At wavelength evaluation of multilayer for EUV lithography

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Outline

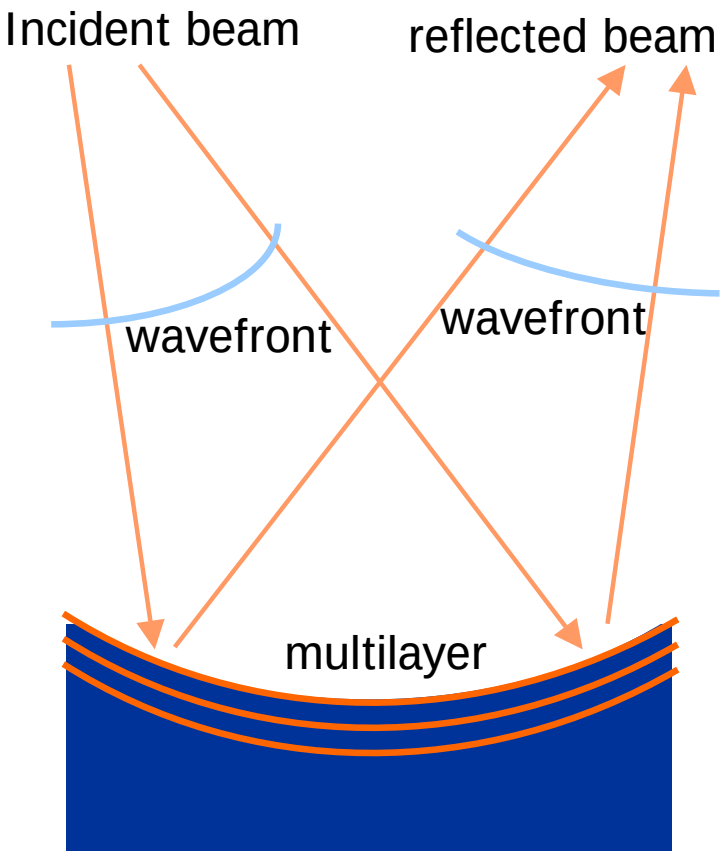
- **objectives**
- **reflectivity measurement**
  - overview
  - alignment
  - measurement result about curved mirror
- **multilayer thickness measurement**
  - comparison with X-ray diffraction
  - measurement result about curved mirror
  - comparison with figure measurement
- **phase shift measurement**
  - overview
  - measurement result about curved mirror
- **summary**

Objective

- **At the production of projection optics, we must measure and assure each single aspherical mirror performances after mutilayer coating.**
- **We improved the reflectomater to measure the reflectivity of aspehrical mirror, as well as to measure layer thickness distribution and phase shift of reflection.**

- **In this poster, following 3 items are reported on the aspherical mirror for EUV projection optics.**
  - reflectivity
  - layer period
  - phase shift

Wavefront error in a single mirror



Wavefront error of projection optics consists of

1. aberration of optical design,
2. alignment error of each mirrors,
3. Substrate surface shape,
4. Multilayer thickness,
5. Phase shift on multilayer reflection.

But we can only measure the wavefront aberration of the projection optics after all mirror assembled.

Wavefront error of a multilayer mirror

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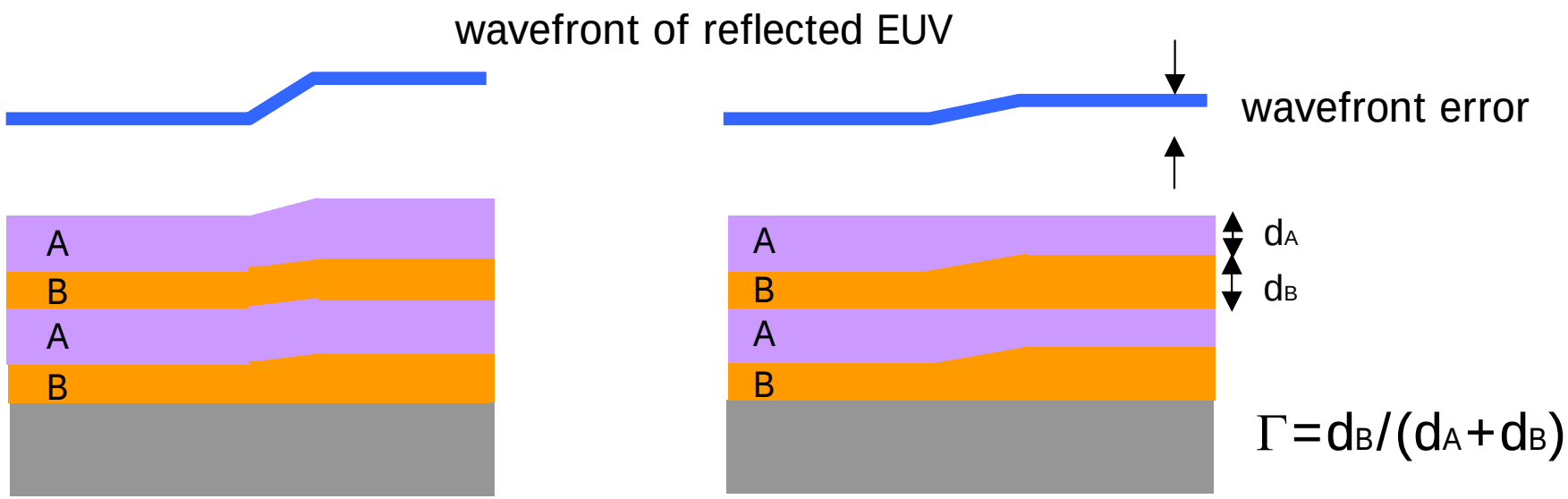
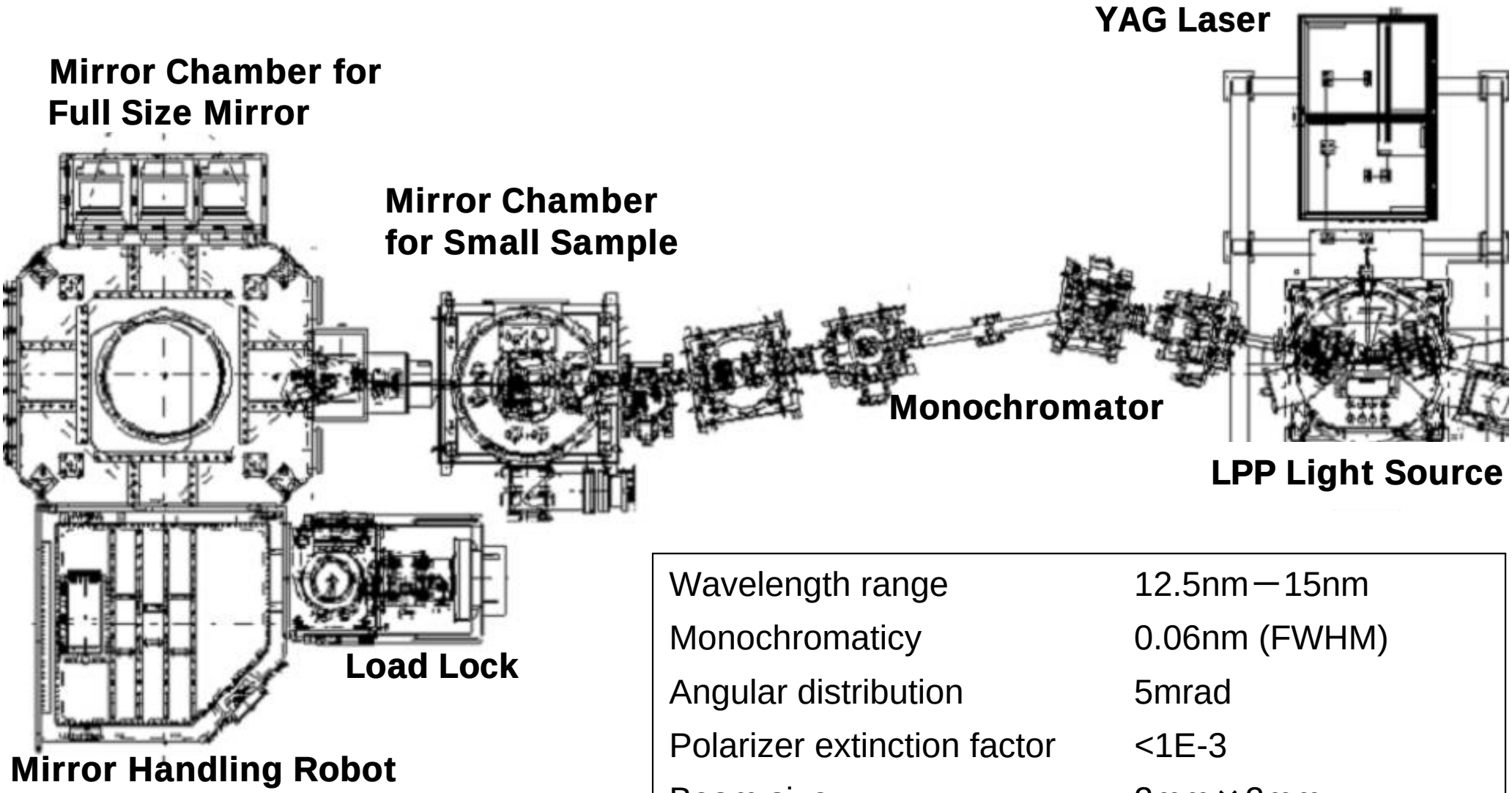
- **multilayer thickness**
  - The shape of mirror surface depends on substrate shape and multilayer thickness distribution. Granted that substrate is as designed, multilayer thickness error causes wavefront error.
- **phase shift**
  - Granted that shape of mirror surface fabricated as designed, the difference of multilayer structure cause wavefront error. (eg. Γ)



