Smoothing of the substrate surface by Mo/Si multilayer coating deposited by ion beam sputtering

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2nd International EUVL Symposium Sep. 30 – Oct. 2, 2003

Outline

- **Introduction**
- Sample Substrates
- Smoothing effect of depositing Mo/Si multilayer
- Reflectivity and angular scattering distribution
- Summary

Introduction

In EUV multilayer-coated reflective optics, not only surface roughness of mirror substrates, but roughness caused by multilayer deposition significantly affects its performance.

(1) We observed the smoothing effect of Mo/Si multilayer coatings deposited by ion beam sputtering.

Surface profiles were measured by AFM before and after coating multilayer. Power spectral density (PSD) was calculated to evaluate surface roughness.

(2) We measured EUV reflectivity and angular distribution of scattering.

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- **Sample Substrates**
  - **AFM images of sample substrate surfaces**
  - **PSDs of sample substrate surfaces**
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Sample substrates

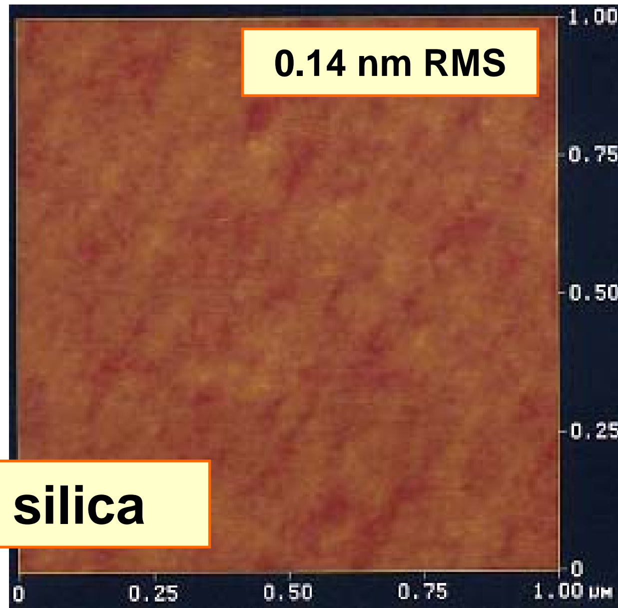
(a) **Polished fused silica**
(HSFR: 0.14 nm RMS)

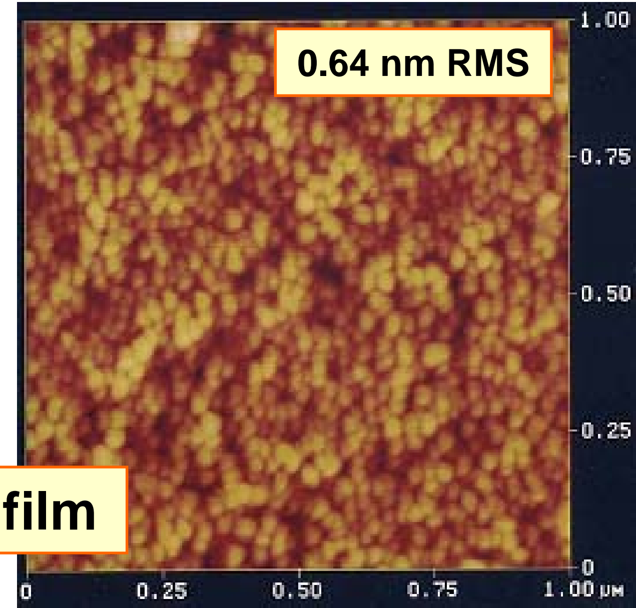
(b) **Polished CaF_2** *(HSFR: 0.49 nm RMS)*

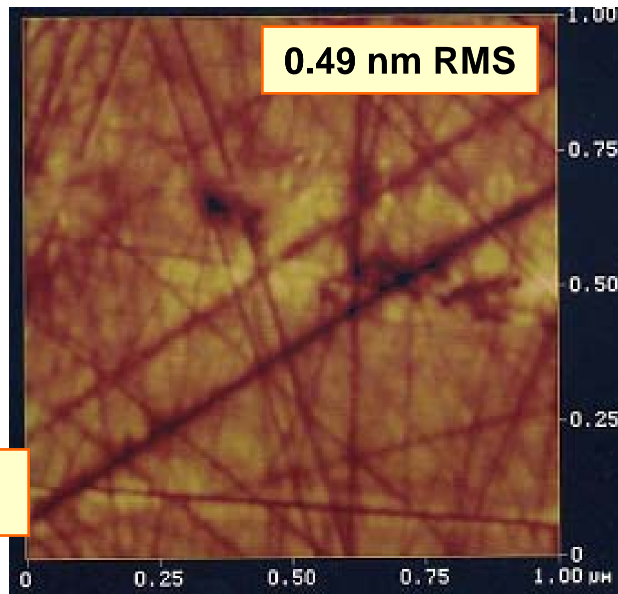
(c) **Optical AR film coating on polished fused silica** *(HSFR: 0.64 nm RMS)*

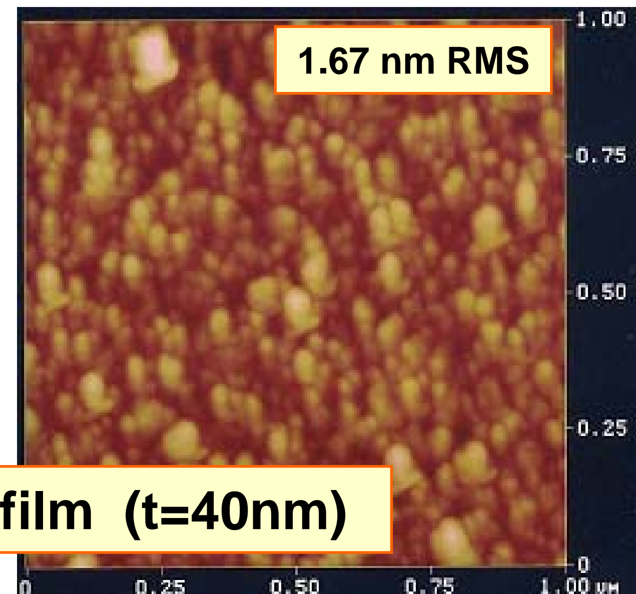
(d) **Thin Ag film (t=40nm) on Si wafer**
(HSFR: 1.67 nm RMS)

