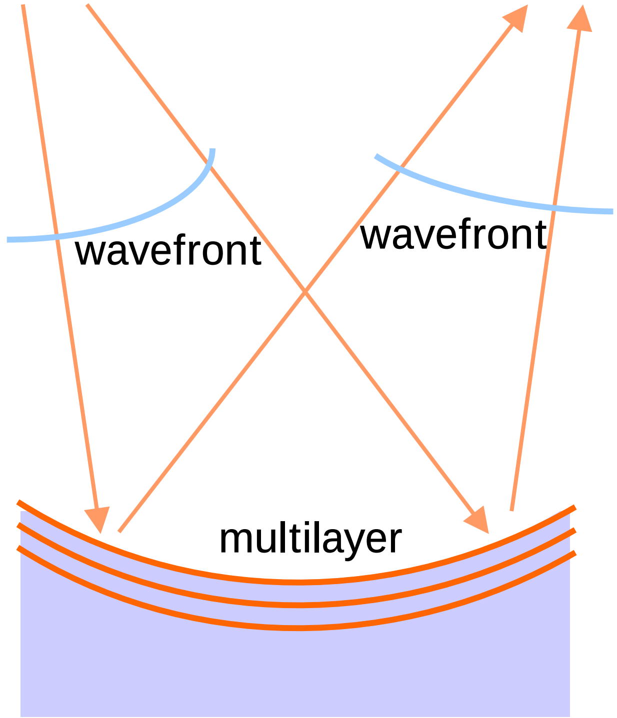
Measurement of Phase Shift on EUV Multilayer Reflection Using EUV Standing Waves

Akira Miyake, Mitsuaki Amemiya,
Fumitaro Masaki, and Yutaka Watanabe

Nanotechnology & Advanced System Research Laboratories ,
Canon Inc.

Wavefront Error of a Multilayer Mirror



For EUV projection optics, wavefront error should be very small. Wavefront error of projection optics consists of
- -aberration of optical design
- -wavefront error caused by imperfection of each mirror
- -alignment error of mirrors.

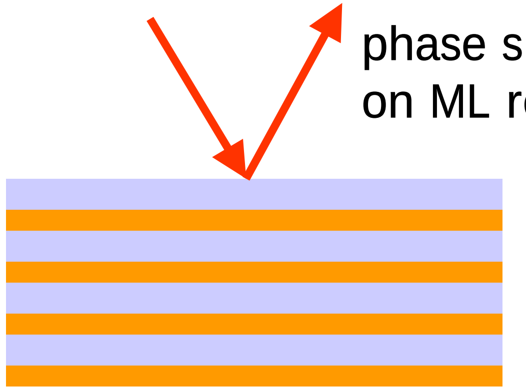
Wavefront error of projection optics can be measured by point diffraction interferometry (PDI).

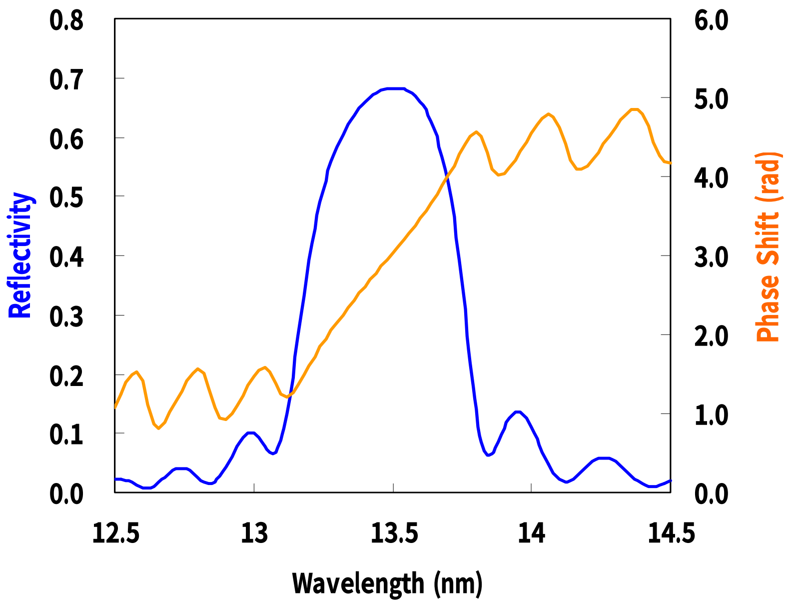
In order to suppress total wavefront error of EUV projection optics by adjustment of mirror position on the basis of measurement of PDI, wavefront error of each mirror must be very small.