Reflectometer :schematic view

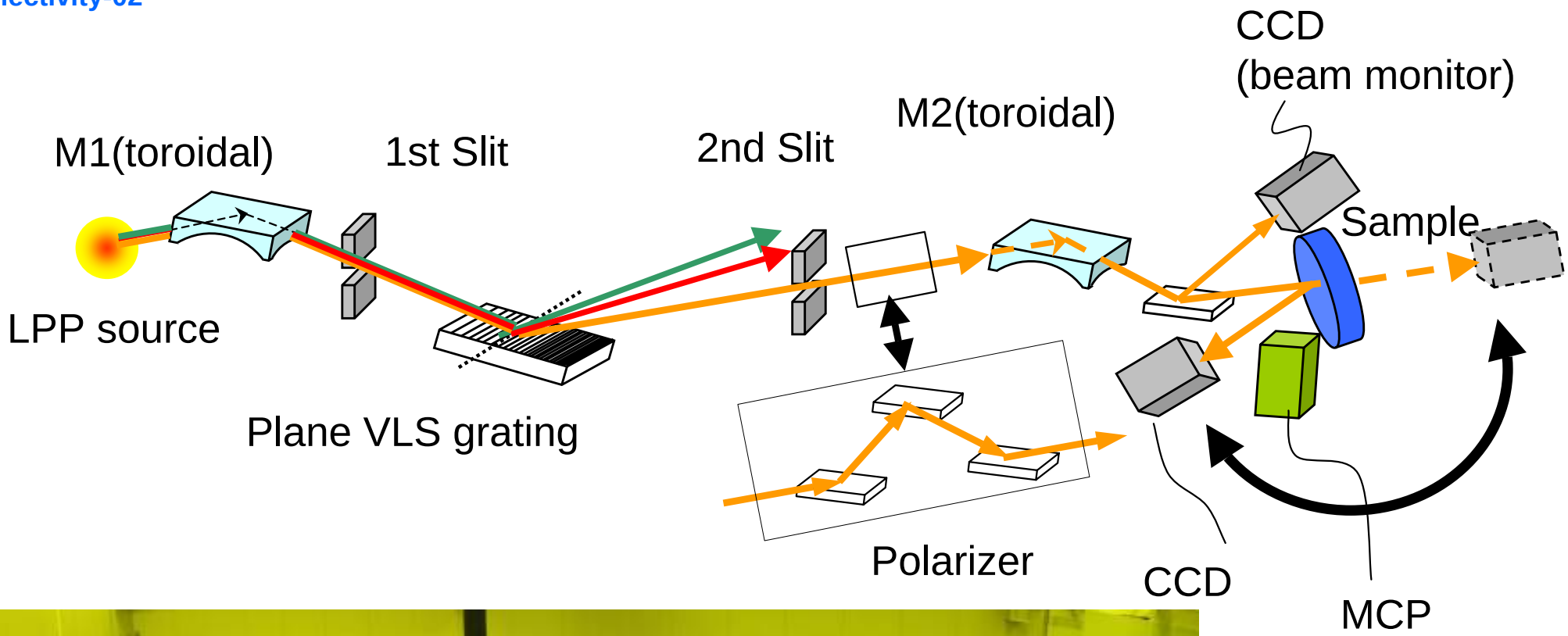
reflectivity-01



Wavelength range	12.5nm－15nm
Monochromaticy	0.06nm (FWHM)
Angular distribution	5mrad
Polarizer extinction factor	<1E-3
Beam size	2mm×2mm
Measurement Repeatability	0.2%