AFM images (1x1μm) of sample substrates

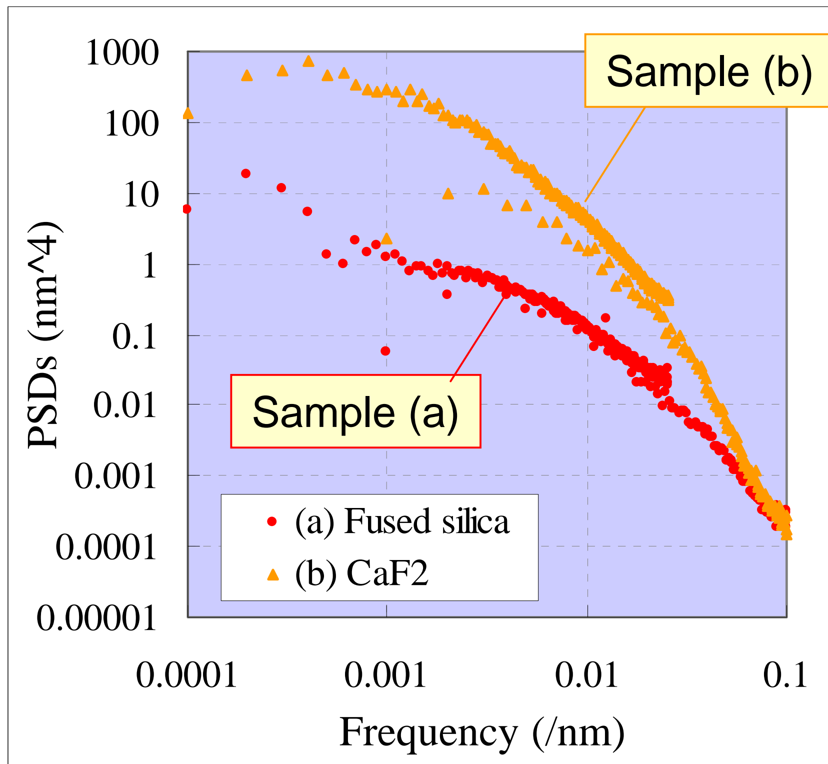


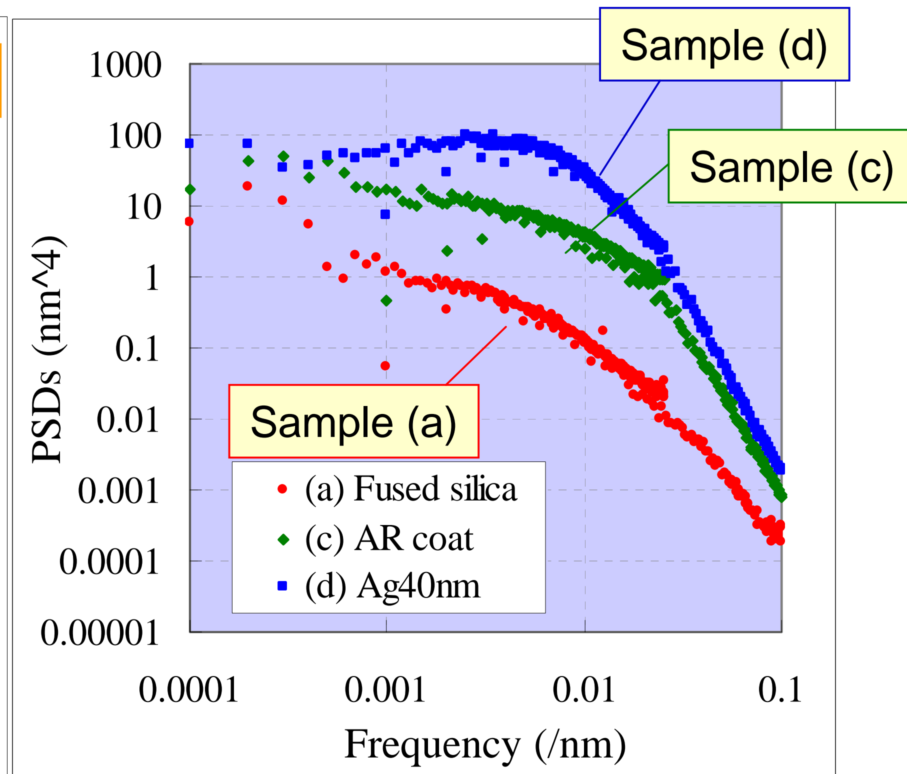






PSDs of sample substrate surfaces





- **Sample (b) had high roughness in relatively low spatial frequency.**
- **Samples (c) and (d) had high roughness, particularly in the region of spatial size of about 100 nm.**

