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Measurement of EUV scattering from Mo/Si multilayer mirrors

N. Kandaka, T. Kobayashi, T. Komiya,
M. Shiraishi, T. Oshino and K. Murakami

Nikon Corp.

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Outline

- Introduction
- Sample substrates before and after depositing Mo/Si multilayer
- Reflectivity and angular scattering distribution
- Summary

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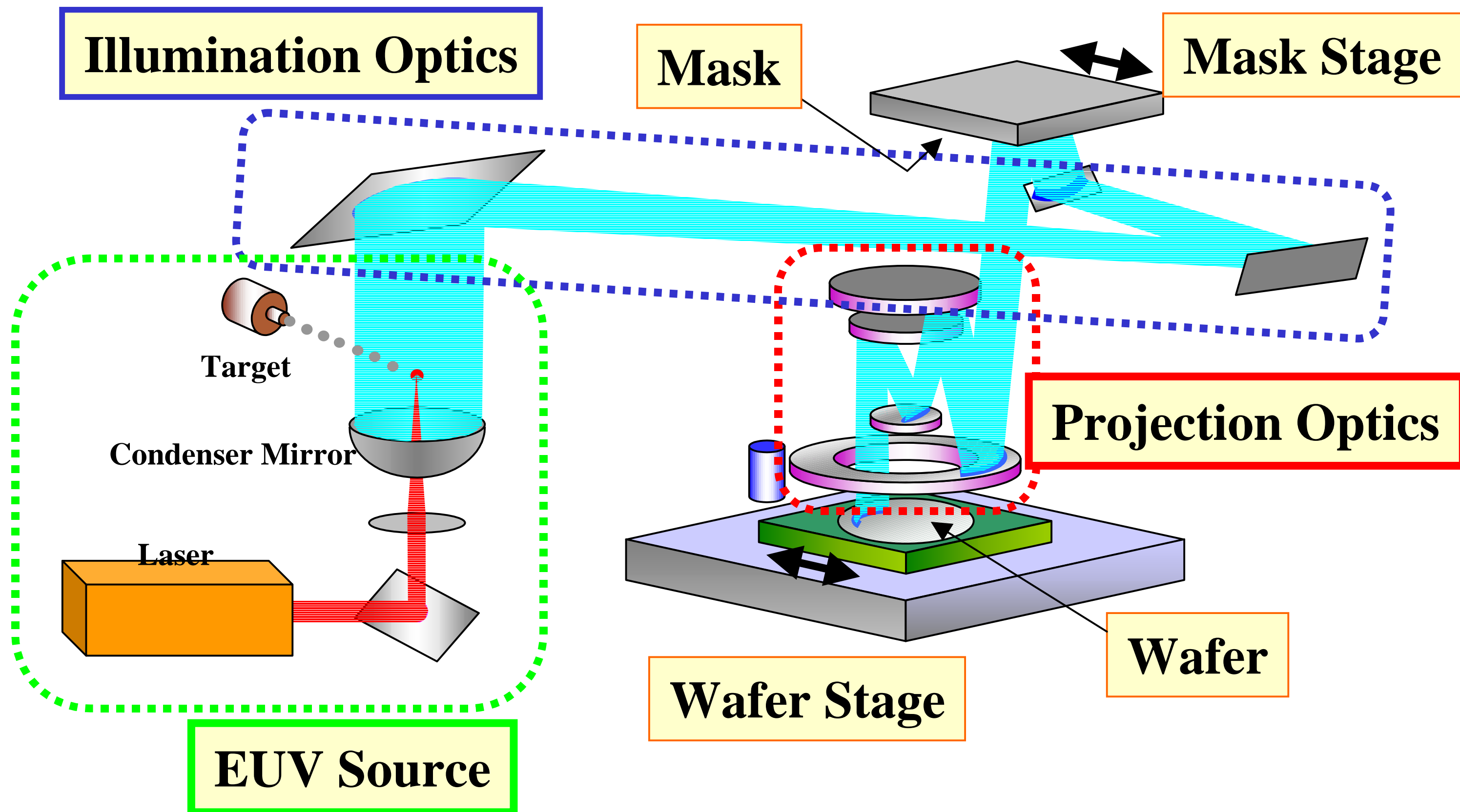
Introduction(1)

Numerous EUV multilayer mirrors will be employed in EUV lithography system.



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Introduction(2)

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 surface roughness 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.

Sample substrates & multilayer deposition

- We prepared 3 polished fused silica substrates (sample A, B and C).

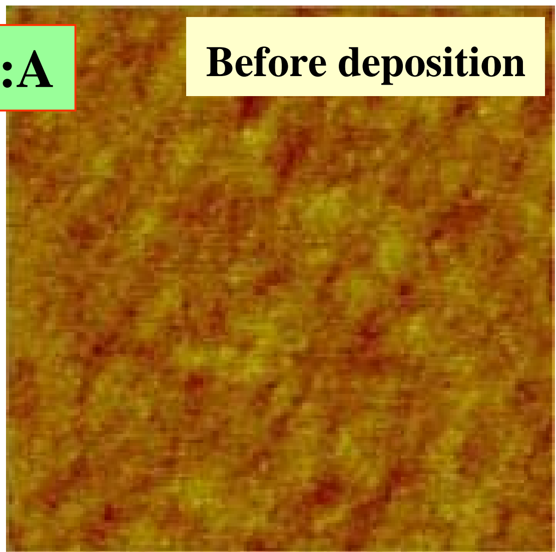
- Mo/Si multilayers were deposited on the substrates by ion beam sputtering.