Wavefront of reflected light is determined by
- -shape of the mirror surface
- -phase shift on multilayer reflection.

Therefore, we have to measure and control them with high accuracy.

Phase Shift on Multilayer Reflection





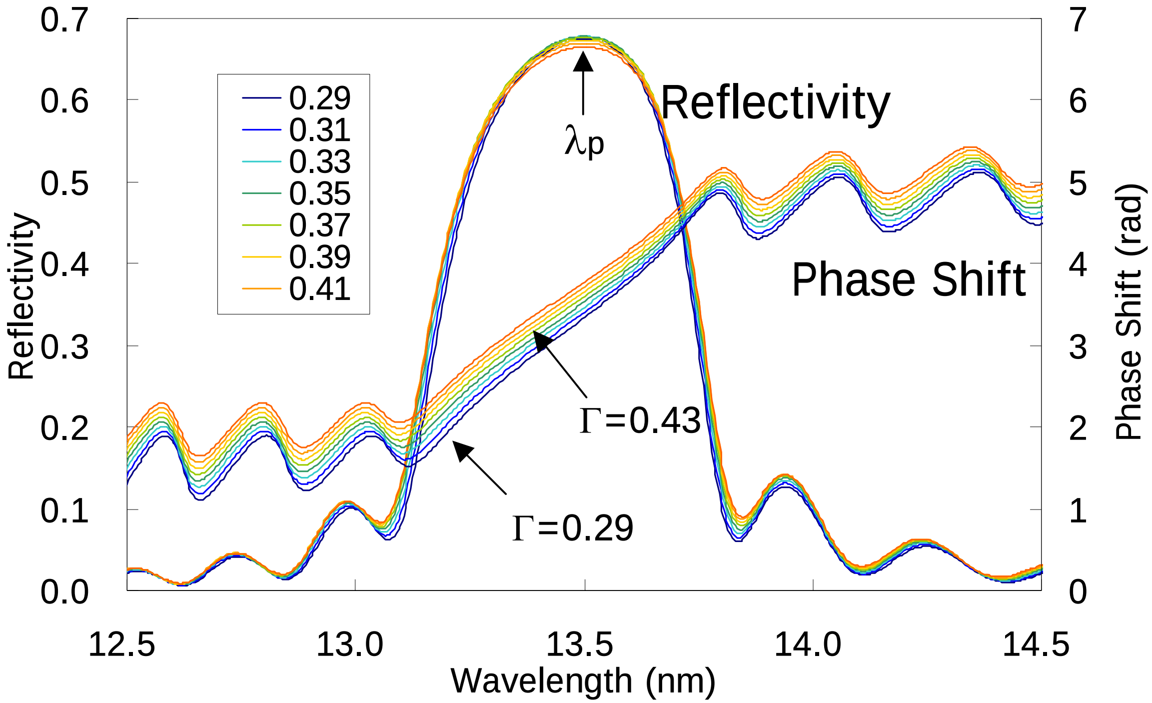
Phase shift on multilayer reflection depends on

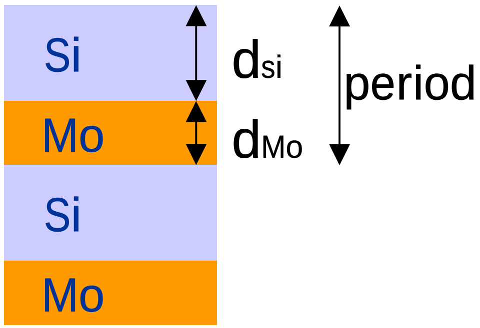
Incident Beam Characteristics
- -Wavelength
- -Incident Angle
- -Polarization

Multilayer Structure

-Thickness	d
-Thickness Ratio	Γ
-Density	ρ
-etc.	