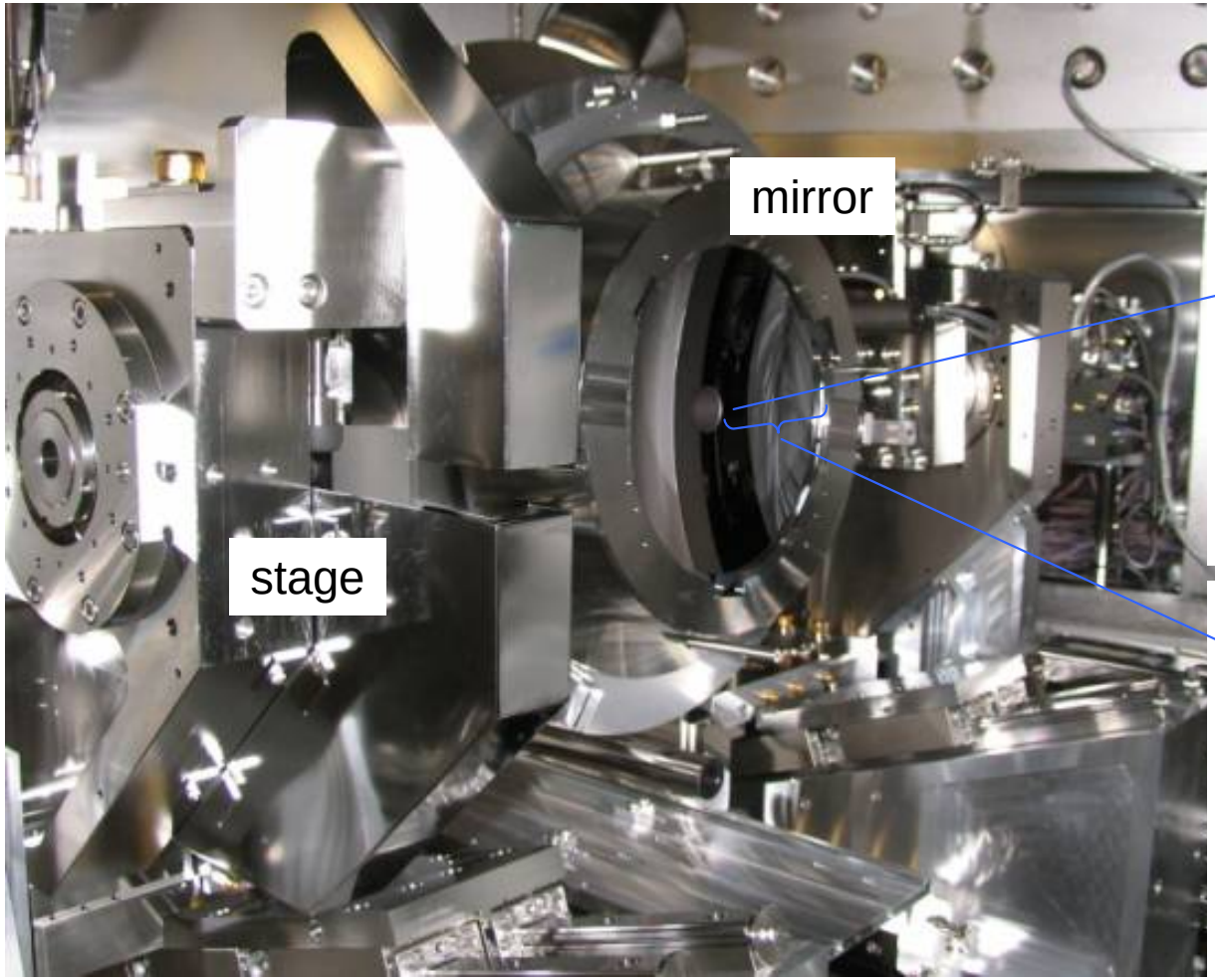
Reflectometer :optical layout

reflectivity-02

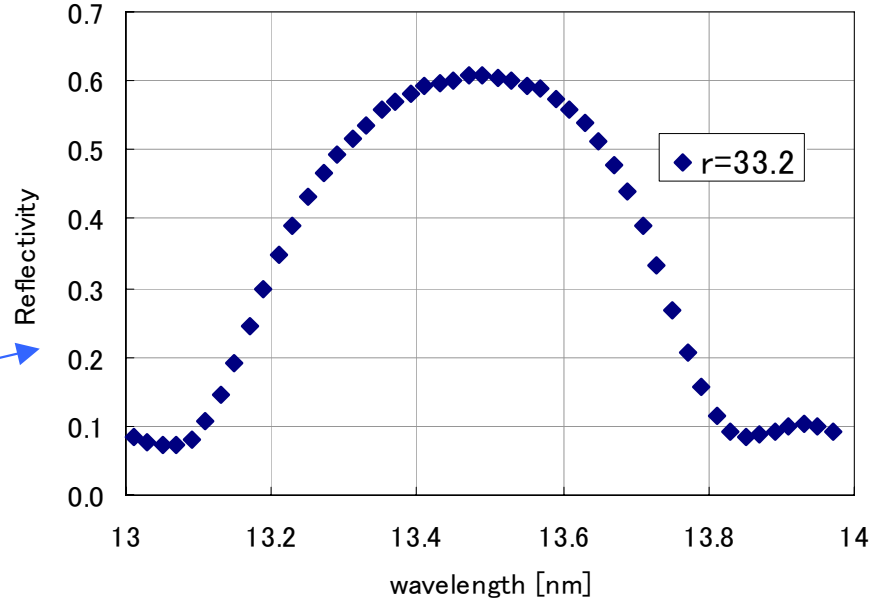


Reflectivity measurement

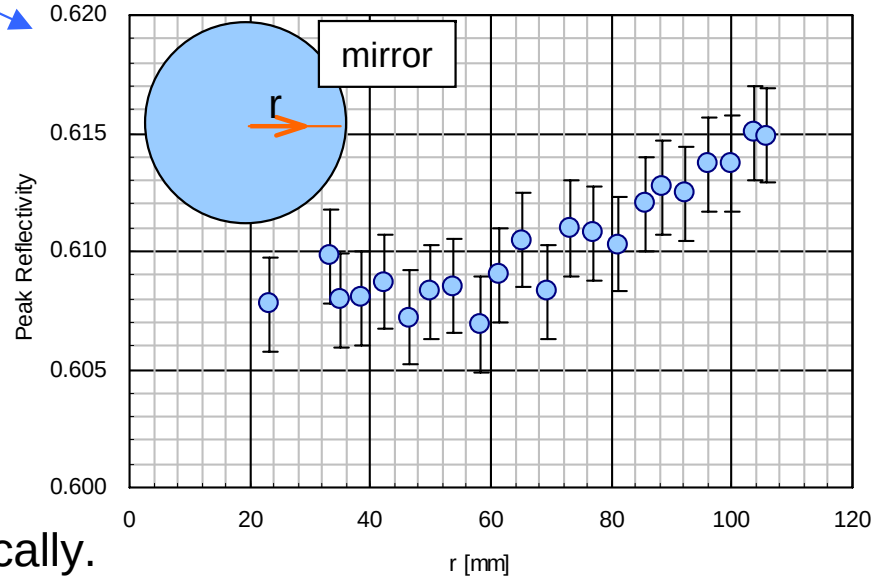
reflectivity-03



measurement result of wavelength dependency



peak reflectivity distribution



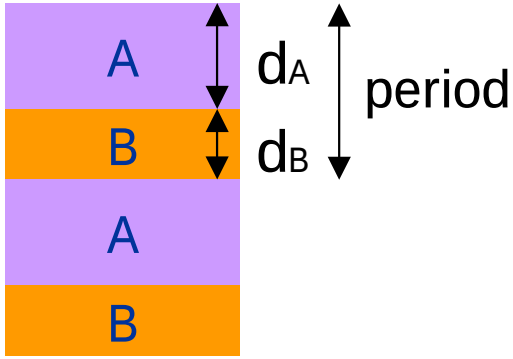
sample stage: 6 axes
detector stage: 3 axes
The reflectivity measurement is performed automatically.

Error factor about thickness measurement

layer period-01

Bragg's law.