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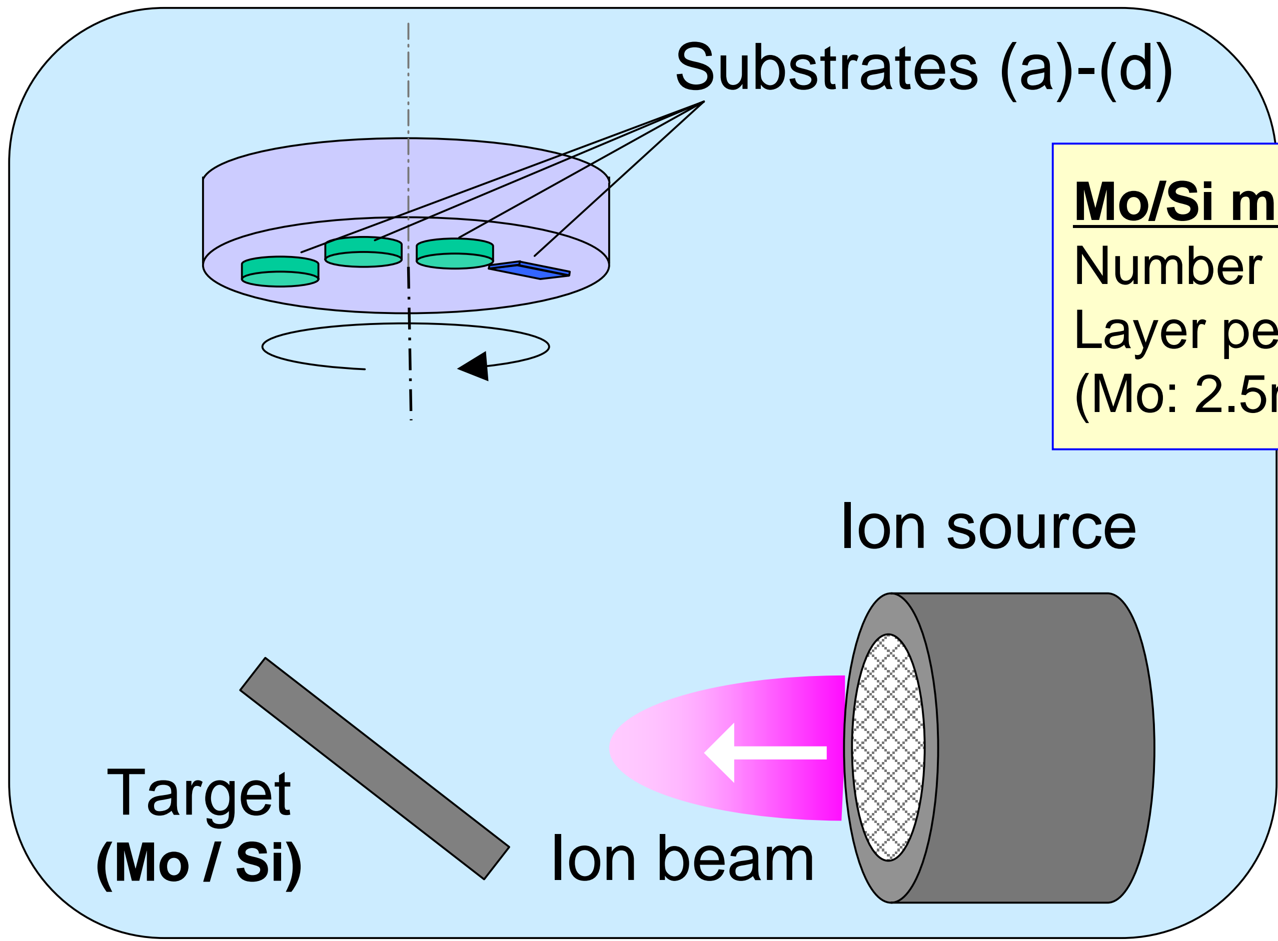
- Introduction
- Sample Substrates
- **Smoothing effect of depositing Mo/Si multilayer**
    - **AFM images of deposited Mo/Si multilayer surfaces**
    - **PSDs of deposited Mo/Si multilayer surfaces**
    - **Surface profiles of deposited Mo and Si thin films**
- Reflectivity and angular scattering distribution
- Summary

Mo/Si multilayer deposition

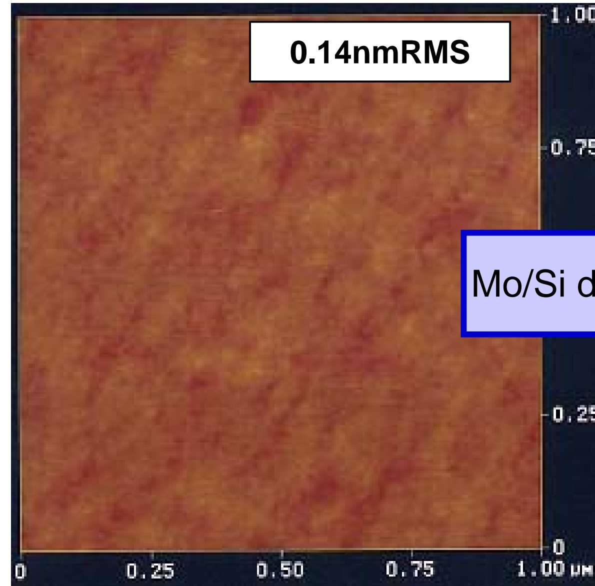


Mo/Si multilayers
Number of pairs: 50pairs
Layer period 7.1 nm
(Mo: 2.5nm, Si: 4.6nm)

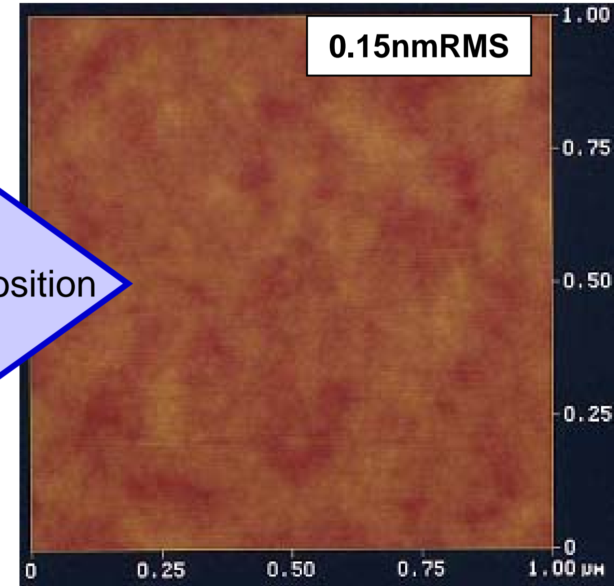
Mo/Si multilayers were deposited on the substrates by ion beam sputtering.

AFM images of Mo/Si multilayer surfaces (1)