Mo/Si multilayers

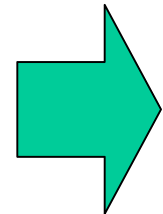
Number of pairs: 50pairs
Layer period: ~7.1 nm
(Mo: ~2.5nm, Si: ~4.6nm)

AFM images (1x1μm) of sample substrates

Sample:A

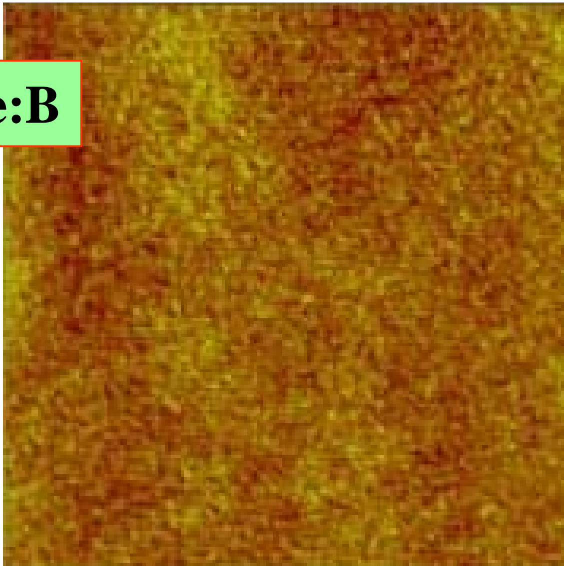


0.136nmRMS

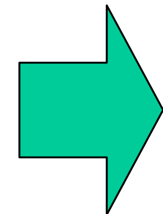


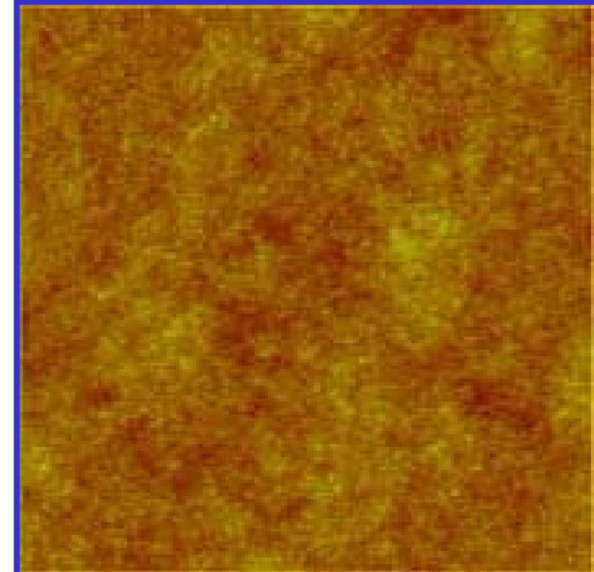
→ 0.112nmRMS

Sample:B



0.155nmRMS





→ 0.117nmRMS

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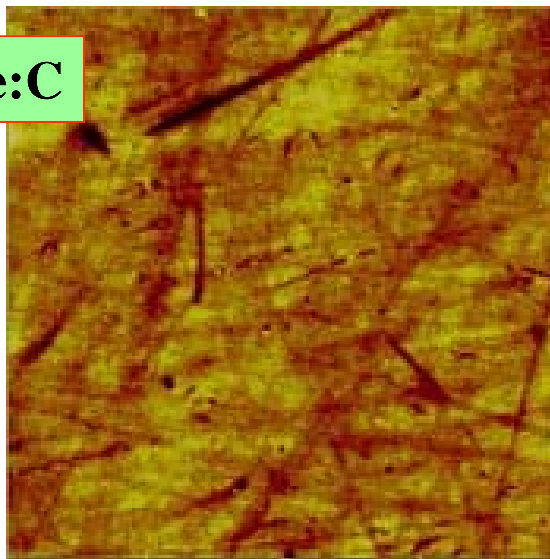
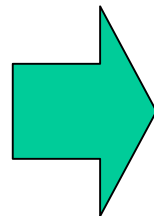
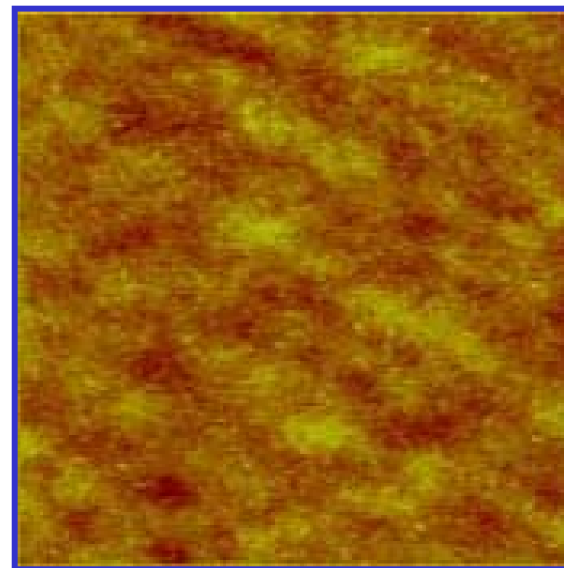
AFM images (1x1μm) of sample substrates

