EUV scattering metrology: Benchmarking of discharge plasma source based table-top scatterometry versus PTB synchrotron based EUV radiometry

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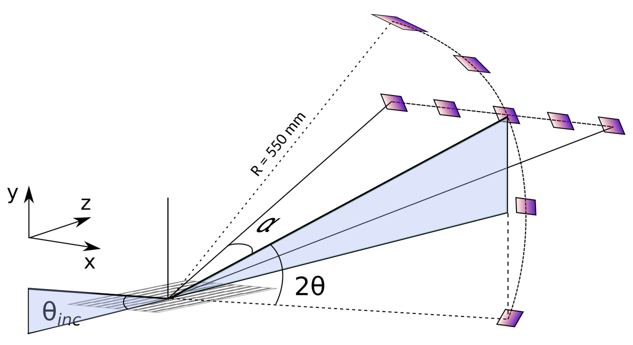
Motivation

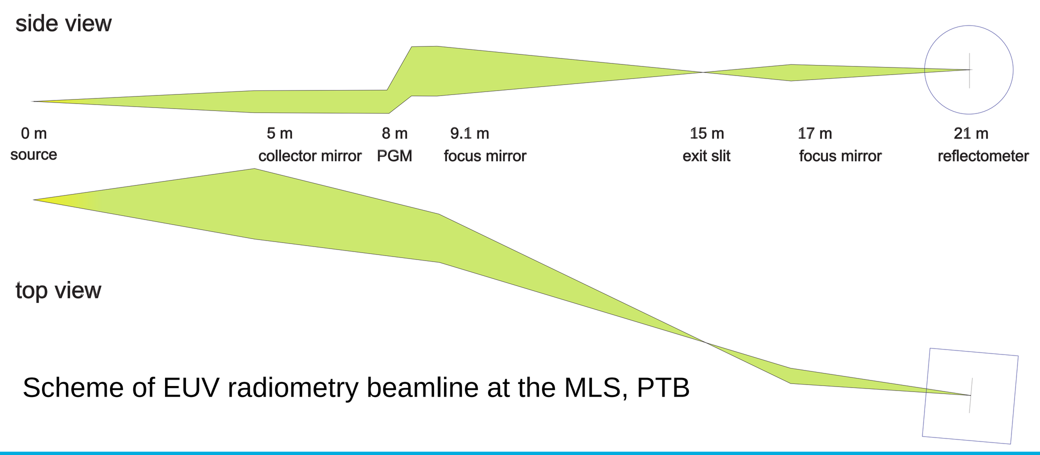
Optical scatterometry is a powerful technique for surface roughness metrology and profile characterization of nano-structured layered surfaces. Besides being a fast, non-contact and non-destructive method, it provides spectrally resolved data on the roughness power spectral density (PSD). Roughness became a very sensitive parameter to be considered, as the wavelength decreases. Accessing scatterometry measurements with laboratory sources could be an advantage for industrial characterization of sub-nanometer rough surfaces.

Scatterometry at PTB Radiometry beamline (MLS)

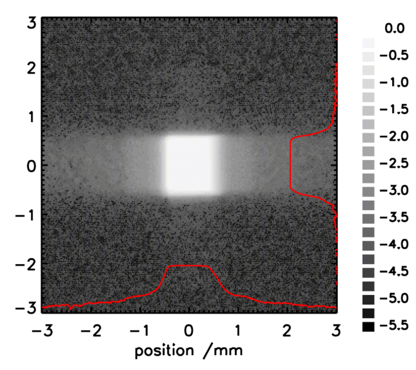
The EUV-Radiometry beamline at the Metrology Light Source (MLS) [1] provides a stable and well defined beam for the EUV-reflectometer. The scattered light is recorded by scanning the angular range with a diode of 4.5 mm x 4.5 mm size at a sample-detector distance of 550 mm. The effective angular resolution is 0.48° and the corresponding solid angle is 1.67 μsr. The diode signal was measured with a Keithley Model-617 programmable electrometer. The dark current was as low as 0.2E-12 A.

The standard spot size for this measurement was 1 mm x 1 mm.