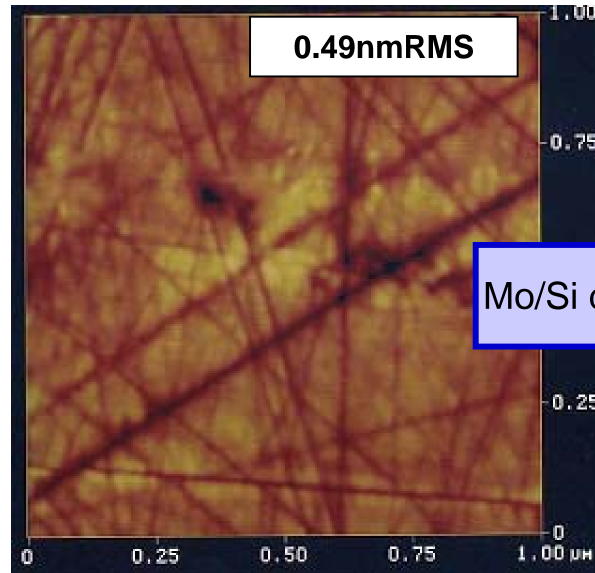
(a) Fused silica



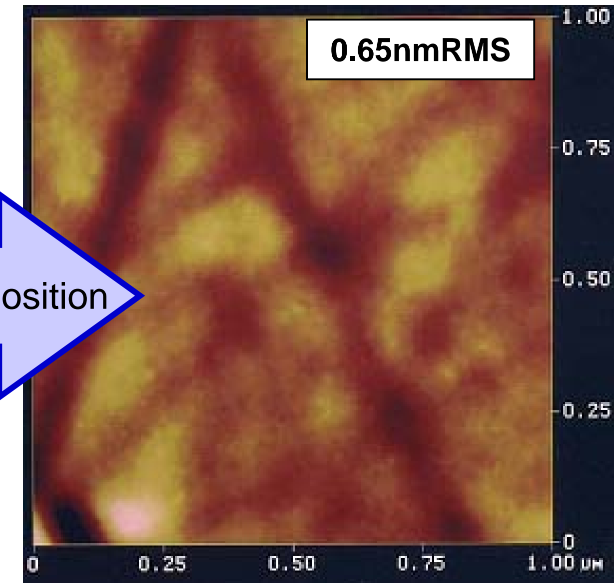
Mo/Si deposition



(b) CaF_2



Mo/Si deposition



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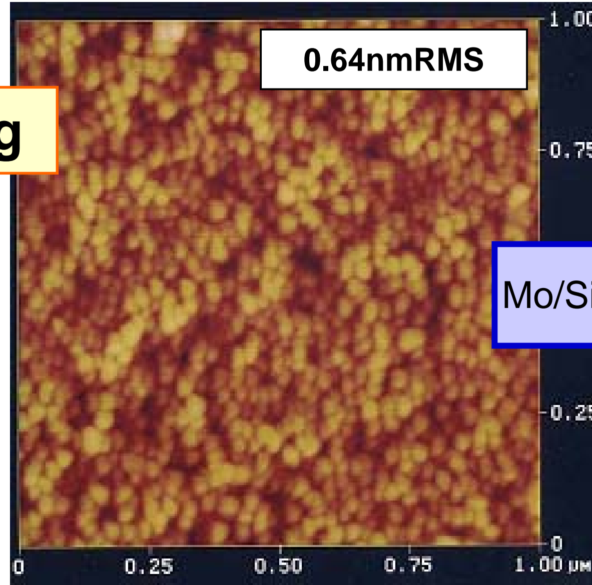
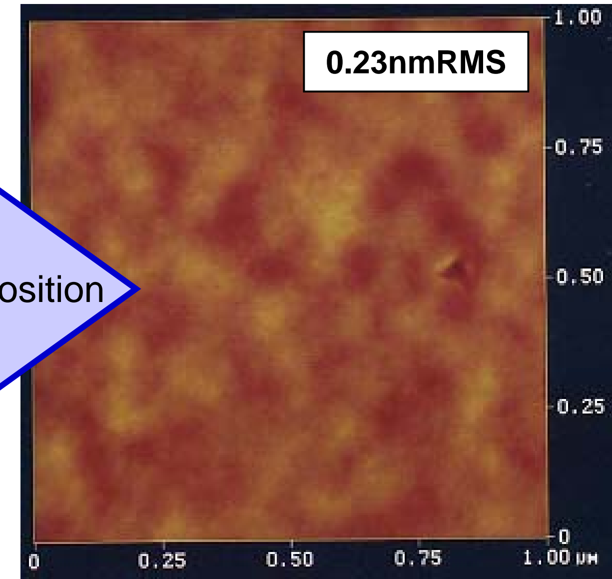
AFM images of Mo/Si multilayer surface(2)