- $2d*\cos\theta=\lambda_p$ (d:layer period, θ:incident angle, λ_p :peak wavelength)



Error factor

- incident angle: $\Delta\theta$
  - derivative of Bragg's law: $\Delta\lambda_p = 2d*\sin\theta * \Delta\theta$
- measurement position: Δr
  - As for curved mirror, the position error Δr cause incident angle error $\Delta\theta$. $\Delta\lambda_p = 2d*\sin\theta * \Delta\theta$
  - With layer period distribution, the position error Δr cause the thickness error Δd. ex. $d(r) = d0(1+c*r^2)$, $\Delta d=2*d0*c*r*\Delta r$
- incident beam wavelength: $\Delta\lambda$

Layer period measurement

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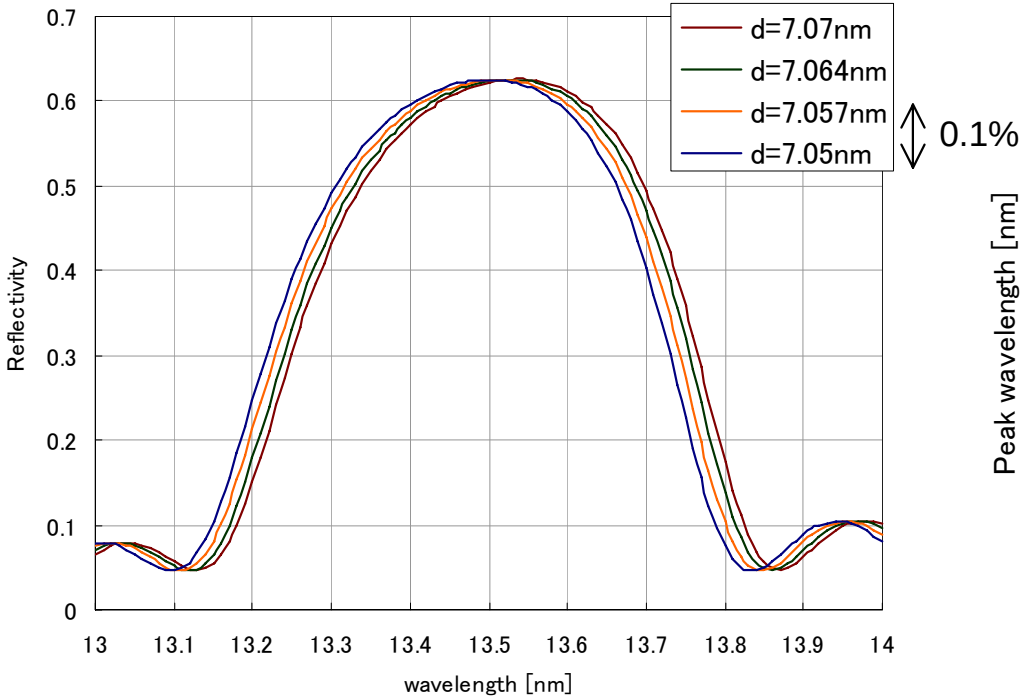
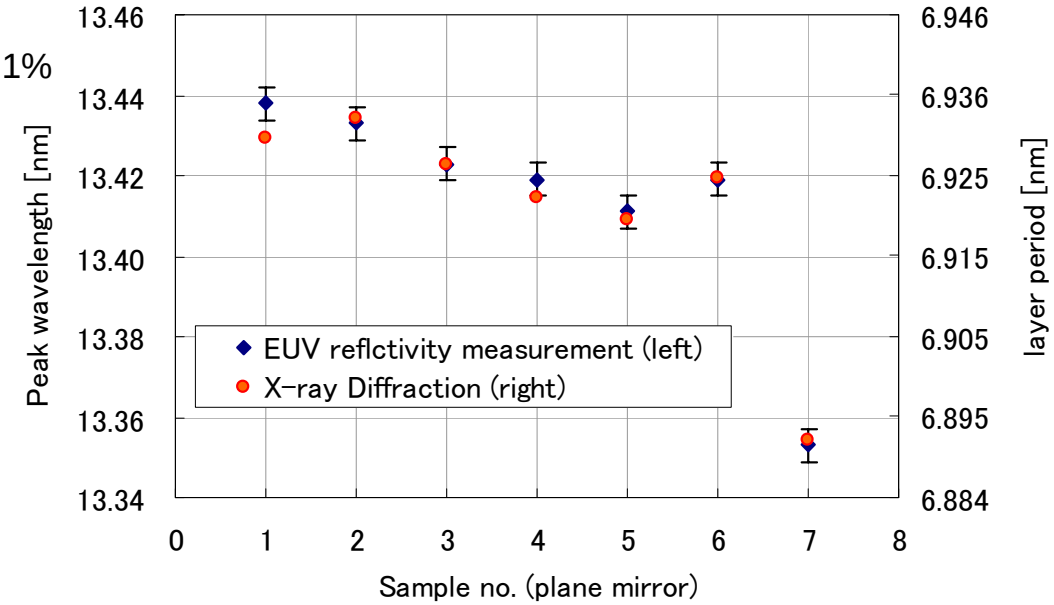
layer period-02

Calculation about relationship between layer period and peak wavelength. 0.1% period change approximately correspond 0.01nm peak wavelength change



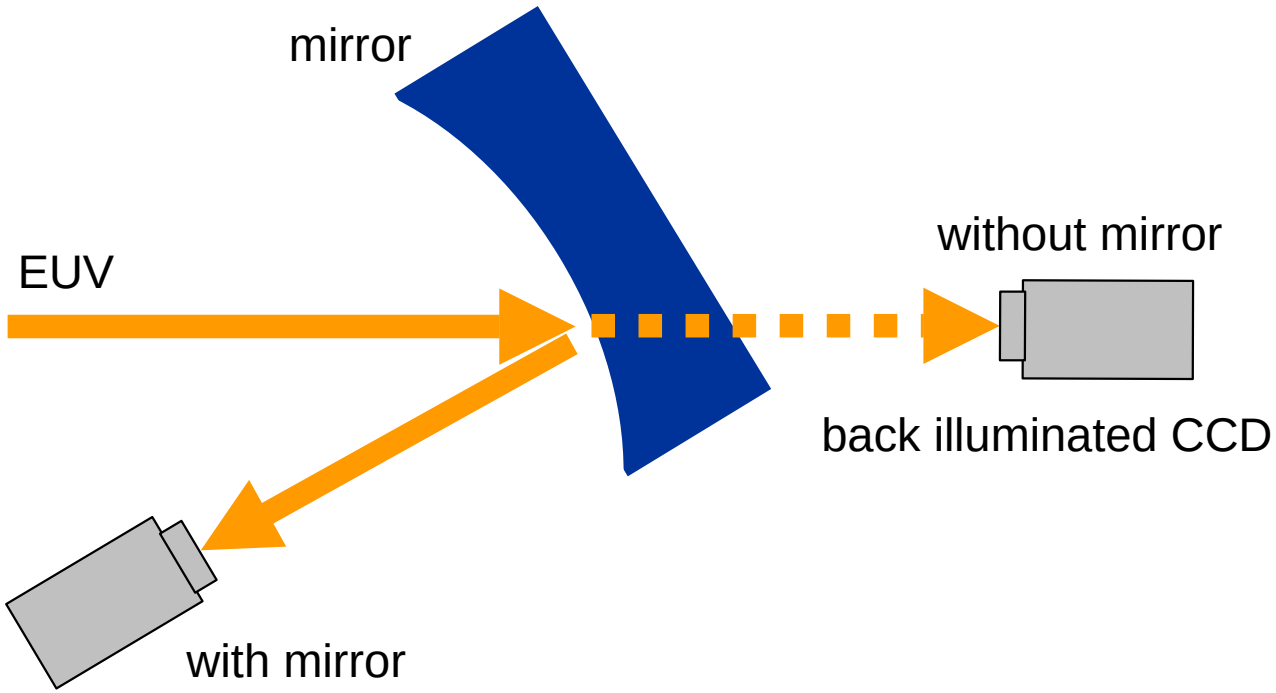
Comparison between X-ray Diffraction and reflectometer sample: plane mirror