Scheme of EUV radiometry beamline at the MLS, PTB



EUV spot size @ Synchrotron Radiation (SR)

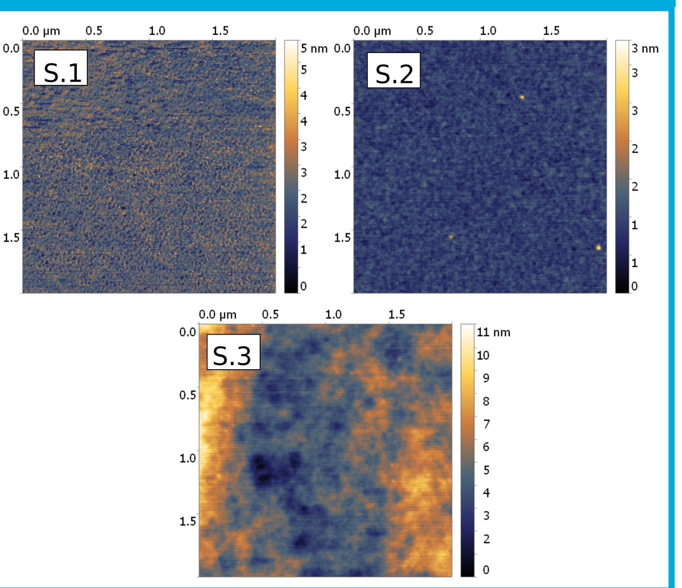
Test samples

Three samples (S.1 - S.3) in total were under investigation. Samples are Si-wafers coated with different periodic multilayer (ML) structure by magnetron sputtering.

RMS roughness (R_q) was measured with AFM at least in 5 different areas of 2 μm x 2 μm size and averaged.

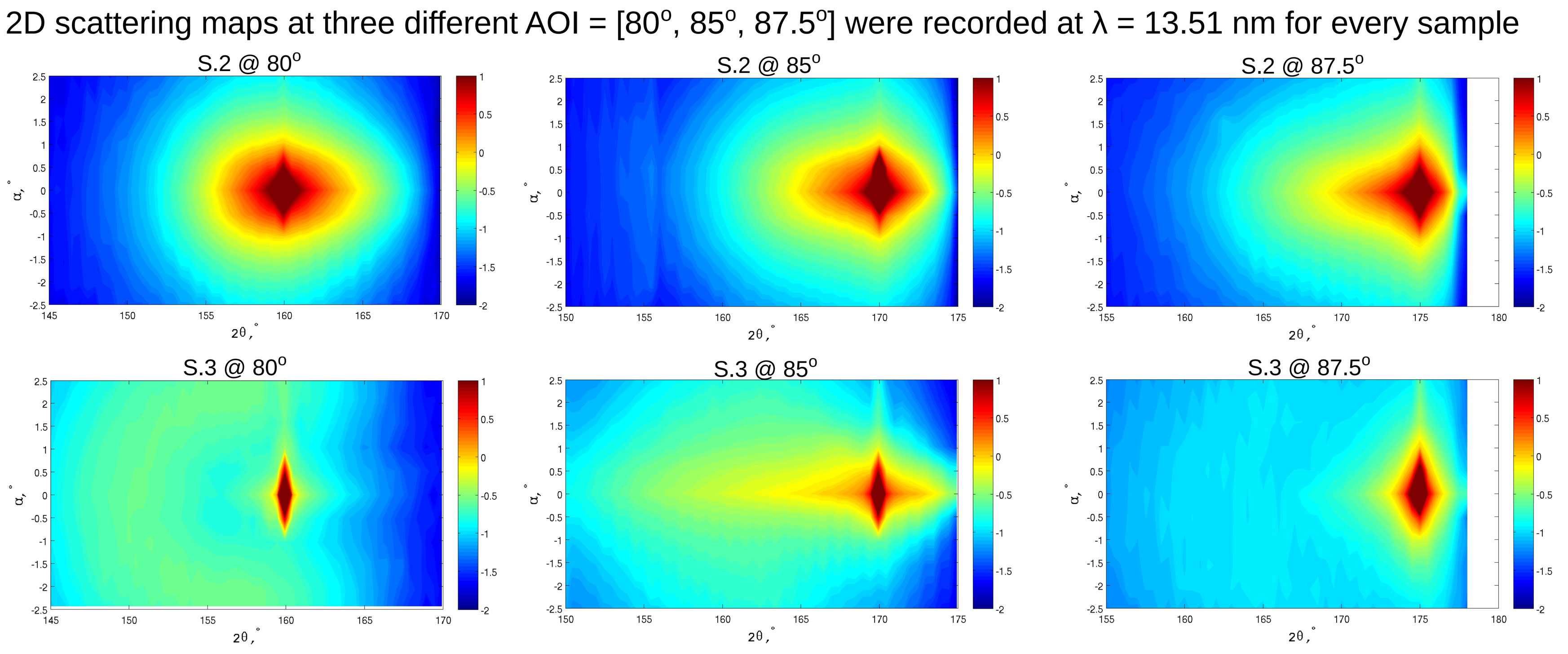
Table 1. List of samples used for scattering measurements