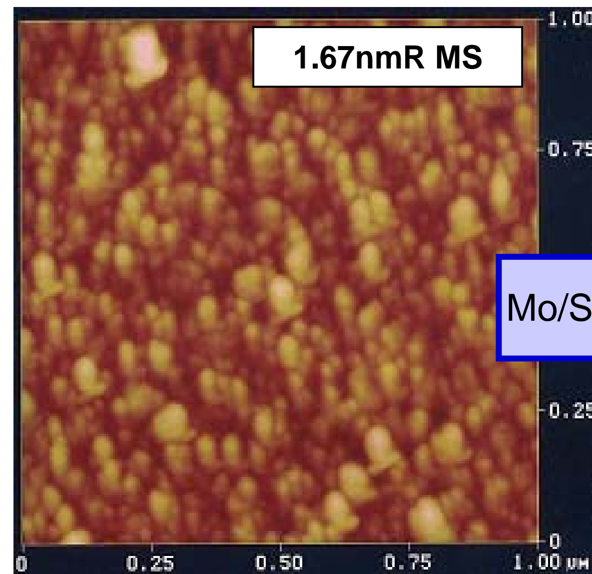
(c) AR film coating



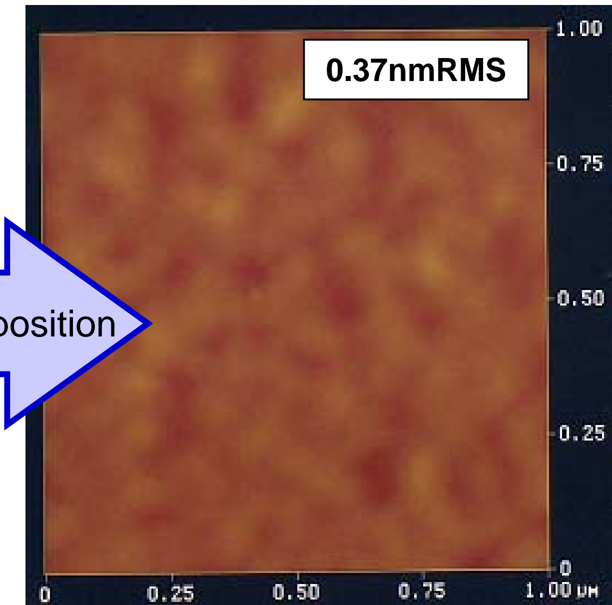
Mo/Si deposition



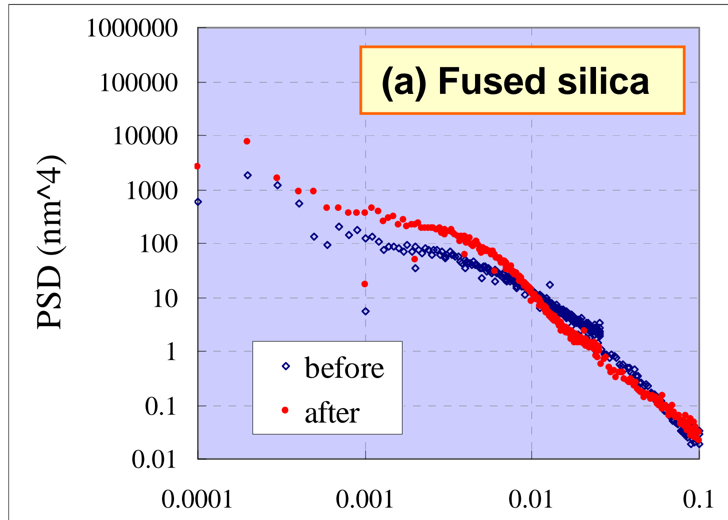
(d) Ag thin film (t=40nm)

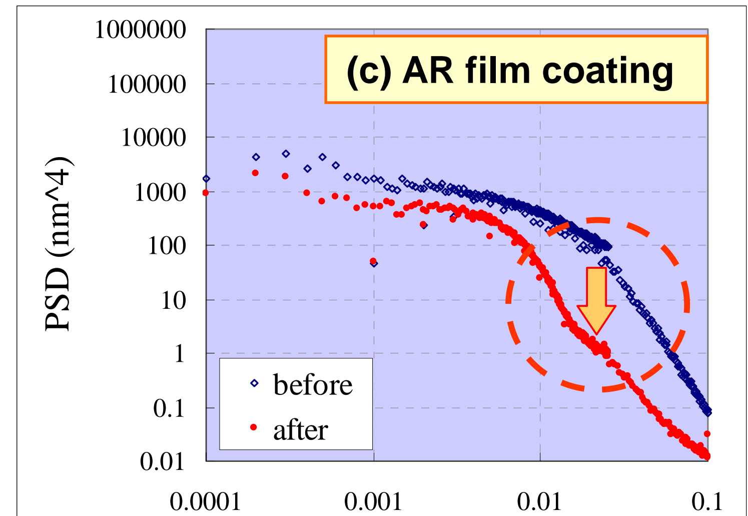


Mo/Si deposition

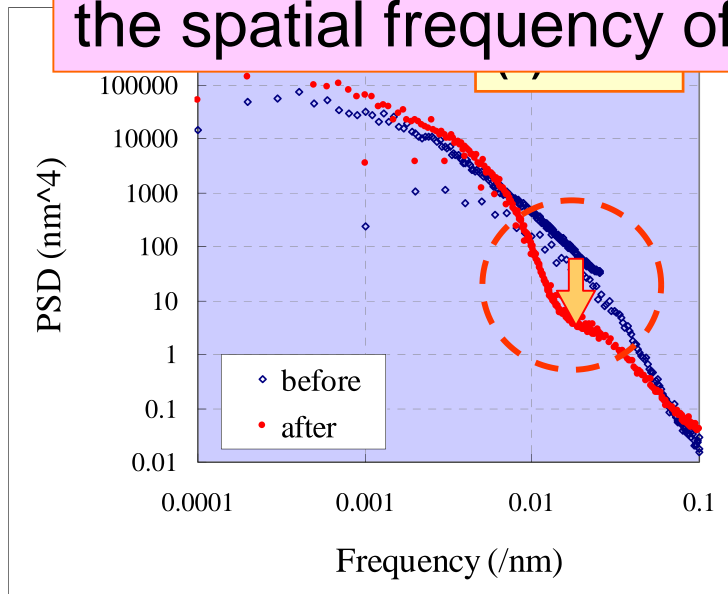


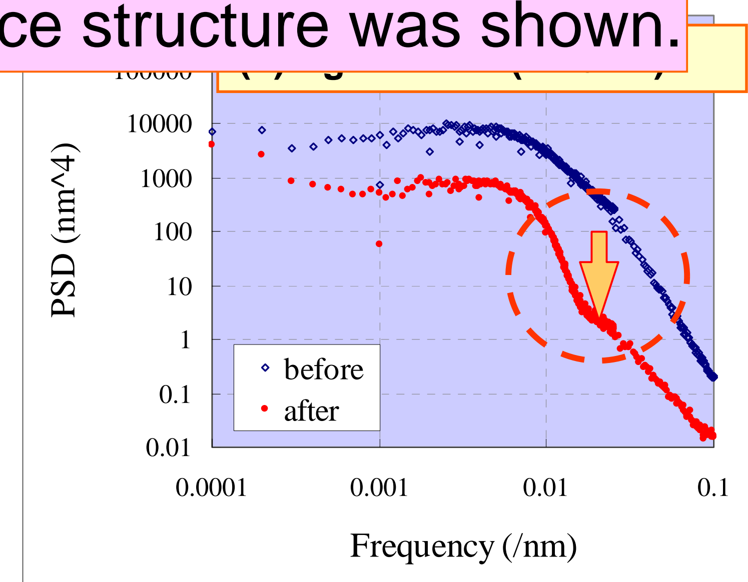
PSDs of Mo/Si multilayer surfaces





A significant dependence of the smoothing effect on the spatial frequency of surface structure was shown.