Sample:C



0.285nmRMS

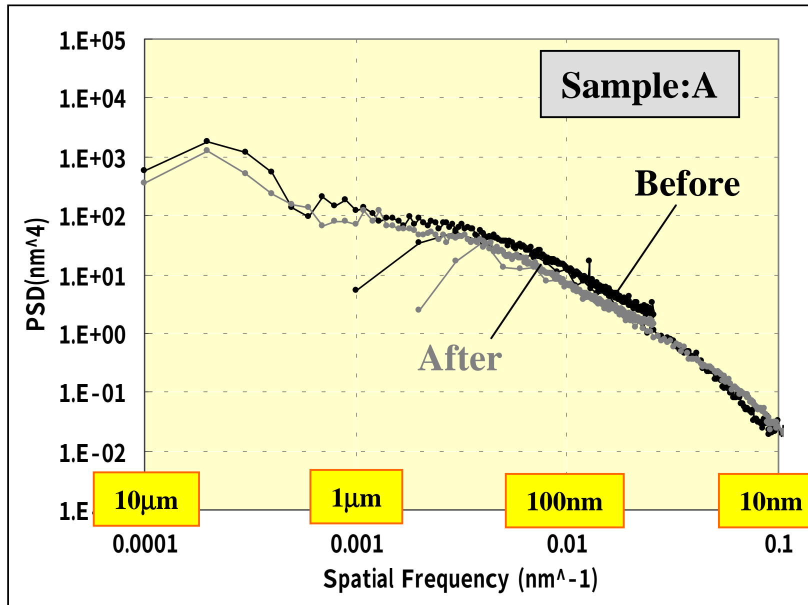


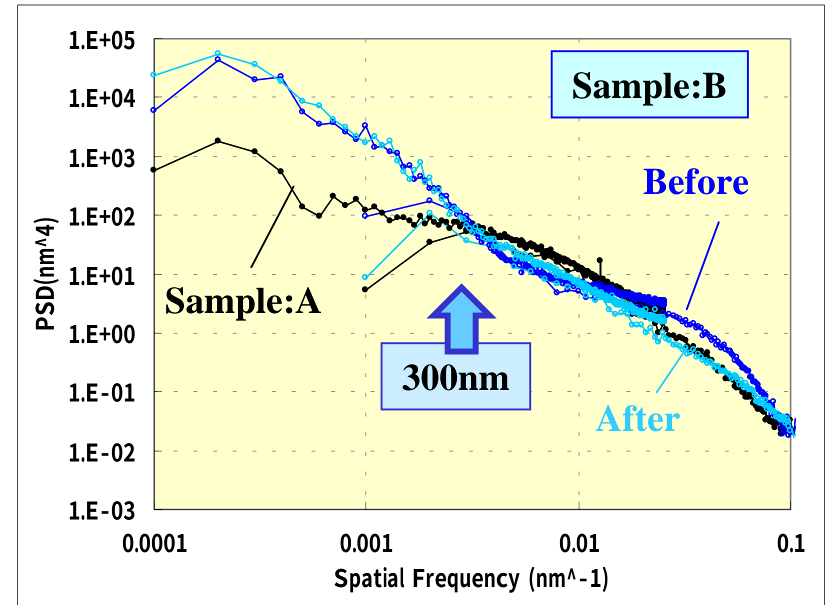


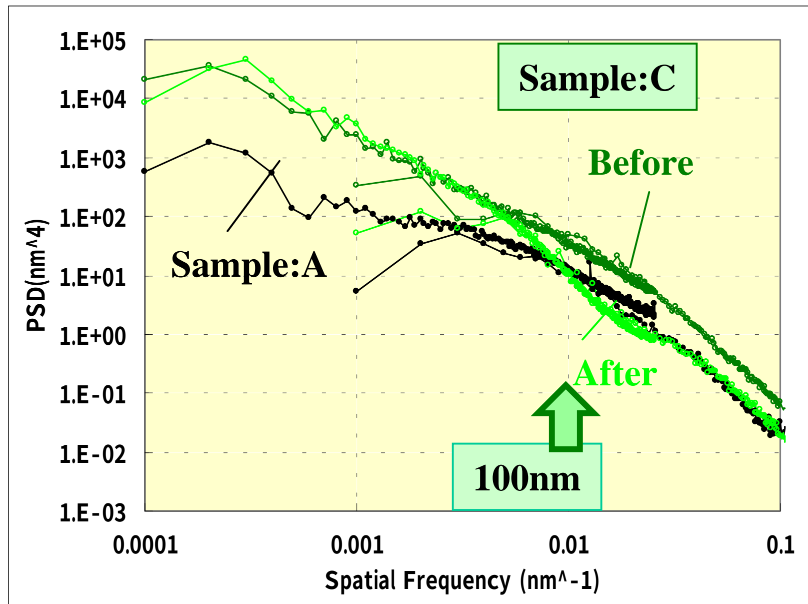
→ 0.161nmRMS

Sample		Before depo. (rms)	After depo. (rms)
A	1μm□	0.138 →	0.112
	10μm□	0.136	0.108
B	1μm□	0.155 →	0.117
	10μm□	0.219	0.239
C	1μm□	0.285 →	0.161
	10μm□	0.297	0.273