Multilayer structure dependency of Phase Shift





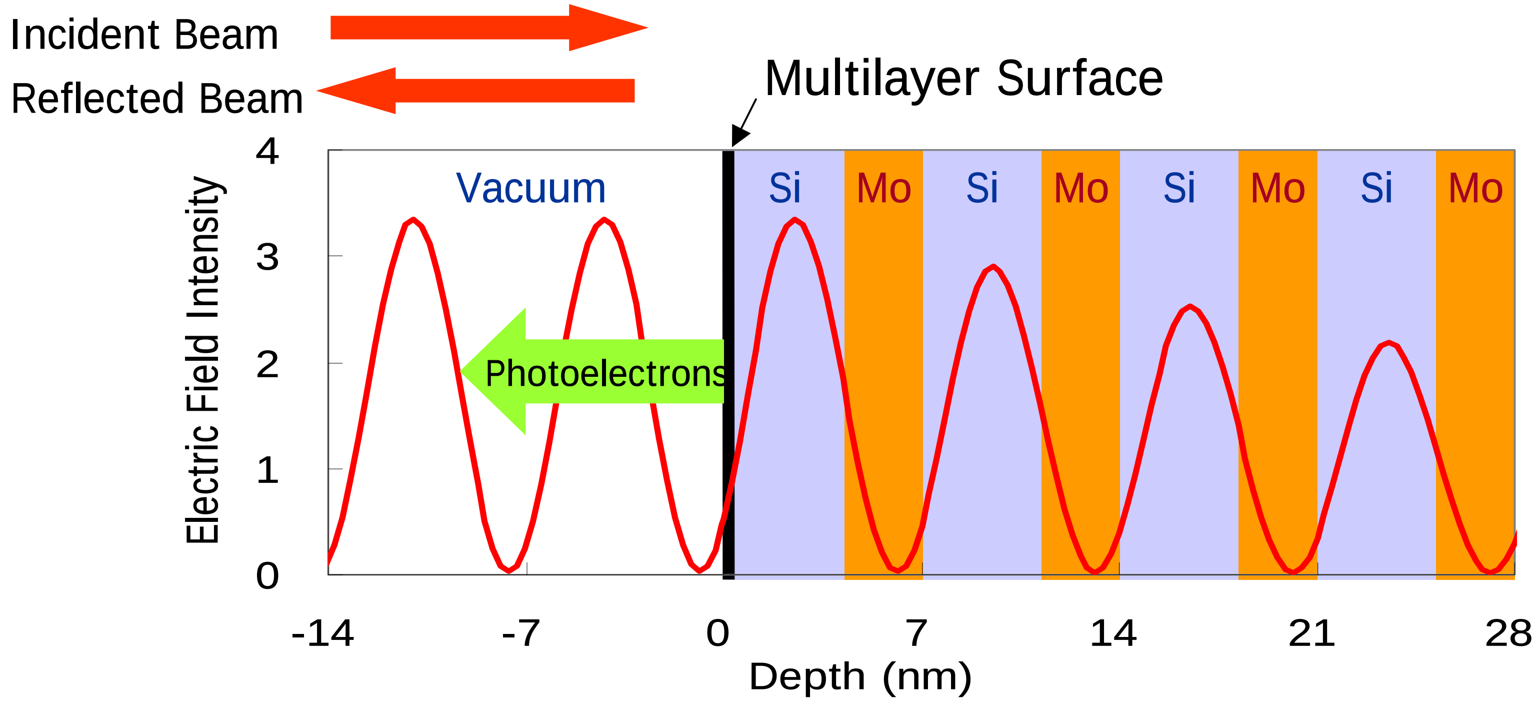
$\Gamma = d_{Mo} / (d_{Mo} + d_{Si})$

Layer period ($d_{Mo}+d_{Si}$) was determined so that λ_p is 13.5nm.

The film thickness ratio variation of 0.02 makes
- Phase shift variation of 0.02 π radian
- Small variation of reflectivity.

If only wavelength dependencies of reflectivity are measured, phase shift variation cannot be distinguished.