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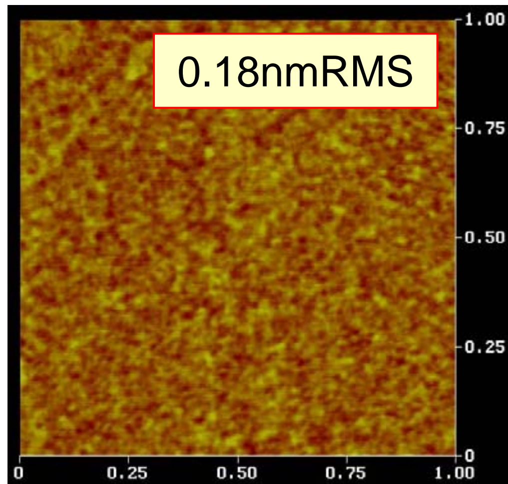
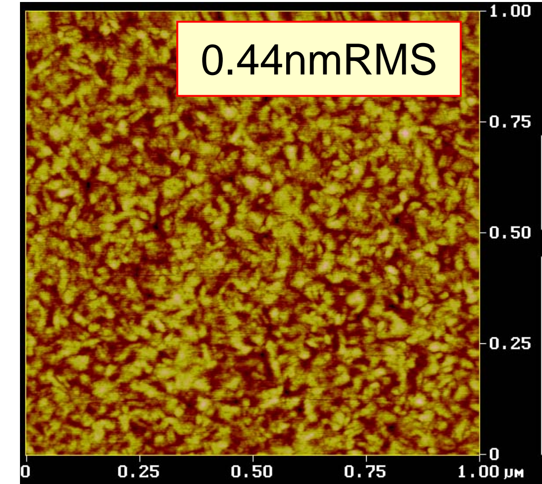
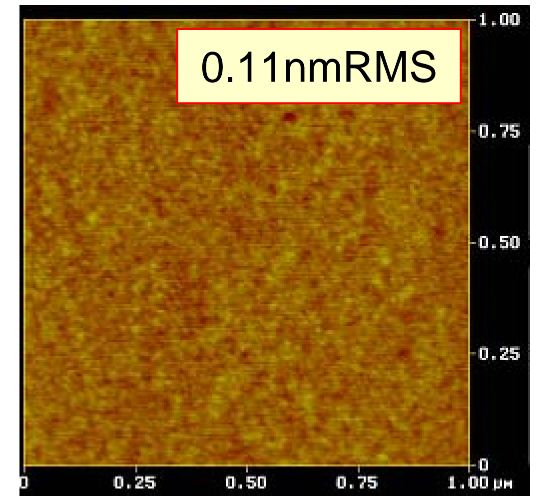
AFM images of Mo or Si thin film surfaces

Si bare wafer

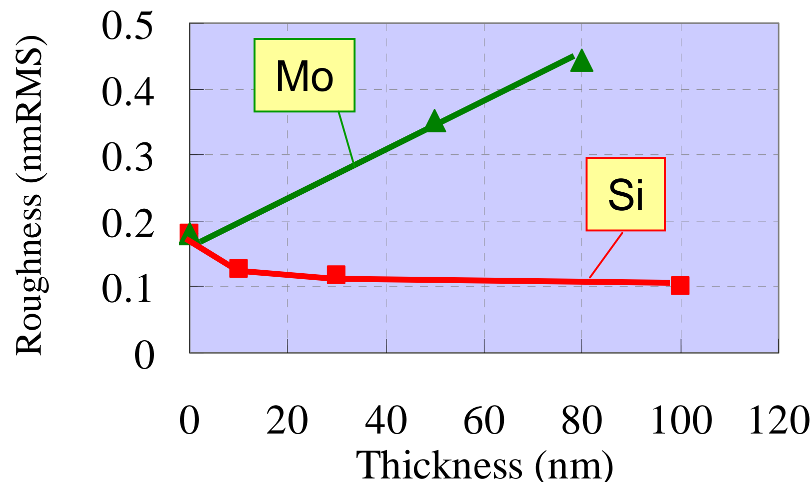


Mo thin film surface (t=50nm) on Si wafer





Si thin film surface (t=30nm) on Si wafer



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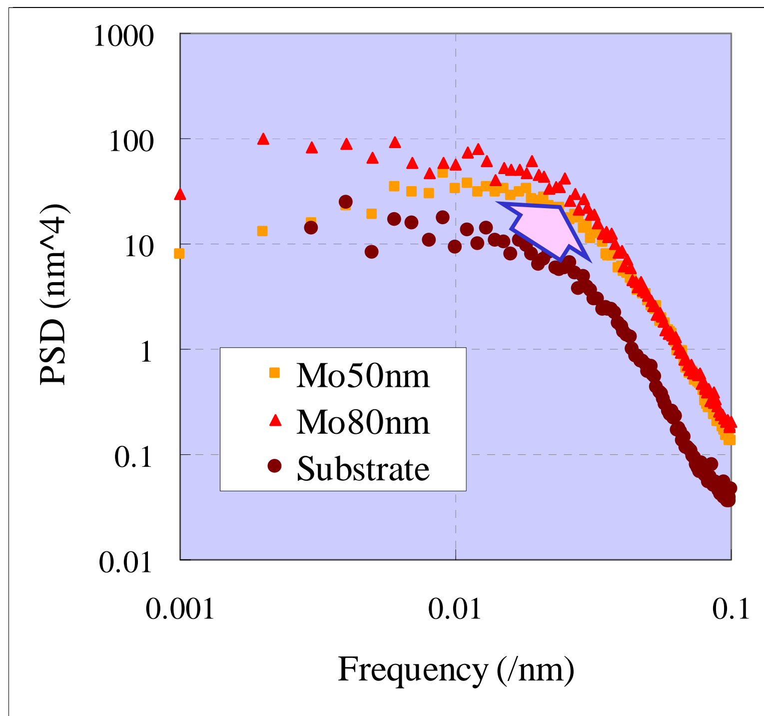
PSDs of Mo, Si thin film surfaces