PSDs of sample surfaces

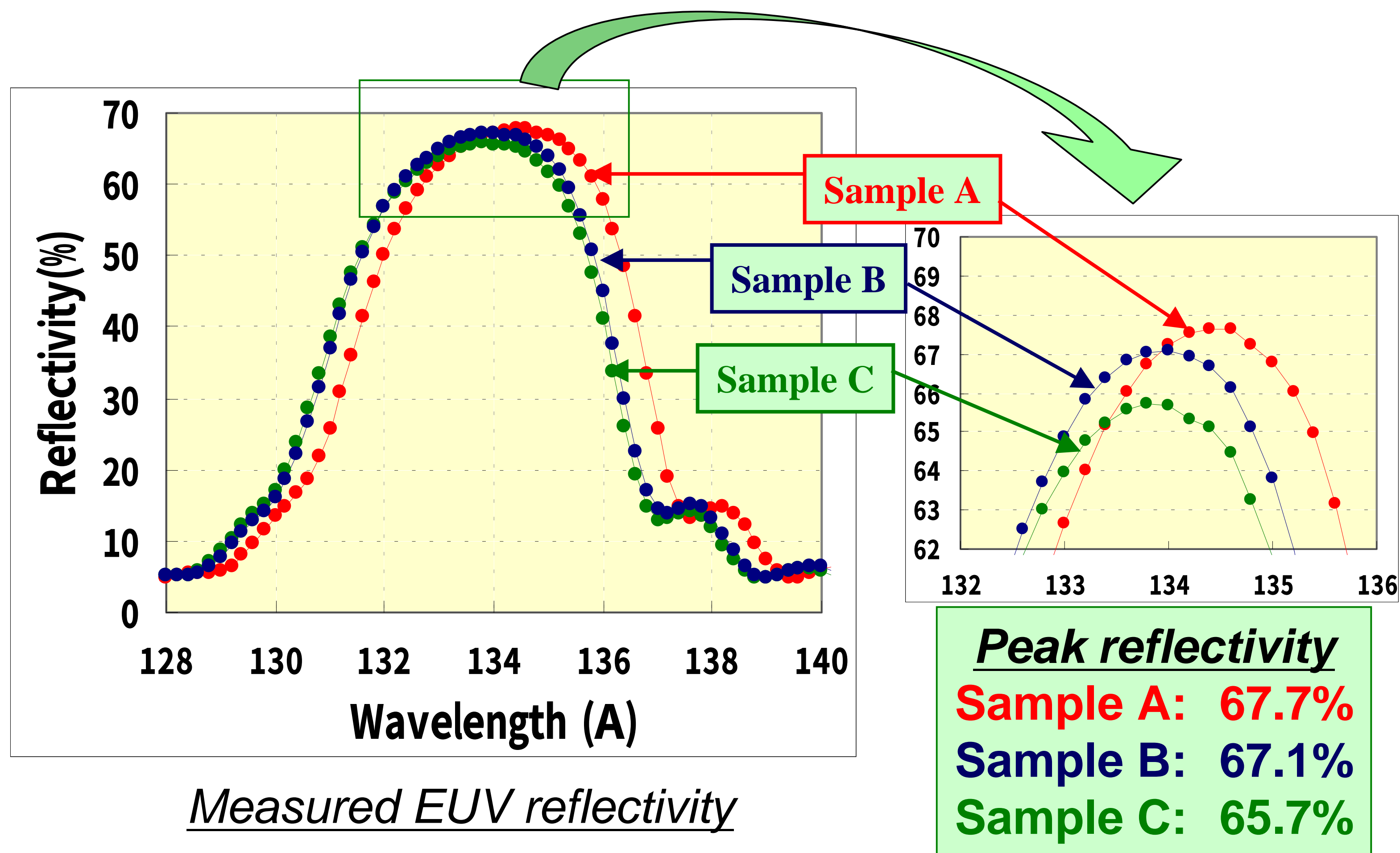






- Substrate roughness in the region of structure size of less than 100 nm were reduced by Mo/Si multilayer deposition by ion beam sputtering.
- Sample B and C have high roughness in the region of structure size of more than 300 nm and 100nm respectively.

EUV reflectivity of Mo/Si multilayers



Measured EUV reflectivity

Peak reflectivity

Sample A: 67.7%

Sample B: 67.1%

Sample C: 65.7%

Measured at Photon Factory BL-12A (KEK)
Angle of incidence : 14 deg

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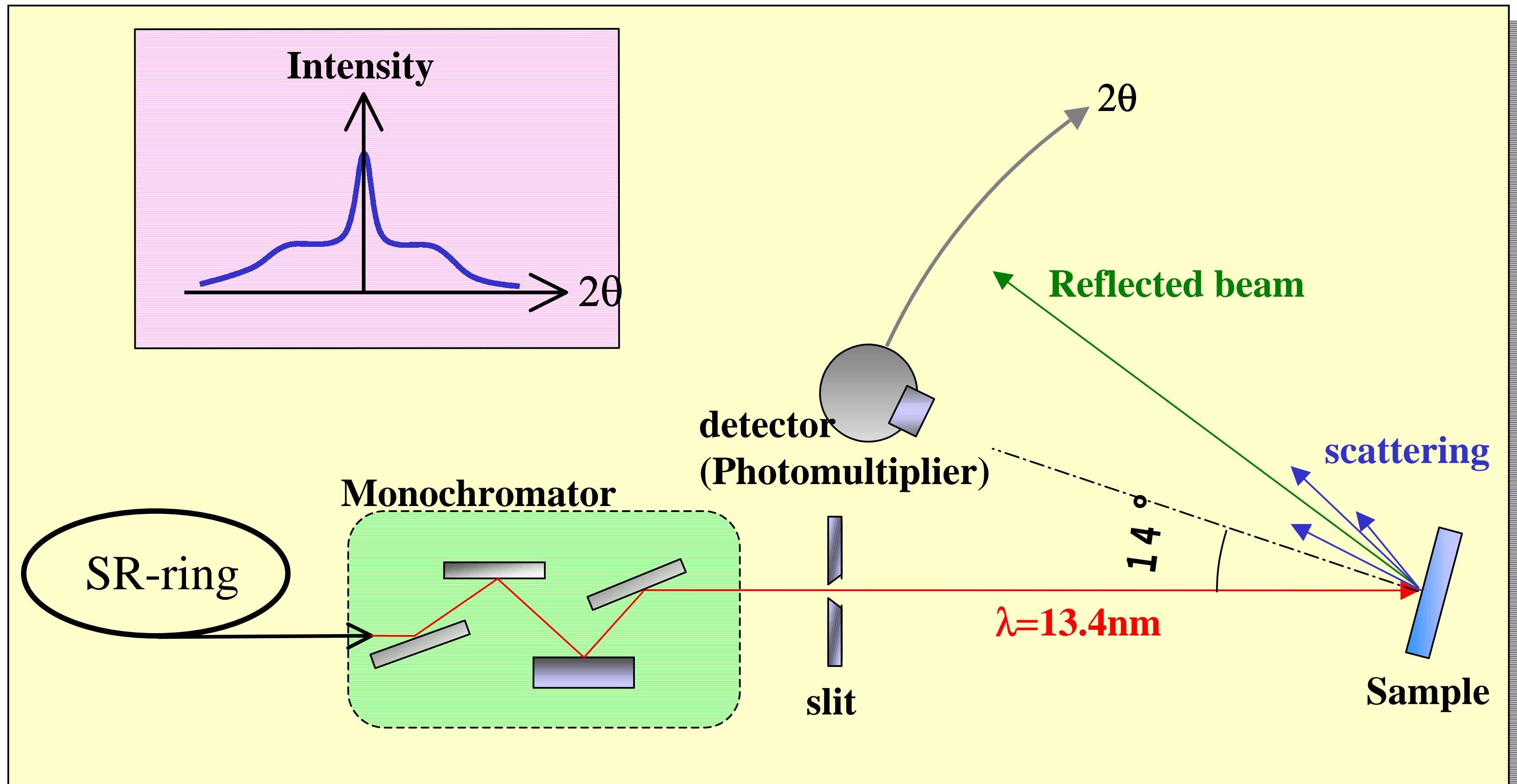
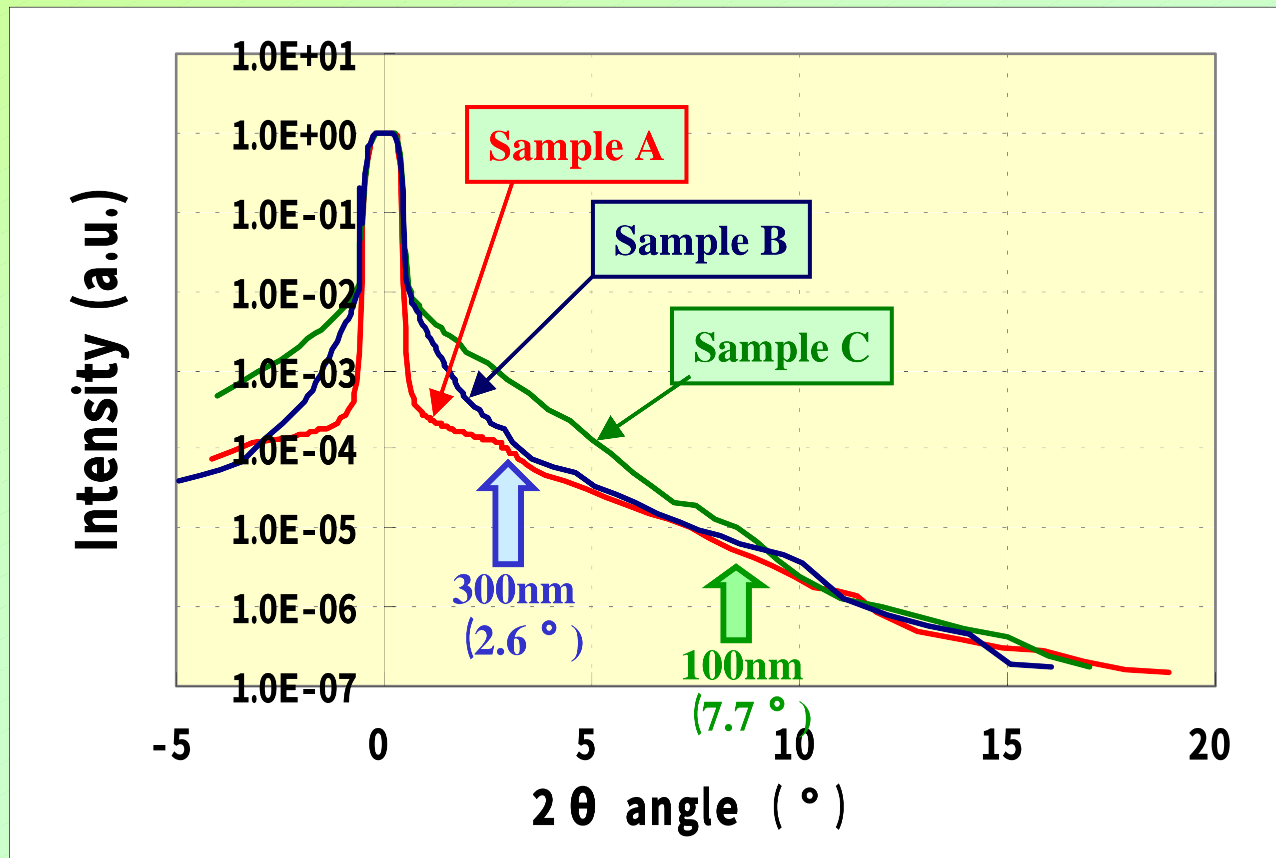
Measurement of EUV angular scattering distribution