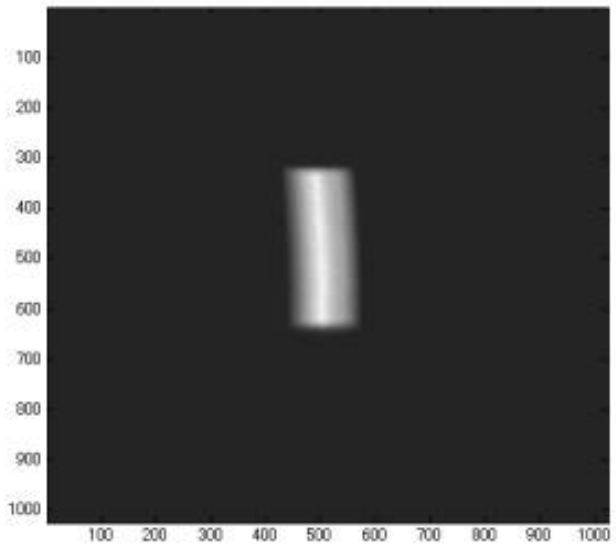


- Reflectivity characteristic depends on multilayer thickness. Peak wavelength distribution shows good agreement with X-ray diffraction(XD) result. It is difficult to measure curved mirrors with XD.
- We evaluate multilayer thickness for EUV projection optics by measuring EUV peak wavelength.
- Total layer thickness was derived from d*N. (d:layer period, N:number of layer pair)

High accuracy mirror alignment

layer period-03





EUV beam spot on CCD

- We use CCD not only as a EUV intensity detector but also as a beam position detector.
- By checking reflected beam position on CCD, we confirm that mirror alignment is correctly performed. We achieved Incident angle accuracy < 1mrad.

Measurement result of peak wavelength

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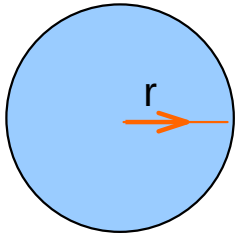
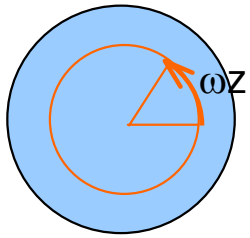
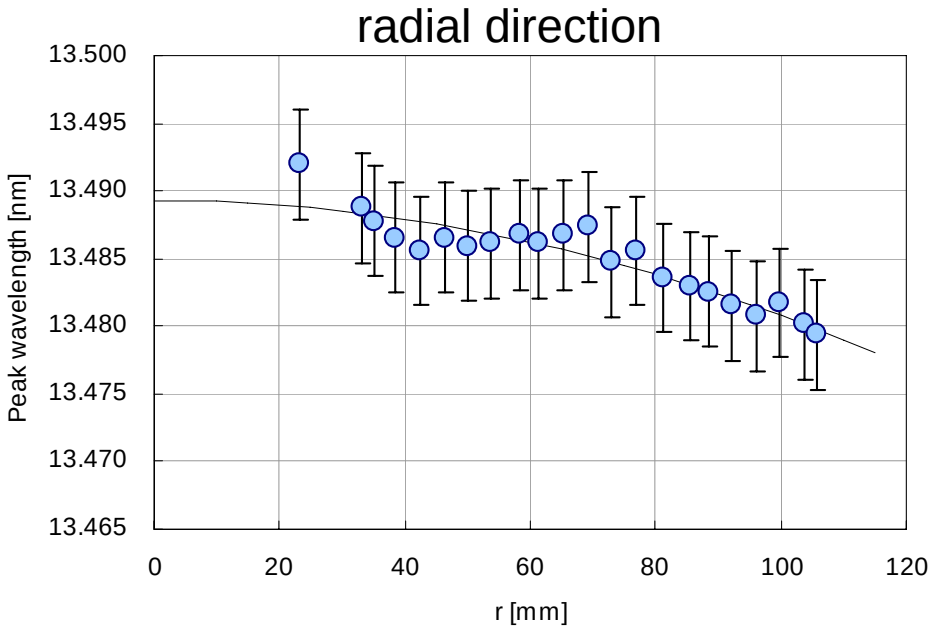
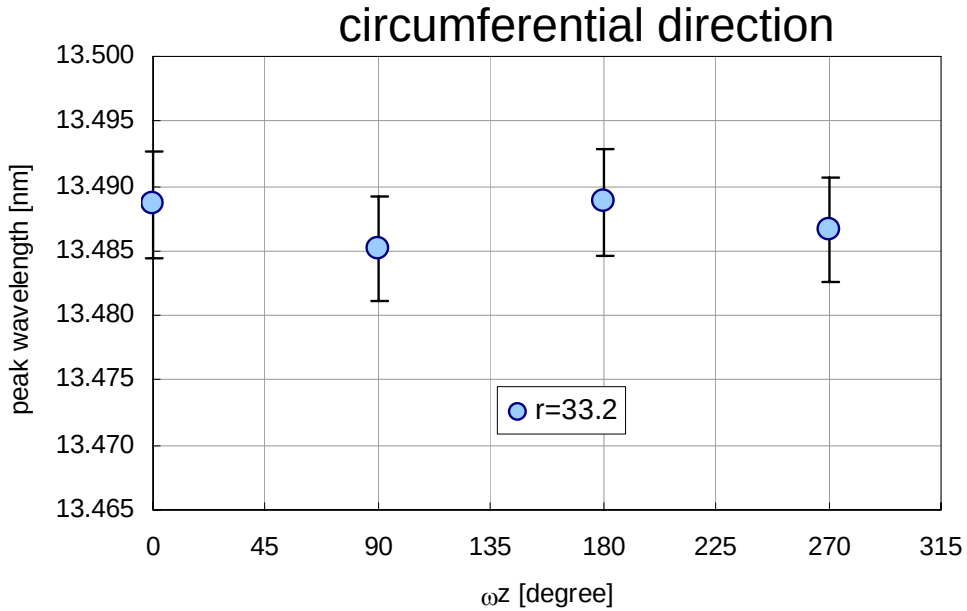
layer period-04



measurement result of curved mirror







- measurement error : <0.03% (this case)
  - Measurement error was estimated from incident angle error, measurement position error and incident wavelength error.
- The multilayer thickness measurement was performed over whole area of EUVL mirror.