Sample Nr.	Surface type	Layers	Rq, nm
01	$ML: B_4C/CeO_2$	40	0.45
02	$ML: B_4C/CeO_2$	10	0.38
03	$ML: Mo/Si$	60	1.34

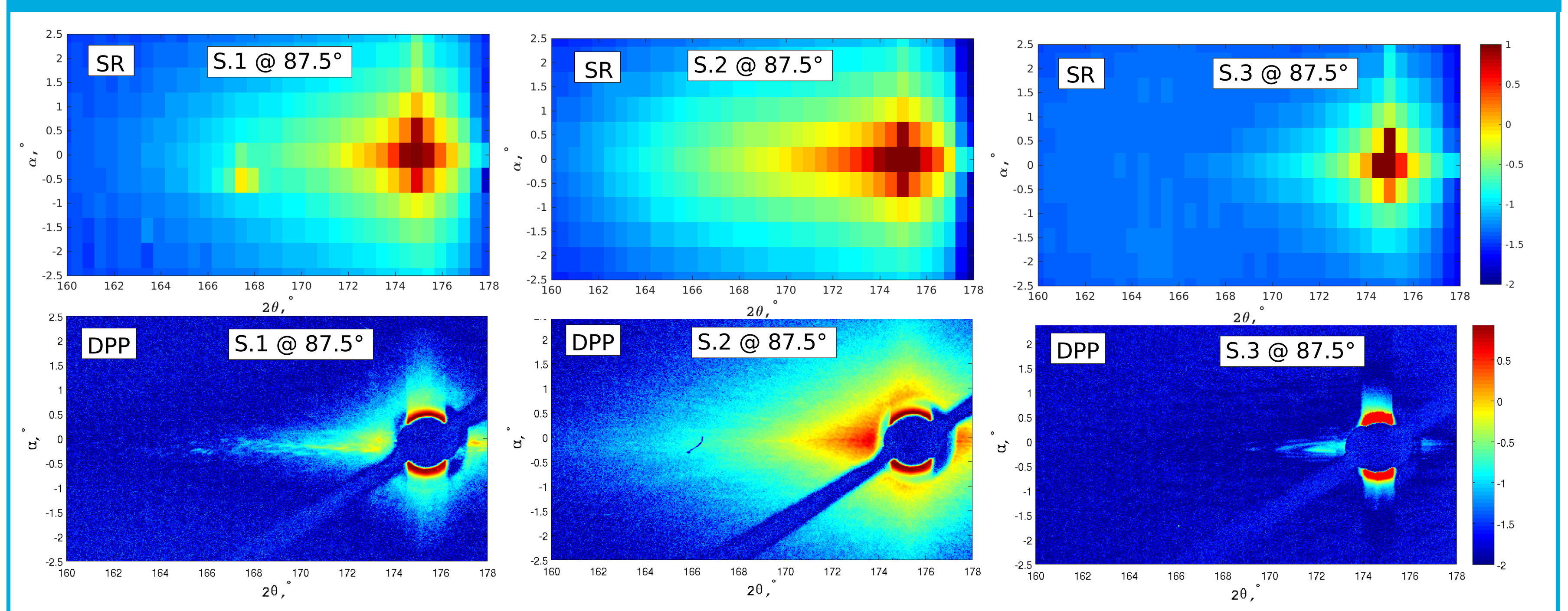


Scattering patterns: AOI-scan @ SR

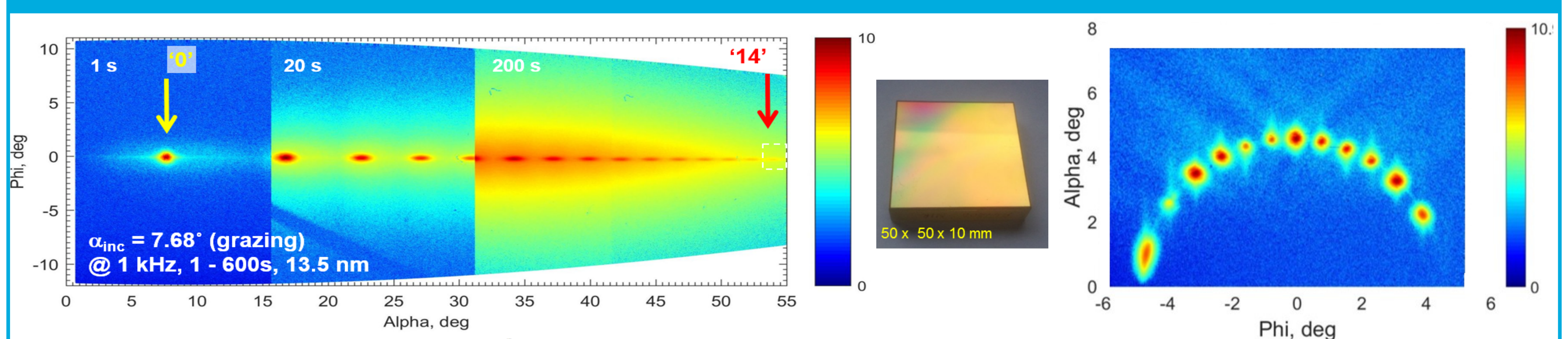
2D scattering maps at three different AOI = [80°, 85°, 87.5°] were recorded at λ = 13.51 nm for every sample

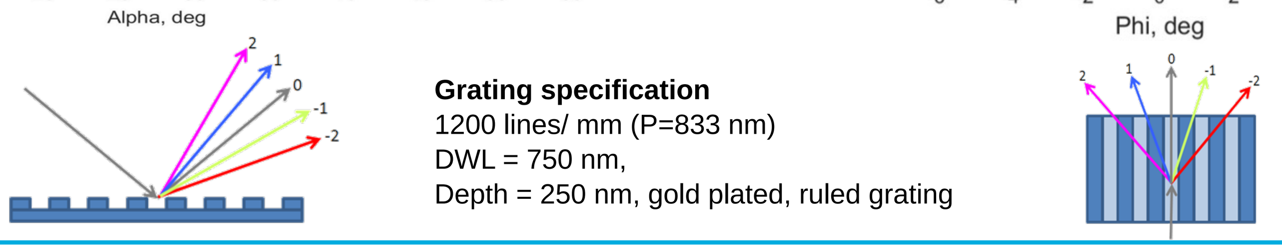


Scattering patterns: DPP vs SR



Diffraction on ruled grating



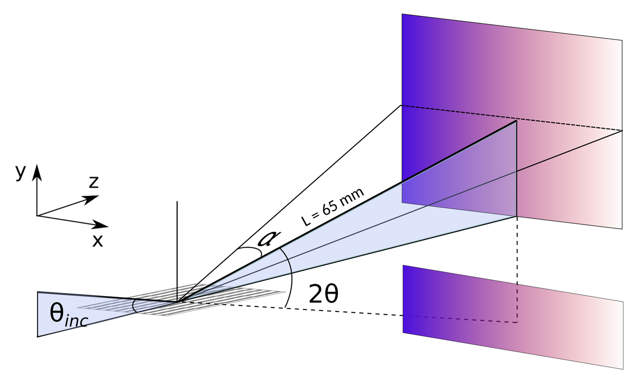


Grating specification
1200 lines/ mm (P=833 nm)
DWL = 750 nm,
Depth = 250 nm, gold plated, ruled grating

Scatterometry with table-top setup and DPP source

The table-top scatterometer setup [2] is powered by a Fraunhofer-ILT discharge-produced plasma (DPP) source FS-5420 [3]. It creates a pinch with diameter 0.5 mm and length 2 mm by exciting Xe gas, pulsing at 1 - 1.5 kHz. Typical pulse duration is around 10 ns and pulse energy 3 - 6 mJ/sr at 13.5 nm in 2% bandwidth. After spectral and spatial filtering, ca. 10^{11} photons are delivered to the sample plane in a 170 μm spot (FWHM).