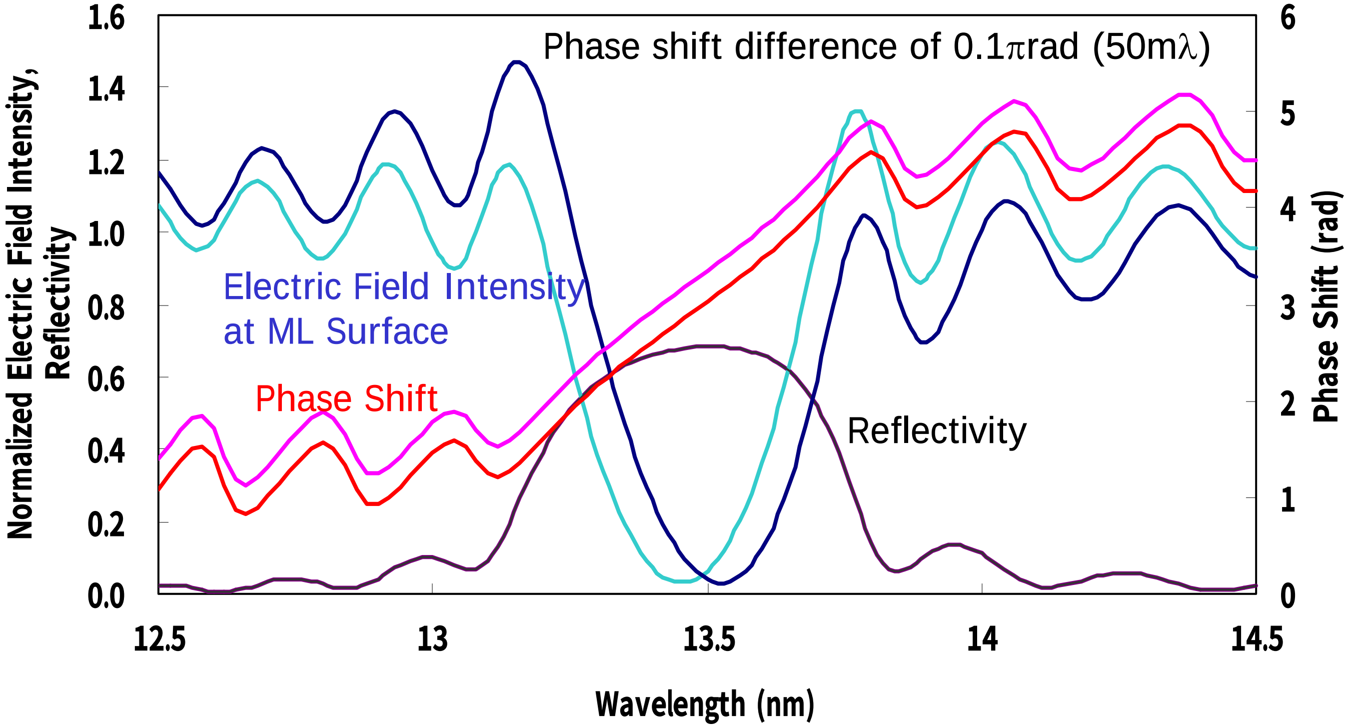
Calculation Model



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.