Measured at Photon Factory BL-12A (KEK)
Wavelength : 13.4 nm
Angle of incidence : 14 deg

EUV angular scattering distribution

- The scattering intensities of samples B and C were higher than that of sample A at less than 3 degrees and 8 degrees respectively.
- 3 degrees and 8 degrees correspond to 100nm and 300nm in the structure size of surface roughness.



Scattering from a single surface

λ: wavelength
R: the normal incidence reflectivity

- Equation (1) is the Born approximation for scattering from a single surface*.

- In the case of small roughness, near normal incidence and small scattering angle, scattering from a multilayer is approximated by equation (1)*.

** E. Gullikson Proc. SPIE 3331 pp72-80*

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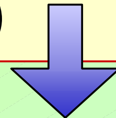
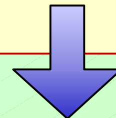
Scattering from multilayer

- Optical path difference of reflected beams are same as wavelength (=13.4 nm)

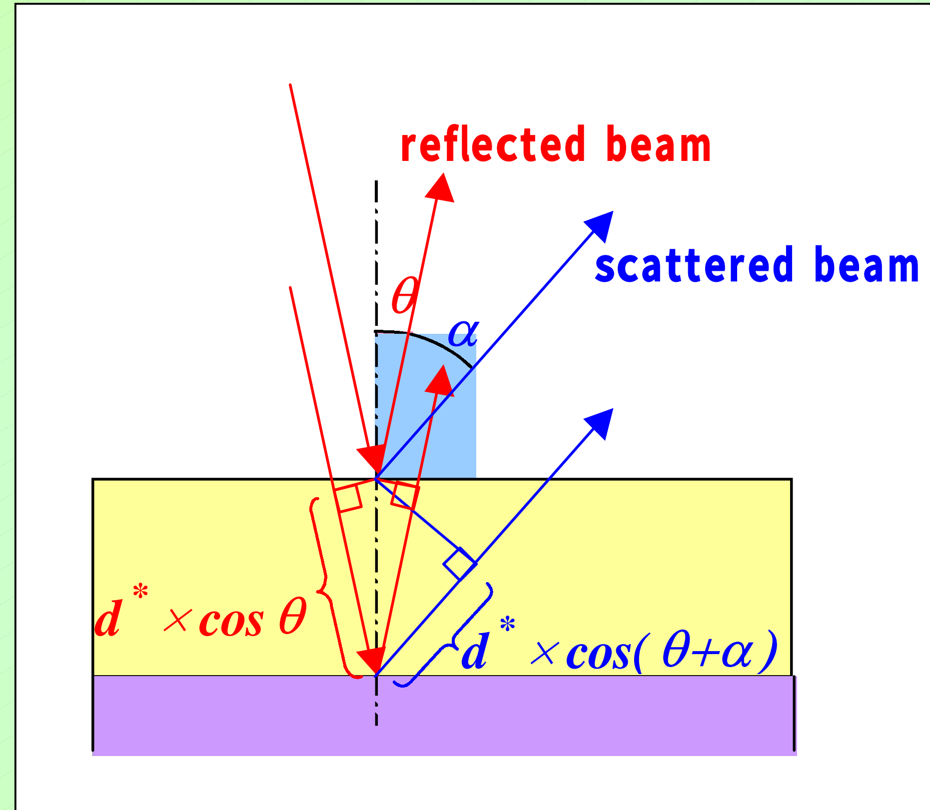


High reflectivity

- Optical path difference of scattered beams are different from wavelength (=13.4 nm)