Comparison with figure measurement

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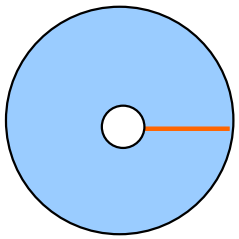
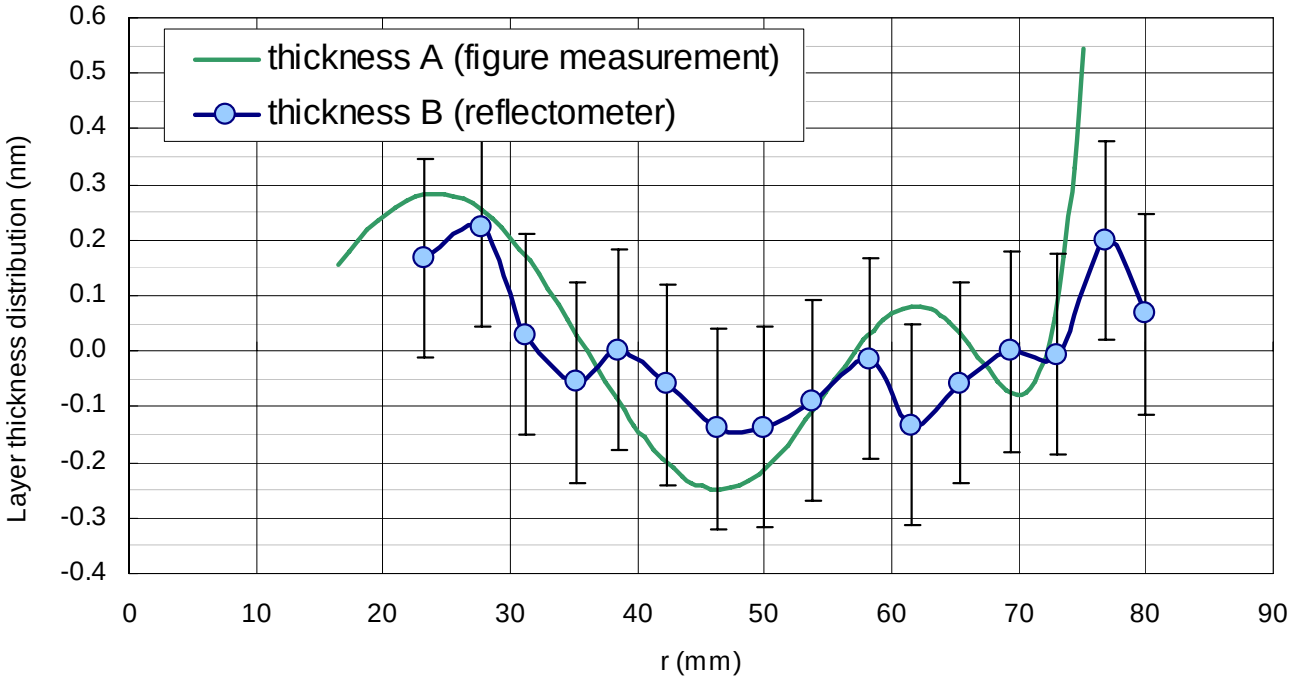
layer period-05

Thickness A =figure measurement(after coating) - figure measurement(before coating)

Thickness B = d*N (d: layer period, N: number of layer pair).

measurement point

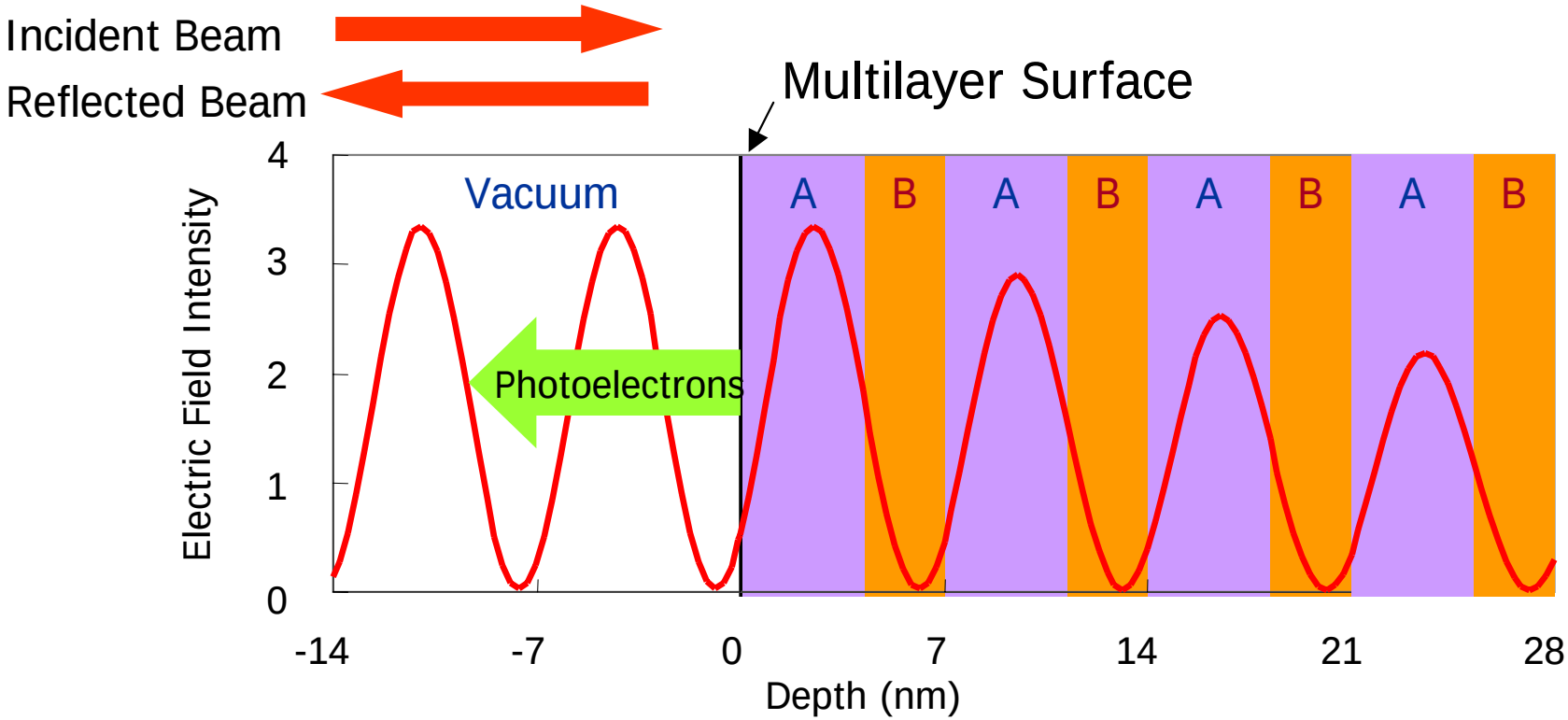




- Both thickness distribution shows good agreement.