The scattered light in the table-top scatterometer was detected with an Andor DX434-BN camera. It uses 16-bit digitalization and a back-illuminated thinned CCD sensor of e2v CCD47-10 with 1024x1024 square pixels of 13 μm x 13 μm size. The full-well-capacity of each pixel is limited to 90160 e-. Setting A/D Rate to 62 kHz (16 μs readout) increases sensitivity to 1.4 e-/count and expands dynamic range to16-bit.



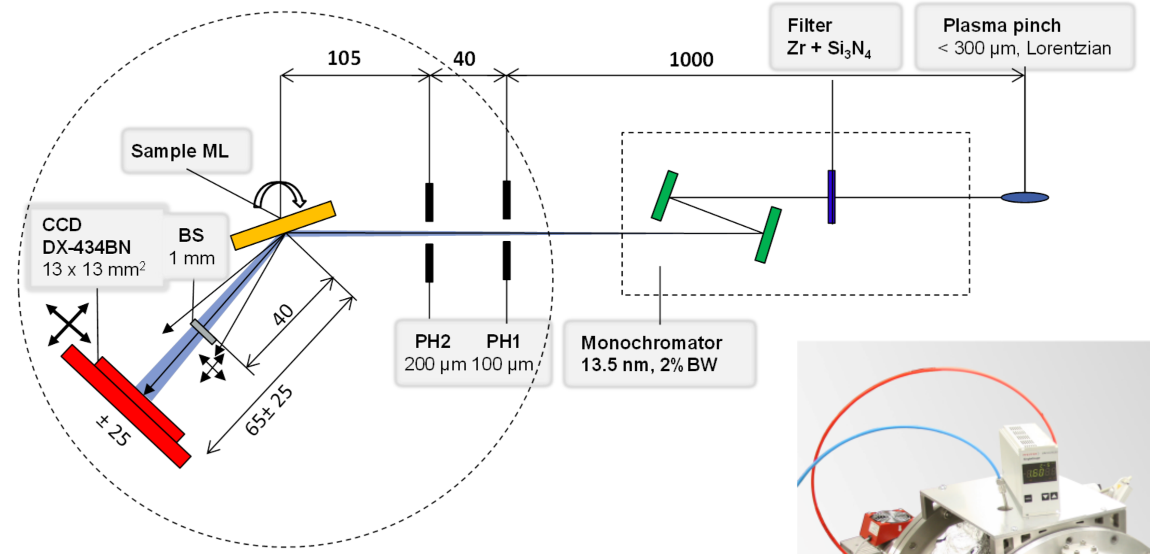
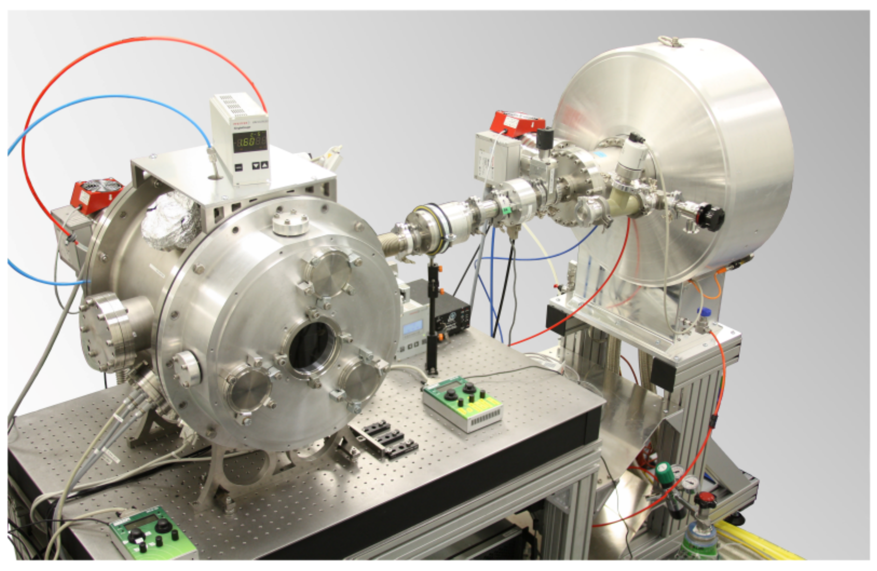
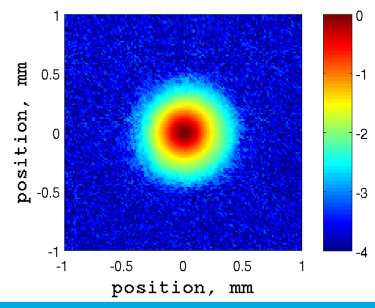