Wavelength Dependency of Electric Field Intensity and Reflectivity

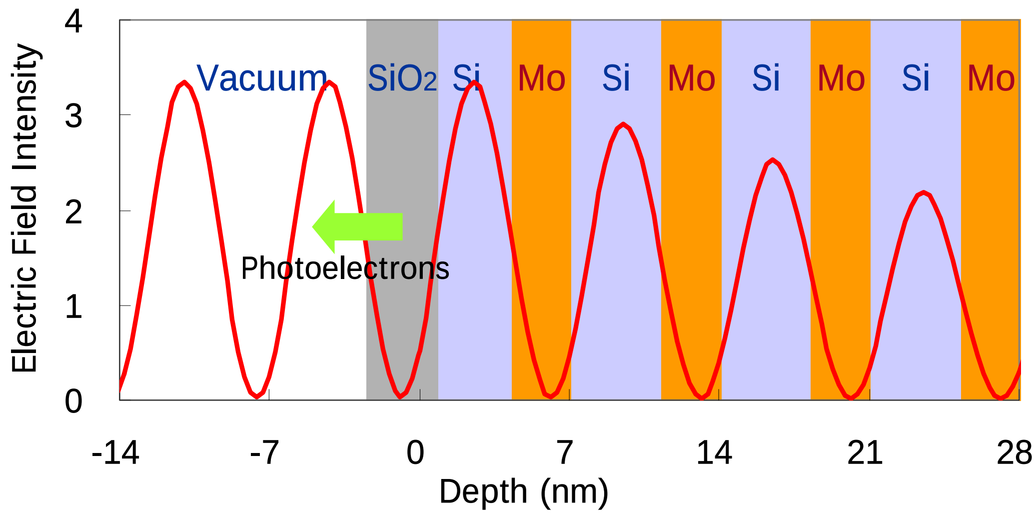


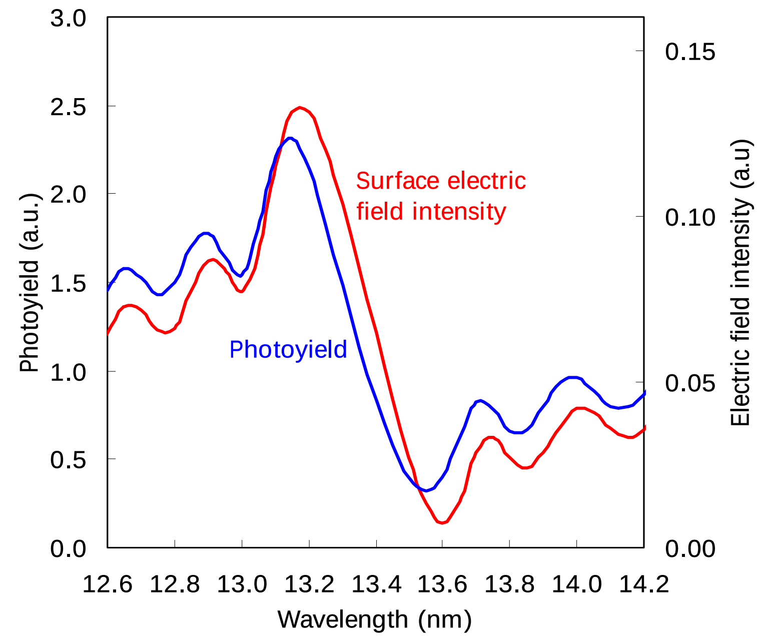
The electric field intensity at a multilayer surface changes drastically according with a change of phase shift on reflection.

If wavelength dependency of photoelectron intensity and reflectivity is measured, electric field intensity on a multilayer surface and phase shift on reflection can be obtained.

Photoelectron Simulation Model

Speed&Quality





Photoelectrons generated inside the multilayer are attenuated and some of them arrive at the surface of the multilayer and are emitted to vacuum.

Existence of oxidized layer of multilayer surface and inter-diffusion layers are assumed.

The calculated photoyield is approximately proportional to the surface electric field intensity.

