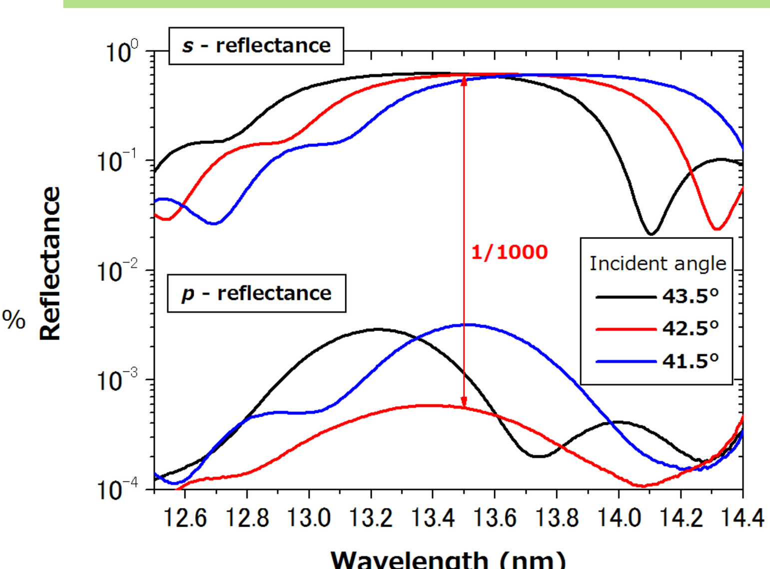
- Broadband-reflectance region with top-hat shape at the wavelength from 12.7 – 14.5 nm

Intensity fluctuation of incident EUV beam with 2 pm wavelength shift



- The intensity fluctuation deteriorates the accuracy of reflectance measurement.

Reflectance measurement result (s-, p- polarized light)



- The reflectance ratio of R_s / R_p was over 10^3.
- The polarization is > 0.999.

Summary

- We developed a reflectometer at BL-10 beamline of the NewSUBARU synchrotron radiation facility and used it successfully to measure the reflectance of a 412-mm-diameter EUV collector mirror with a polarization of 1.00.
- We obtained the peak reflectances in CWHM and FWHM, which were slightly different from the PTB measurement results.
- We will improve the reflectometer performance, and contribute to the improving EUV optics for EUVL, especially the EUV large collectors for EUV light source.
- The accuracy of reflectance measurement was improved from 2.0% to < 0.2% due to the broadband reflection spectrum.
- We developed broadband multilayer mirror for the PCU, which is essential for accurate reflectometry of the collector mirror.
- The Vertical and Horizontal PCU provide fully s- and p- polarized EUV-light for the reflectometer, respectively.

Acknowledgement

This work was supported by the Project for Creation of Research Platforms and Sharing of Advanced Research Infrastructure, MEXT, Japan.
We would like thank PTB's measurement staff, especially thank to Dr. Frank Scholze, Dr. Christian Laubis, and Dr. Christian Buchholz.