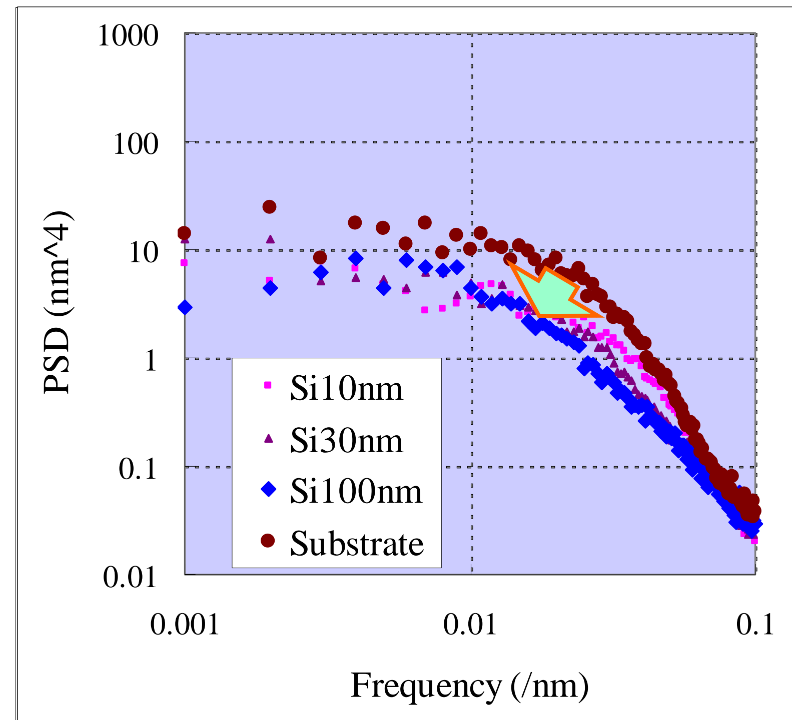
Mo thin film surface

t=50, 80nm



Si thin film surface

t=10, 30, 100nm



Mo thin film increased the roughness of surfaces in wide range of
frequency

The smoothing effects were shown in Si thin film as well as

The smoothing effect of Mo/Si multilayer is due to Si layers in the multilayer structure.

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  - **EUV angular scattering distribution of Mo/Si multilayers**
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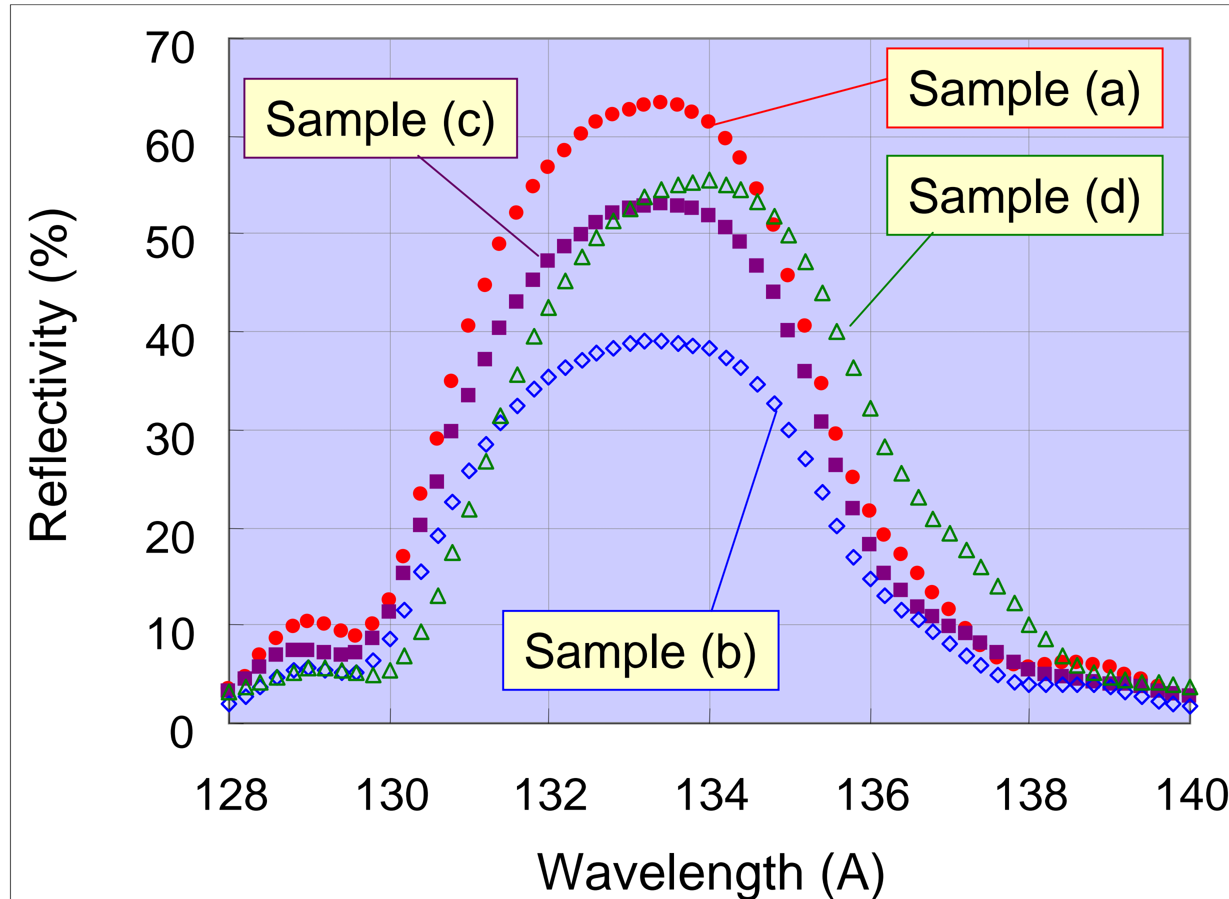
EUV reflectivity of Mo/Si multilayers