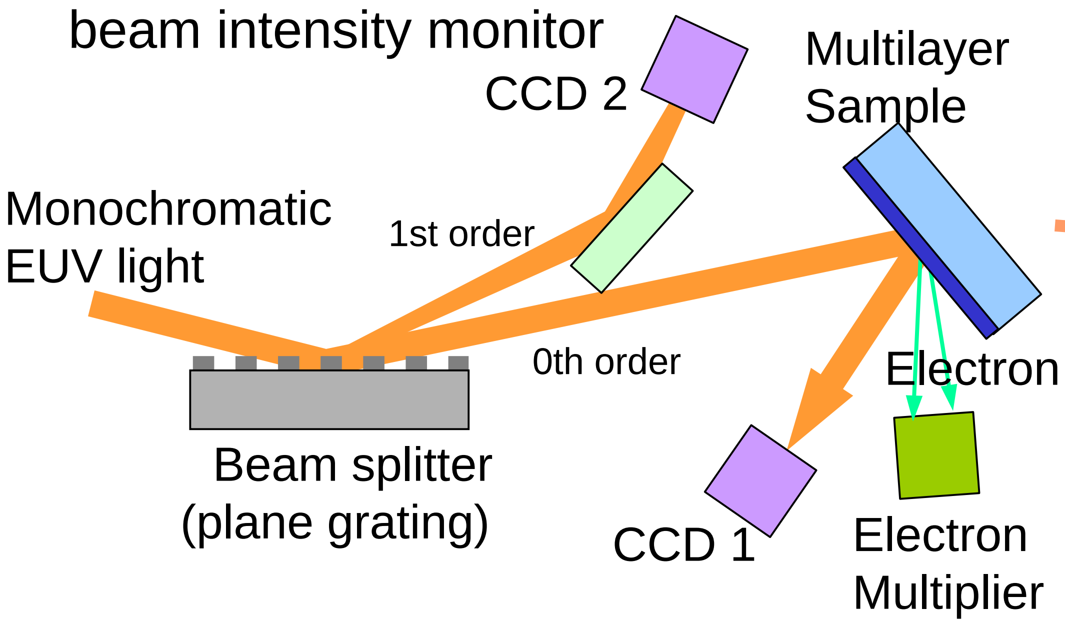
Reflectometer : Photograph

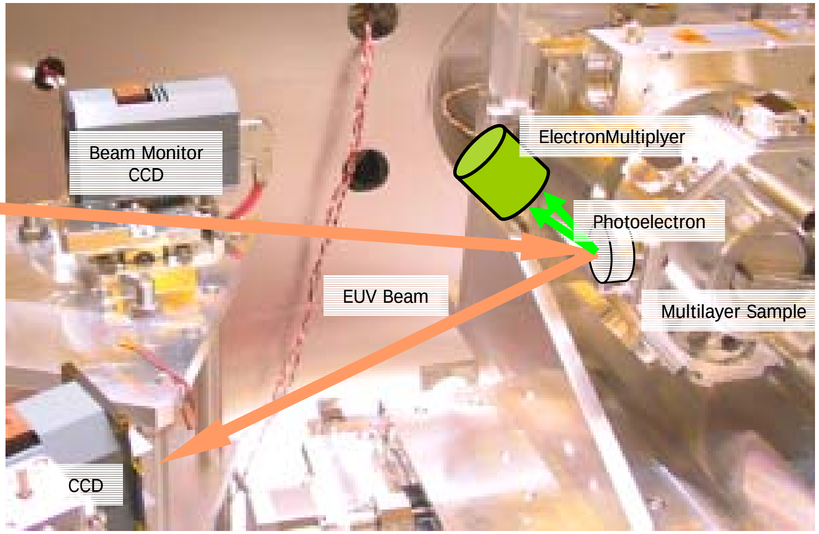
Speed&Quality

Mirror chamber **Sample chamber** **Monochromato** **Controller** **LPP source**

Maximum Mirror Size：
ϕ500mm

Experiment (setup)