Scattered intensity will be lower than that calculated by using equation (1)



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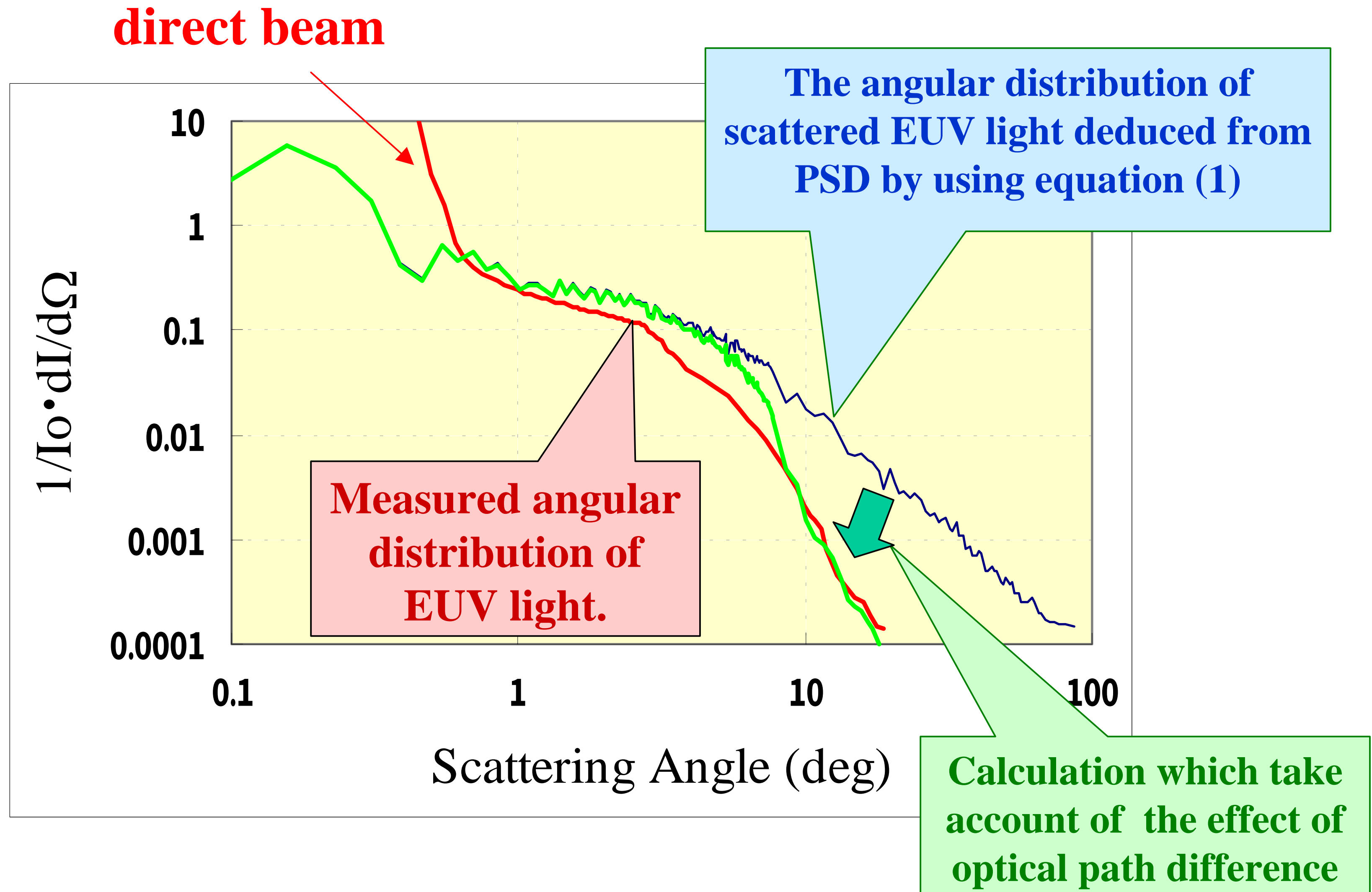
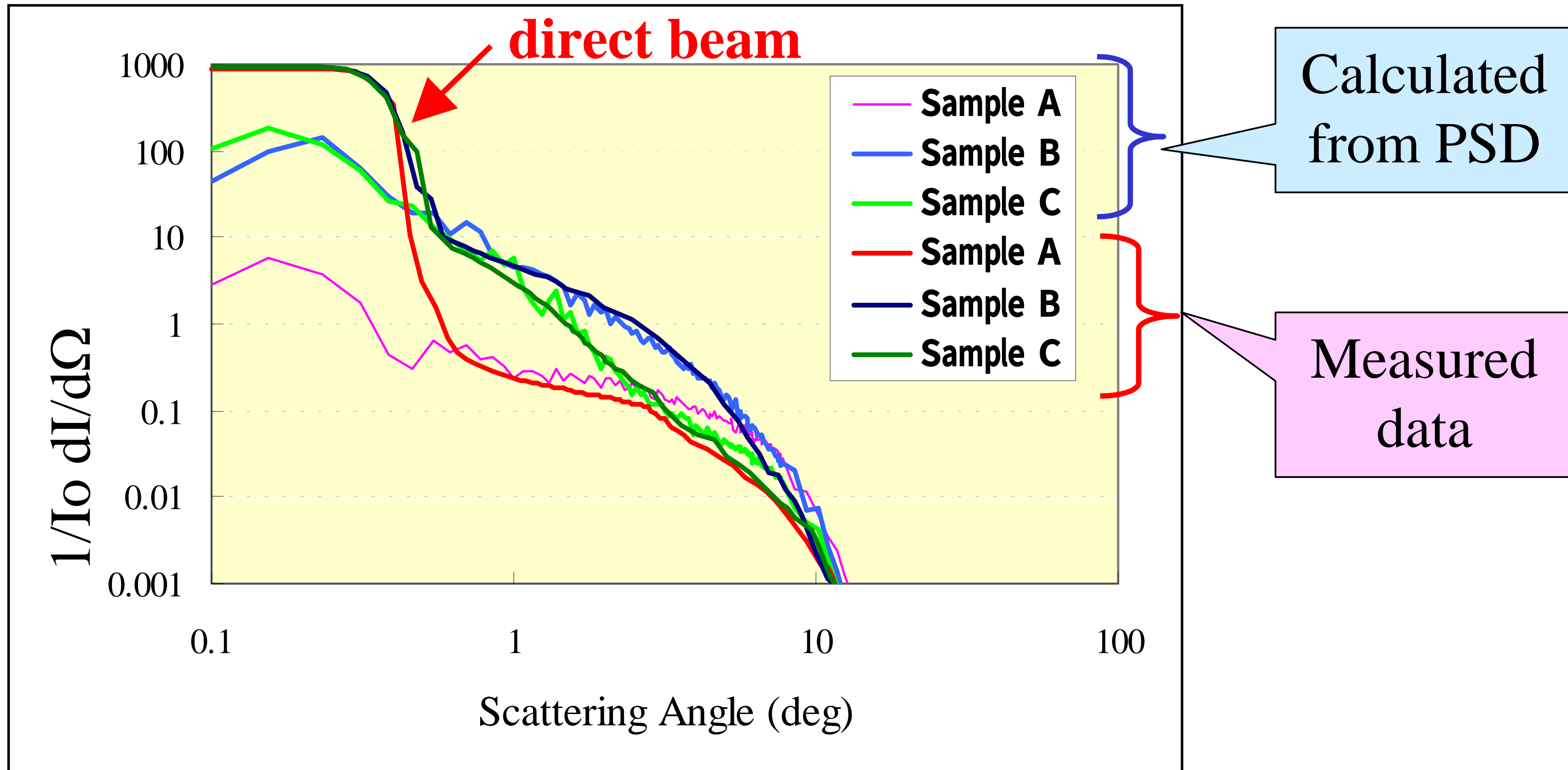
Calculation of angular scattering distribution