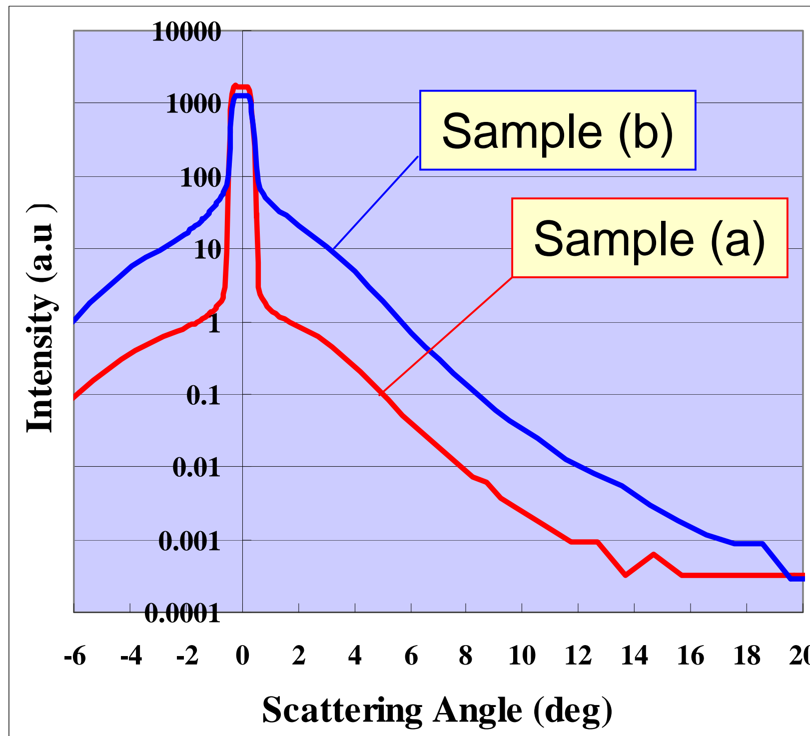


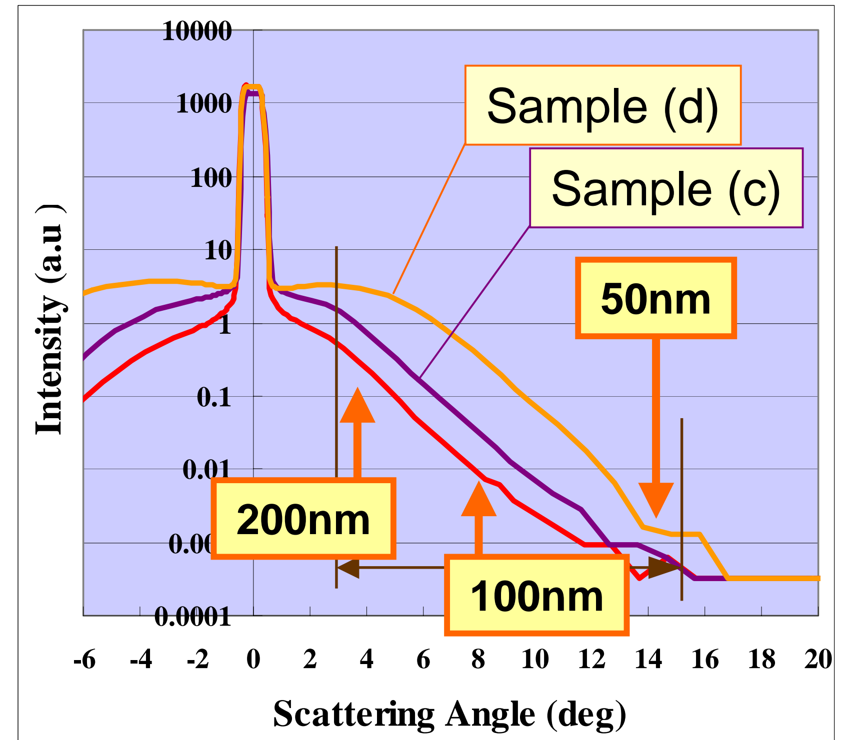
Measured at Photon Factory BL-12A (KEK)
Angle of incidence : 15 deg

EUV angular scattering distribution

The scattering intensity of sample (b) was significantly higher than that of sample (a) at all angles.

The scattering intensities of samples (c) and (d) were higher than that of sample (a) at 3 to 15 degrees.





Measured at Photon Factory BL-12A (KEK)
Wavelength : 13 nm
Angle of incidence : 20 deg

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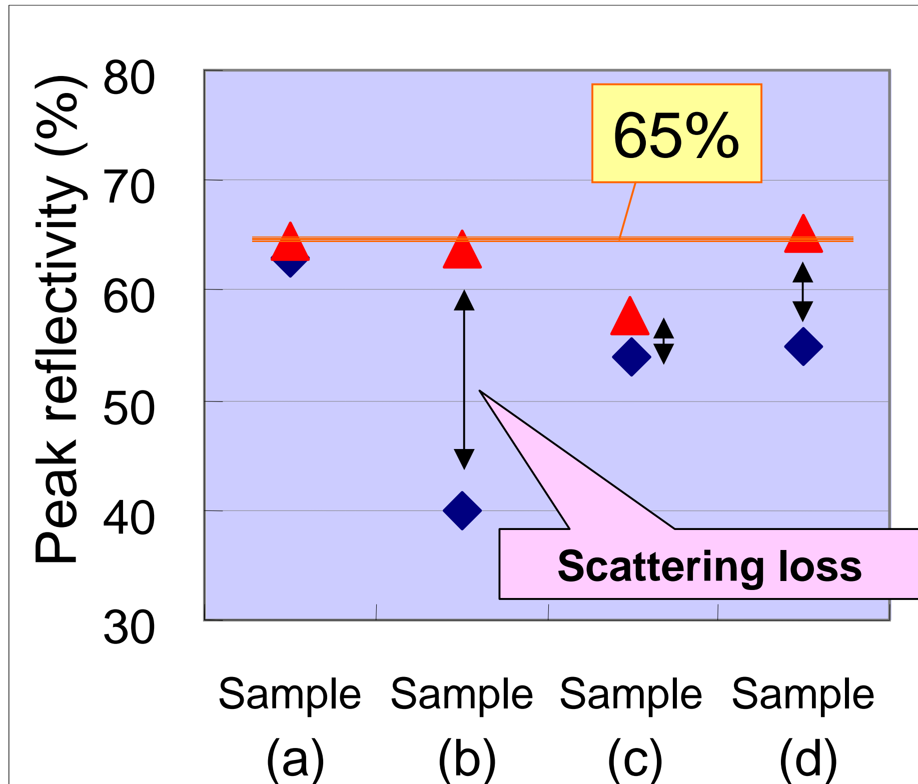
The loss of EUV reflectivity due to scattering



By adding the *scattering loss** to the peak reflectivity, the total intensity became the same for all samples except sample (c).

***Scattering loss*:**
The total value of scattering intensity integrated throughout the whole range of solid angles

Measured at Photon Factory BL-12A (KEK)
Wavelength : 13 nm
Angle of incidence : 20 deg

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Summary

- Smoothing effect of depositing Mo/Si multilayer by ion beam sputtering significantly depends on the spatial frequency of the surface structure. The roughness was reduced considerably in the region of spatial frequency of less than 100 nm.

- The smoothing effect of the Mo/Si multilayer is mainly caused by Si layers in the multilayer structure.

- EUV angler scattering distribution and the surface profile of substrate (PSDs) agreed well.

- By calculating the total scattered EUV intensity, the scattering loss of the reflectivity was estimated for samples (a), (b) and (d). (Sample (c) showed a much lower reflectivity than that estimated from the scattering loss.)