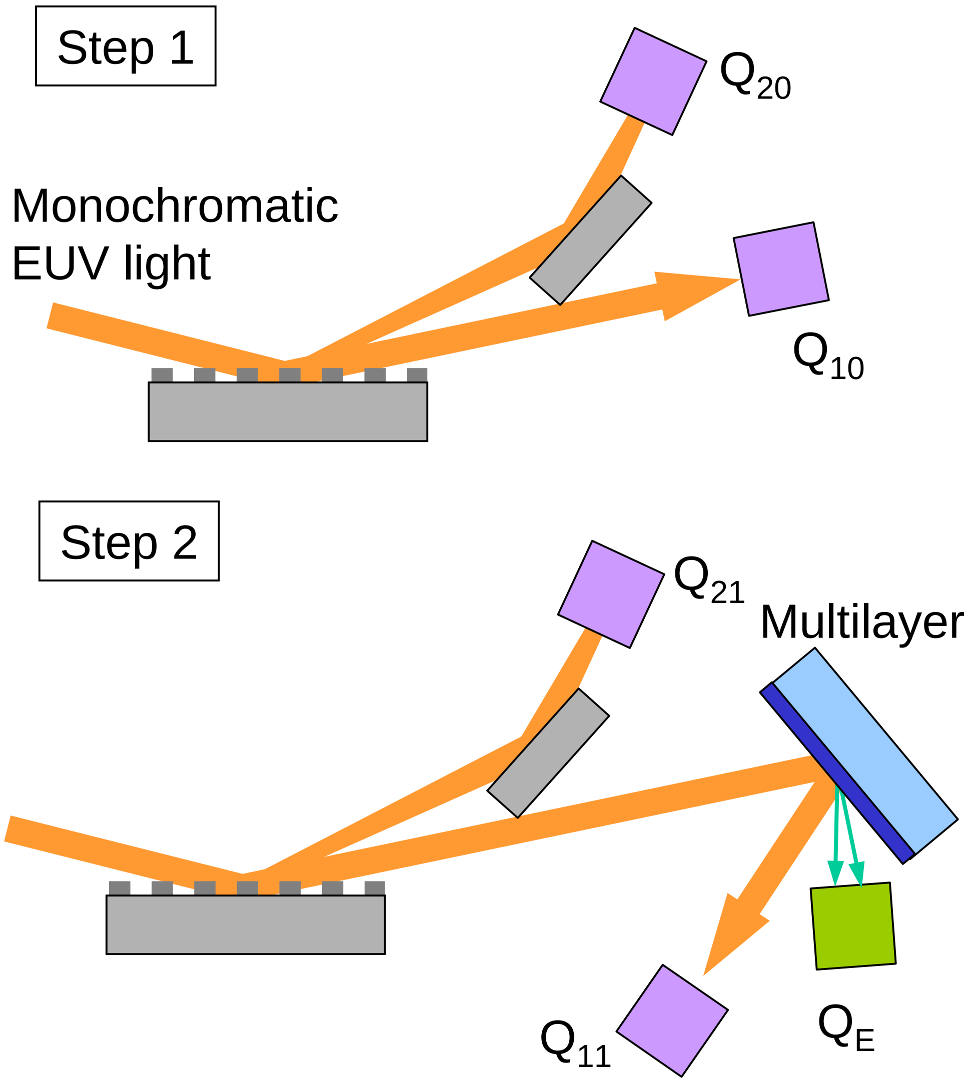
In order to compensate instability of incident beam , a beam intensity monitor is equipped between a monochromater and a sample.

A plane grating works as a beam splitter of the beam monitor.

0th order : to sample, 1st order : to CCD of the beam intensity monitor

Reflectivity and photoelectron yield can be measured at the same time.

Experiment (procedure)



Instability of the incident beam is compensated with the beam monitor. Compensated reflectivity is given by