Calculation of angular scattering distribution



The measured EUV angler scattering distribution and the calculated EUV angler scattering distribution agreed well.

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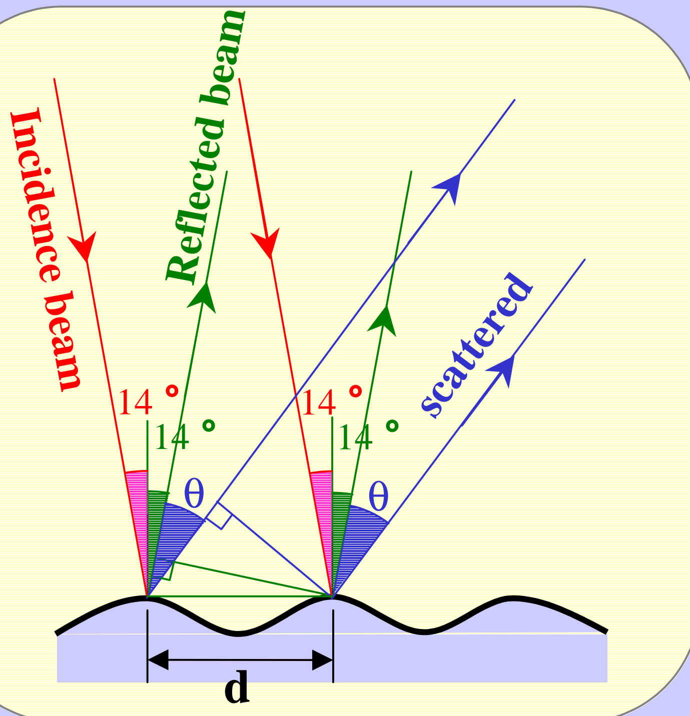
Scattering on rough surface

Scattering angle is depend on the spatial frequency of roughness

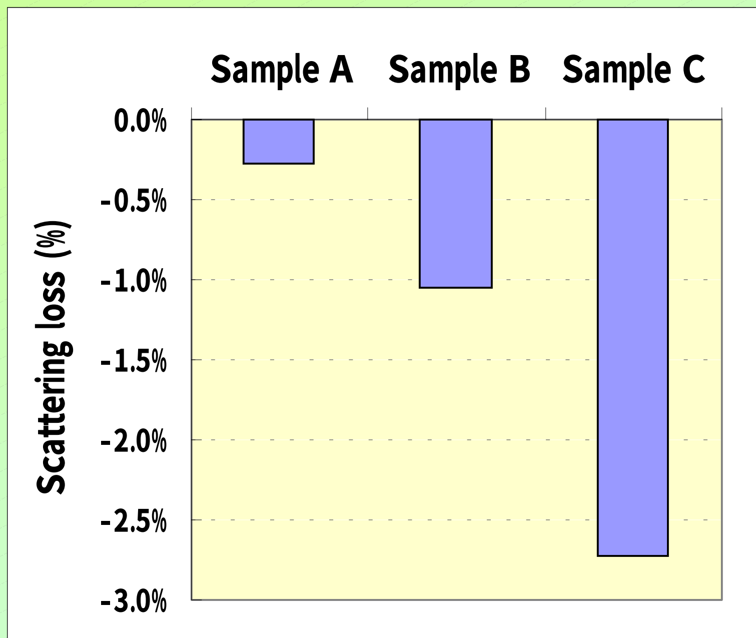


$$L = d \cdot \sin(14° + \theta) - d \cdot \cos(14°)$$
$$= d \cdot (0.242(\cos\theta - 1) + 0.970 \sin\theta)$$
$$\sim 0.970 \cdot d \cdot \sin\theta \quad \text{(approx.)}$$
$$= \lambda \; (= 13.4\,\text{nm})$$