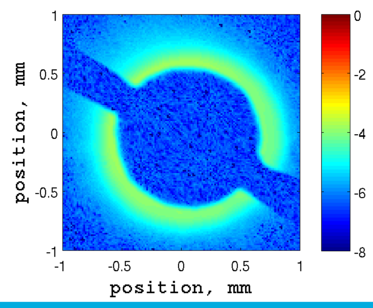
Photo of table-top scattereometer with DPP source



EUV spot size @ DPP



EUV spot halo @ DPP

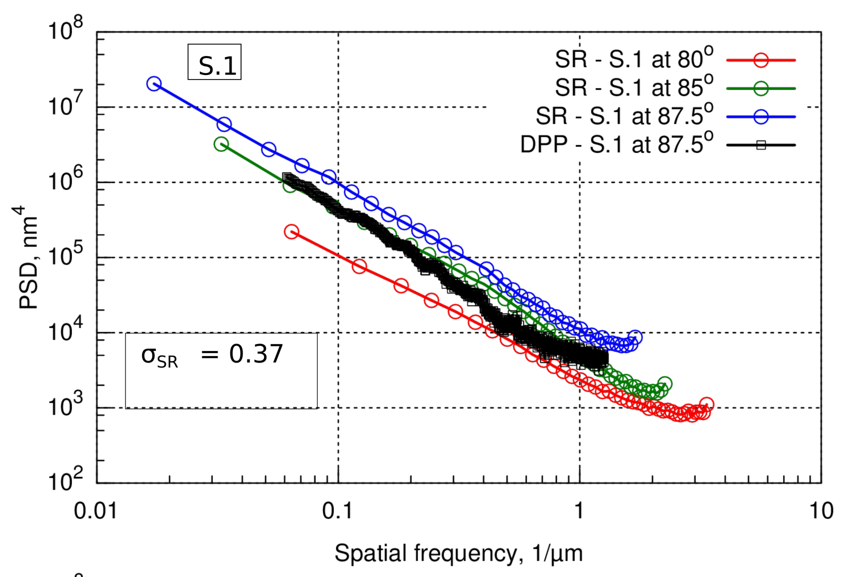


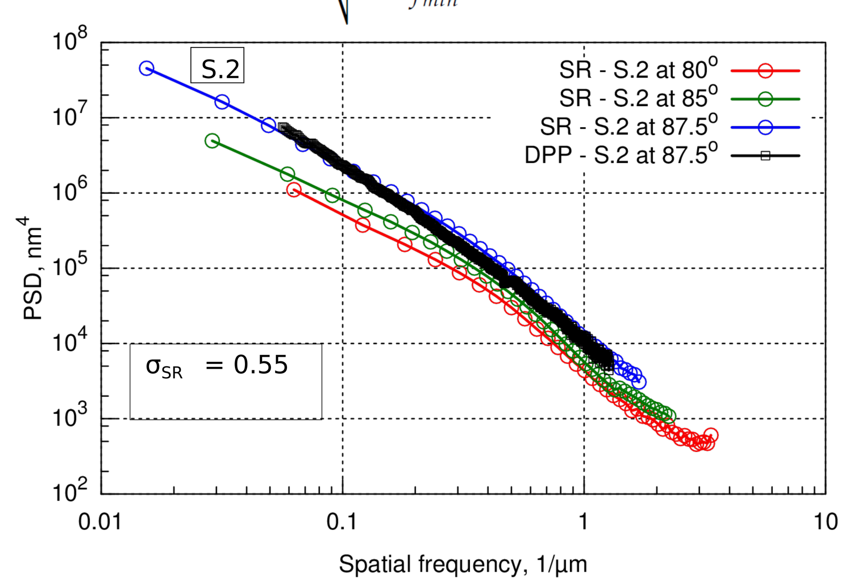
Power Spectral Density (PSD) analysis

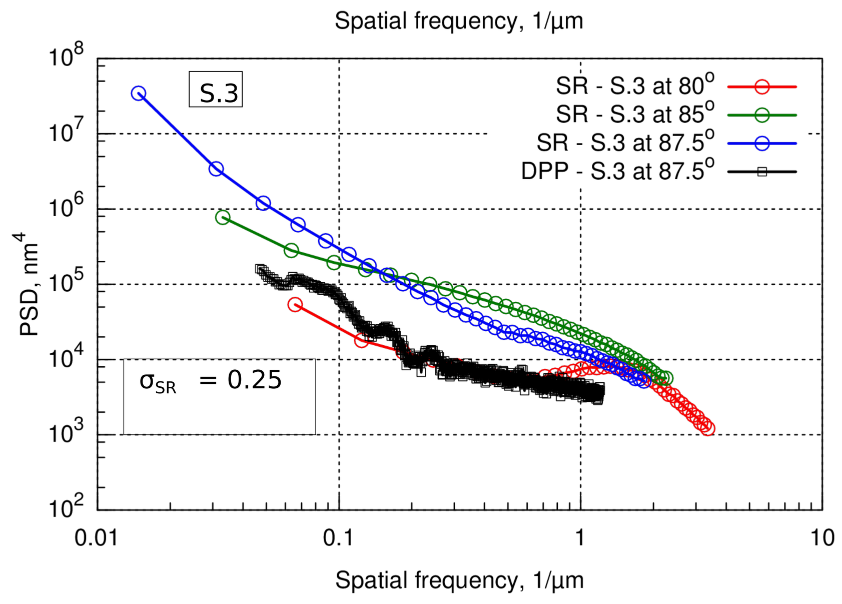
For every sample surface Angular Resolved Scattering (ARS) was measured at three AOIs: [80 °; 85 °; 87.5 °] and compared at 87.5 ° with data from the table-top scatterometer.

According to Rayleigh-Rice (RR) surface scatter ARS can be represented in terms of a two-dimensional surface PSD function. By integration PSD over frequency band, σ_{rms} can be derived.

$$ARS(\theta_s) = \frac{16\pi^2}{\lambda^4}\cos\theta_i(\cos\theta_s)^2 Q_r PSD(f) \qquad \sigma_{rms} = \sqrt{2\pi\int_{f_{min}}^{f_{max}} PSD(f)\,f\,df}$$







Measured PSD for three different sample surfaces compared between two setups: one with synchrotron radiation (SR) and one with DPP source.
Angle dependent polarization reflectance coefficient Q_r was taken from experimental angular scans for each sample.

We see good agreement between the PTB synchrotron radiation based measurements and the DPP laboratory scatterometry for multilayer mirrors. The observed differences though between DPP and SR experiments and between different AOIs are attributed to the dynamic scattering effects not taken into account in present analysis.

Conclusions

We compared measurements of angular resolved diffuse EUV scatter under grazing incidence using a DPP source based laboratory set-up with measurements using synchrotron radiation at the PTB laboratory at the storage ring MLS.

The performance of the DPP-based scatterometer is similar to that of the synchrotron one. We have demonstrated the use of the compact scatterometer for nano-scale surface investigations as well as for characterization of fine surface structures.

The EUV scattering under grazing incidence is related to the topology of the surface and nanometer-scale sub-surface layers determined by the radiation penetration depth.

References

[1] C. Laubis, et al. "Update on EUV-Radiometry at PTB", Proc. SPIE, 977627 (2016)
[2] O. Maryasov et al. "Table-top EUV scatterometer MARYS with high-brightness discharge plasma source", JARA-FIT Annual Report (2015)
[3] F. Kuepper, K. Bergmann et al. "Source operation manual", Fraunhofer ILT (2014)

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