Phase shift measurement (principle)

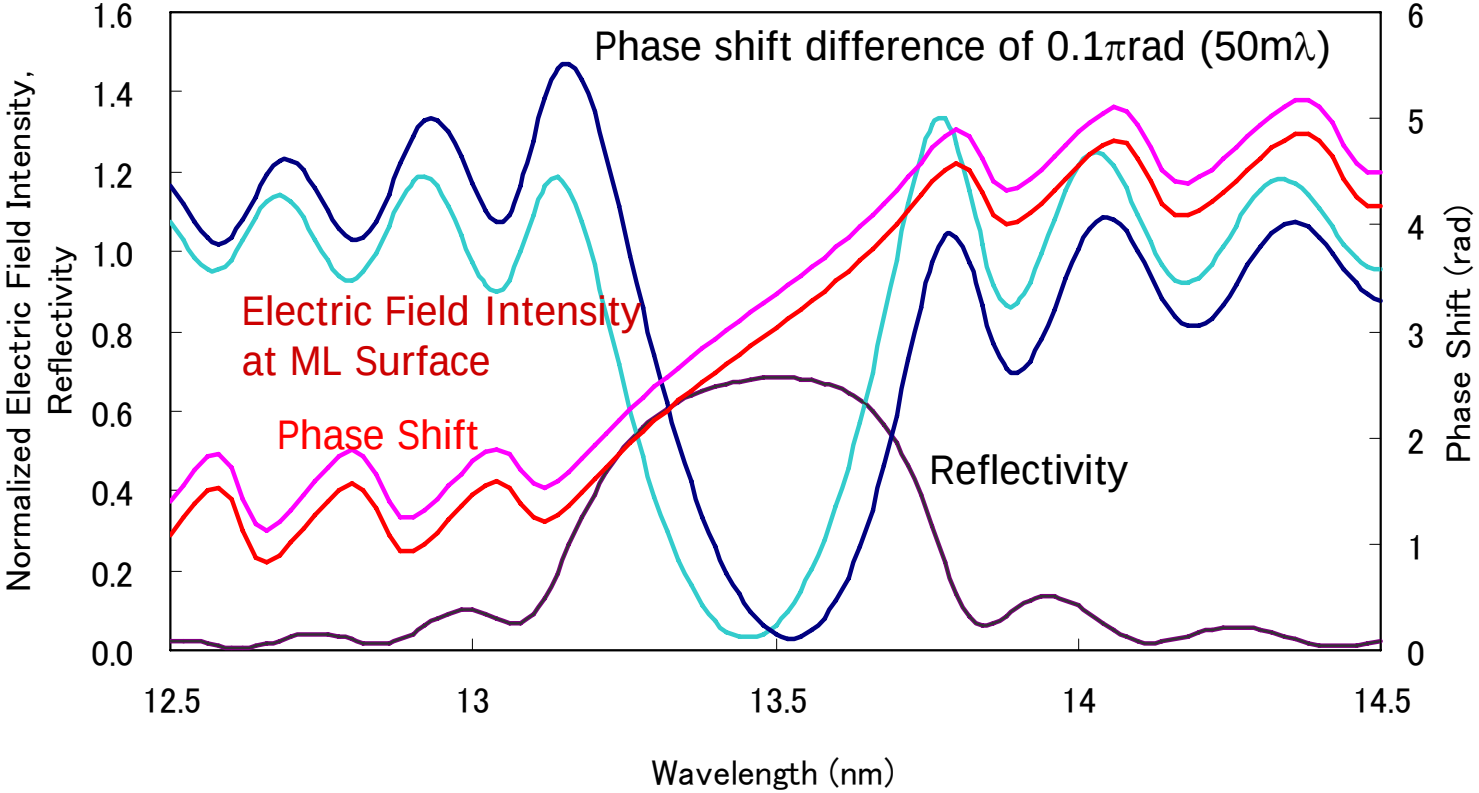
phase shift-01



Standing wave is a superposition of the incident light and the reflected light. Electric field of the standing wave depends on phase shift and reflectivity.

Photoelectron intensity is proportional to electric field intensity on the multilayer surface approximately, because escape depth of low energy (<100eV) electron is small compared to thickness of each layer.

Relation between electric field intensity and phase shift

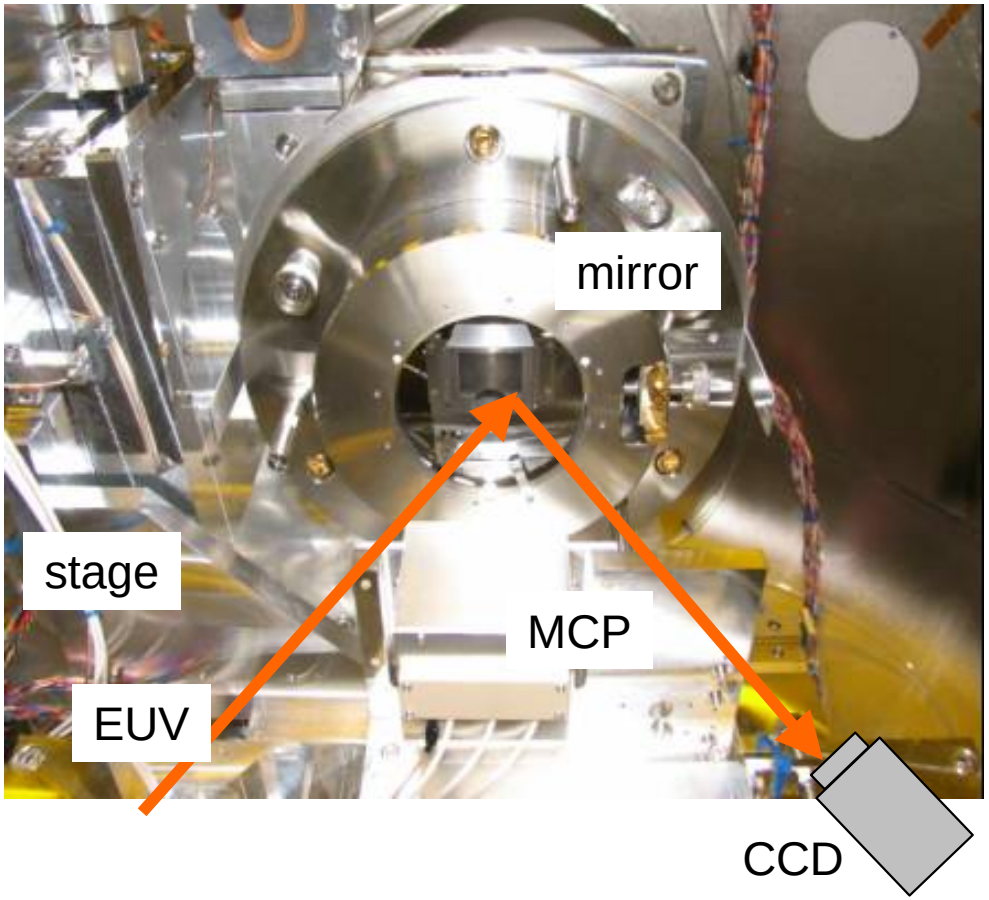


A change of the Phase Shift on Reflection is close relation to a change of the Electric Field Intensity(Photoelectron intensity).