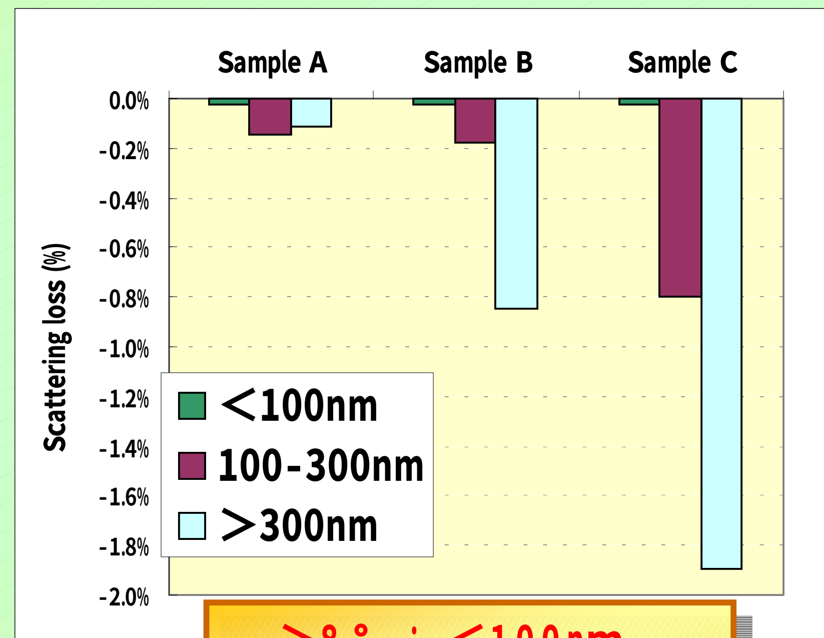
Scattering loss of reflectivity

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

Total scattering loss



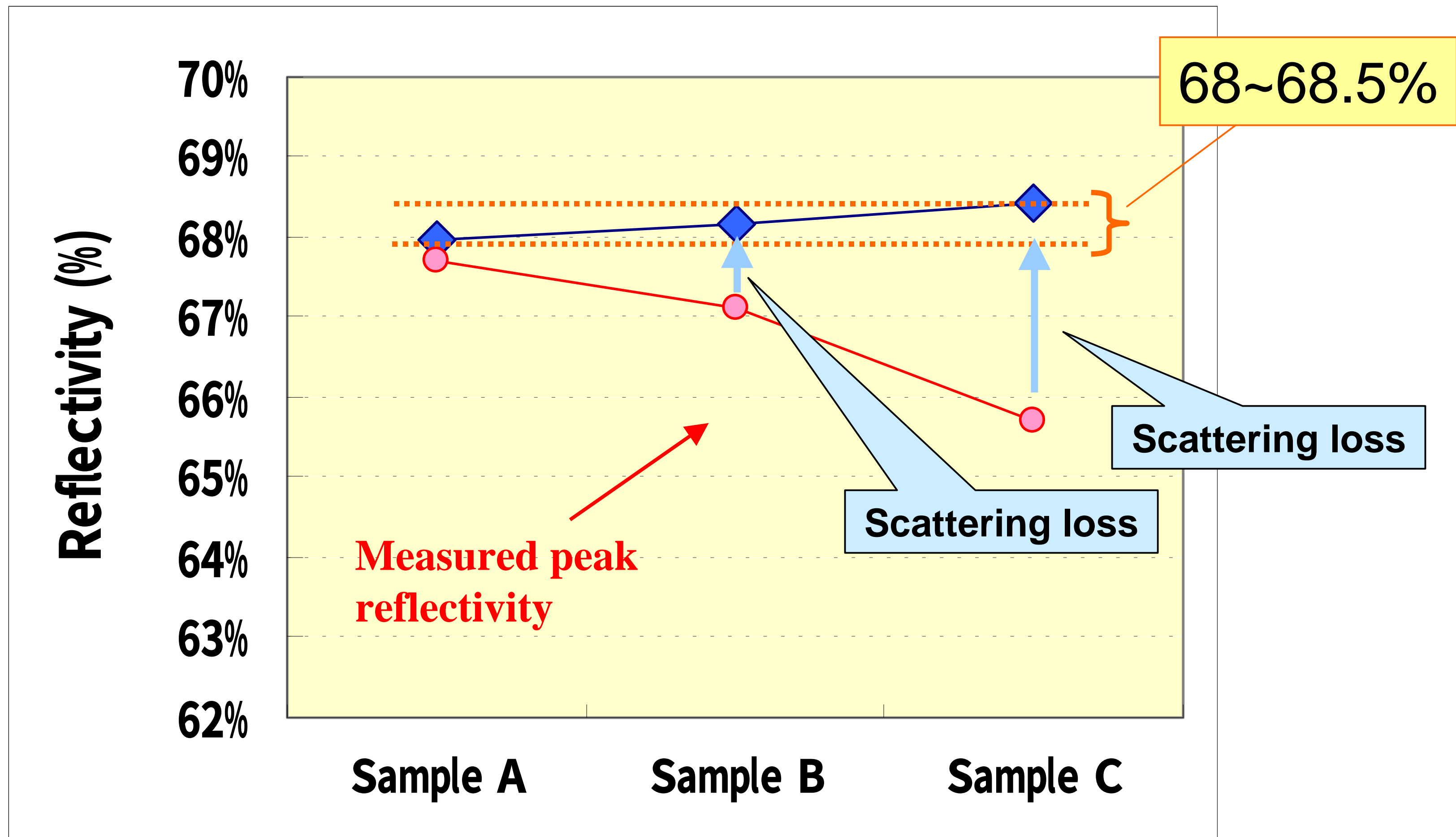
Dependence of the scattering loss on the region of spatial frequency of roughness



＞8° ：＜100nm
2.6～8°：100～300nm
＜2.6°：＞300nm

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.



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Summary

- 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 each sample.