$$R = (Q_{11} x Q_{20}) / (Q_{10} x Q_{21})$$

Intensity of photoelectron per incident beam intensity (photoyield) is given by

$$Y = Q_E x S_{CCD} x R / (Q_{11} x S_{EM}) ,$$

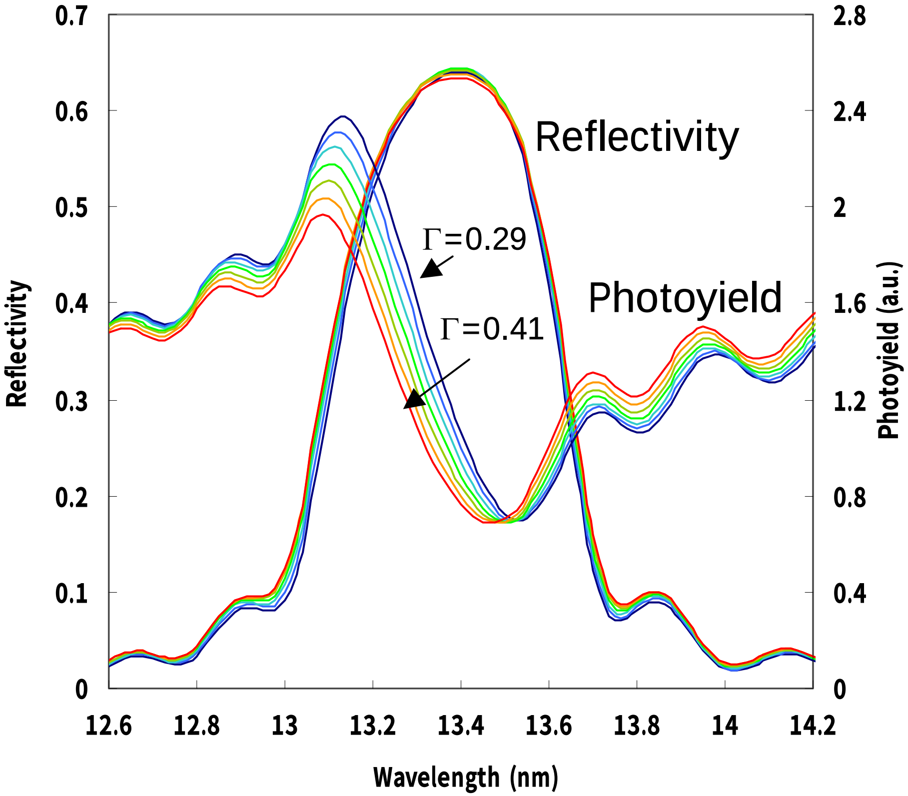
where

S_{CCD} : sensitivity of CCD

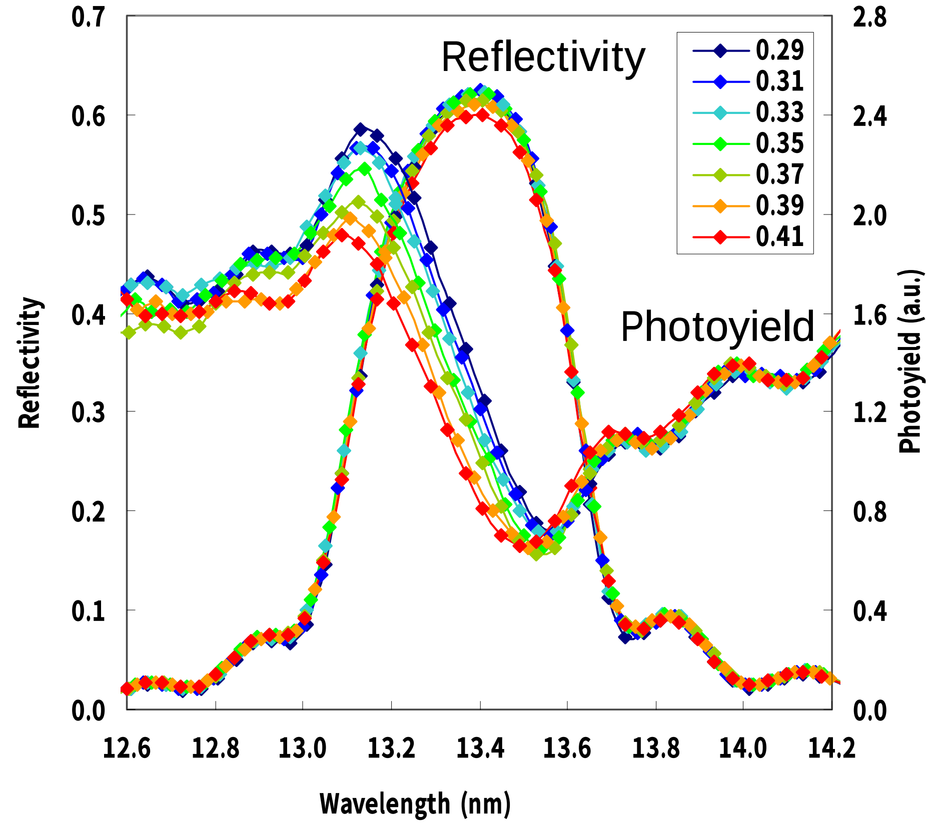
S_{EM} : sensitivity of EM

Wavelength dependency of S_{CCD} and S_{EM} are assumed to be constant.

Comparison of Calculation and Experimental Results



Calculation



Experiment

Calculation results show good agreement with the experimental results. Variation of phase shift is detectable with high resolution of less than 0.02 πrad (10 mλ).

Summary

Speed&Quality

For each mirror of EUV projection optics, shape of the mirror and phase shift on multilayer reflection must be measured and controlled. It is important to evaluate variation of the phase shift over a mirror surface.

Measurig an EUV standing wave on multilayer, information of the phase shift can be obtained.

Reflectivity and a photoyield were measured simultaneously using an EUV reflectometer. Variation of phase shift is detectable with high resolution of less than 0.02 πrad (10 mλ).