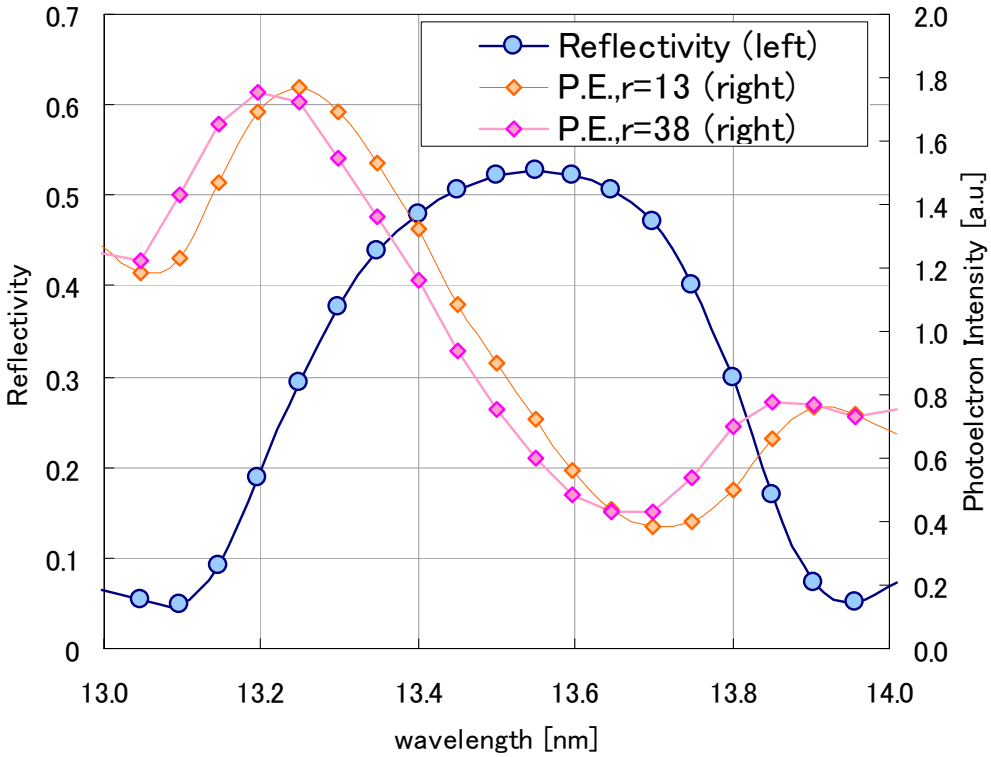
Once wavelength dependency of photoelectron intensity and reflectivity is measured, we can get the phase shift on reflection.

Experimental setup

phase shift-03



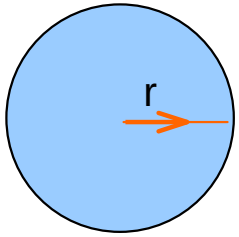
An example of measurement result



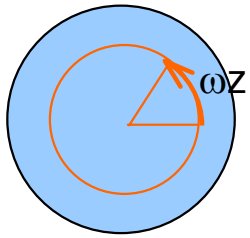
- Reflectivity and photoelectron yield can be measured at the same time.
- Curved mirrors can be measured.
- Phase shift was derived from the wavelength dependency of photoelectron yield.

Measurement result of phase shift

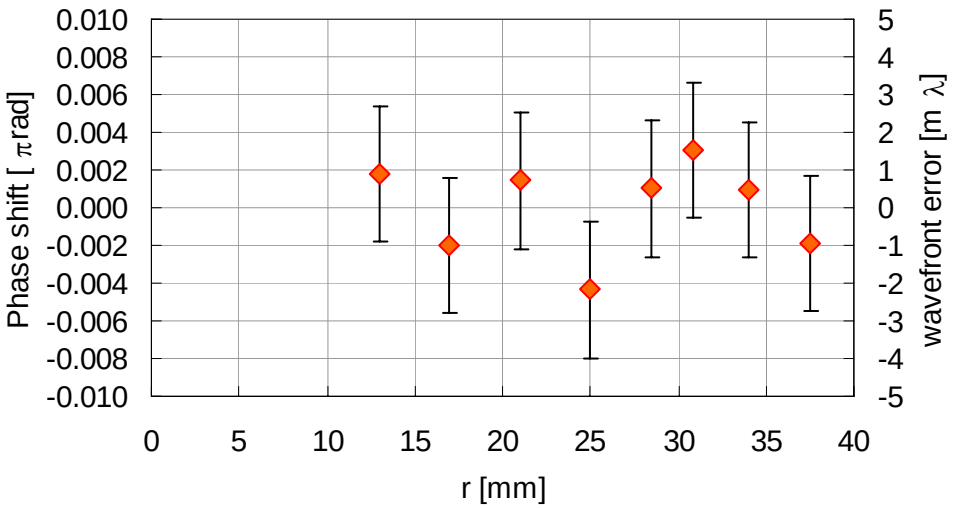
phase shift-04



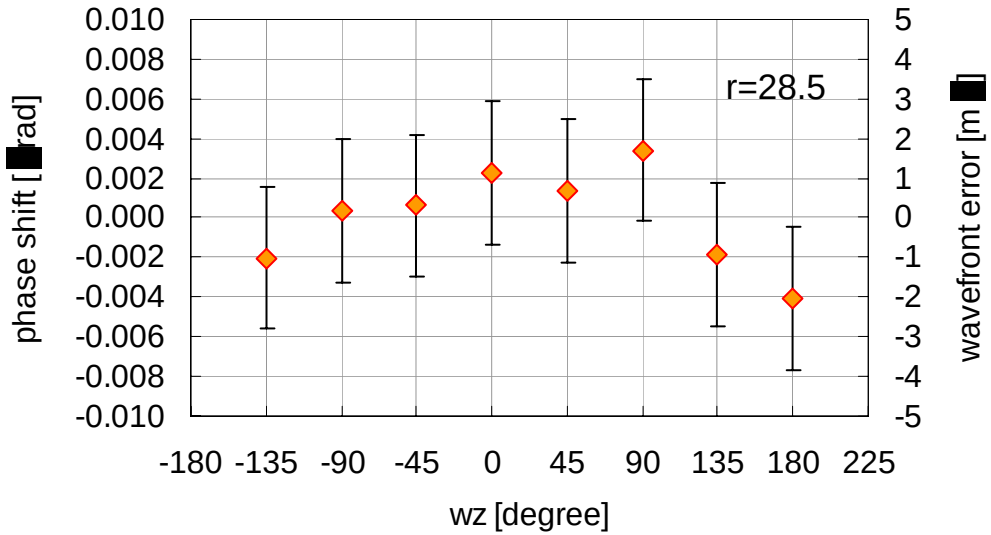
Measurement result of curved mirror
The power component was subtracted.



radial direction



circumferential direction



- The phase shift distribution on the curved mirror was obtained.
- measurement error : <2mλ

Summary

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- Reflectivity, ML thickness and phase shift measurements on aspherical mirror proved their performance available in production phase .
- These measurements makes possible to manufacture high-performance EUV projection optics.
- Reflectivity measurement
  - Whole area of EUVL mirrors can be measured.
  - The alignment and measurement are performed automatically.
- Multilayer thickness measurement
  - Whole area of EUVL mirrors can be measured.
  - The measurement results shows good agreement with X-ray diffraction and figure measurement.
- Phase shift measurement
  - Phase shift measurement of curved mirror was performed.
  - Measurement resolution is achieved less than 2mλ