High-accuracy EUV reflectometry at PTB

EUV Radiometry

Frank Scholze, Christian Laubis, Christian Buchholz, Andreas Fischer,

Sven Plöger, Frank Scholz, Heike Wagner, and Gerhard Ulm

Physikalisch-Technische Bundesanstalt

Abbestraße 2-12, 10587 Berlin, Germany

Abstract

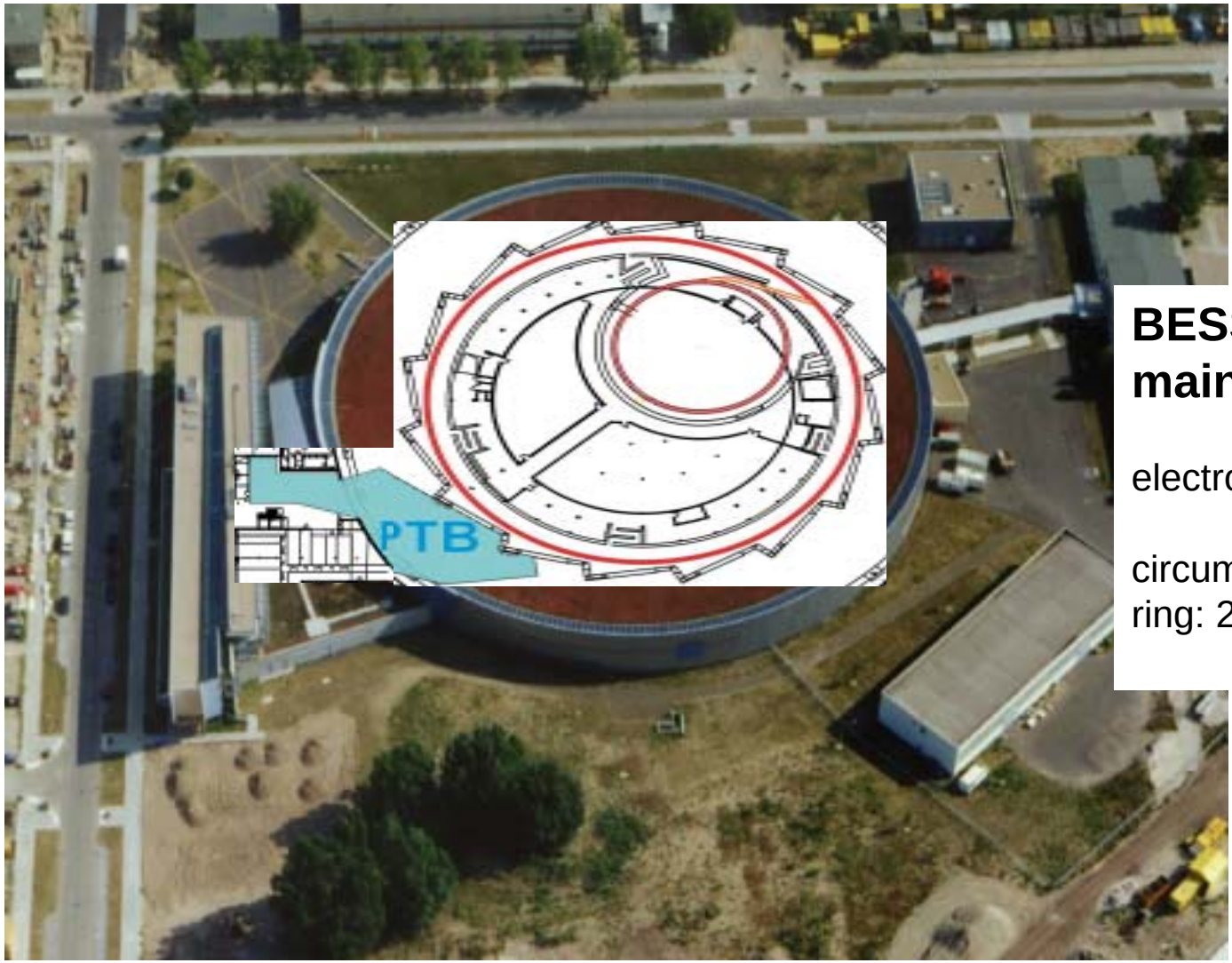
The routine availability of high-accuracy soft X-ray radiometry is a prerequisite for the development of extreme UV lithography. In order to meet these demands, the PTB radiometry laboratory at the electron storage ring BESSY II pursues the characterisation and calibration of optical components and radiation detectors in the VUV and soft X-ray spectral regions as a major task.

A large reflectometer enables the PTB to characterise EUVL optics up to 550 mm in diameter and 50 kg in mass, meeting the demands for the present designs of projection optics. For the peak spectral reflectance of a mirror in the EUV region, an absolute uncertainty of u=0.10% is achieved. The long-term reproducibility of the peak wavelength is better than 1.1 pm with a repeatability of 0.06 pm.

The long-term reproducibility of the PTB measurements provided a basis for the coating development within the European EUCLIDES and MEDEA projects. The measurement of the photocurrent emitted from the mirror surface was developed as a versatile tool for the determination of the phase of the reflected radiation relative to the mirror surface. A micro-reflectometry facility with about 10 µm spatial resolution was set-up for investigation of small structures.

PTB Radiometry Laboratory at BESSY II

EUV Radiometry



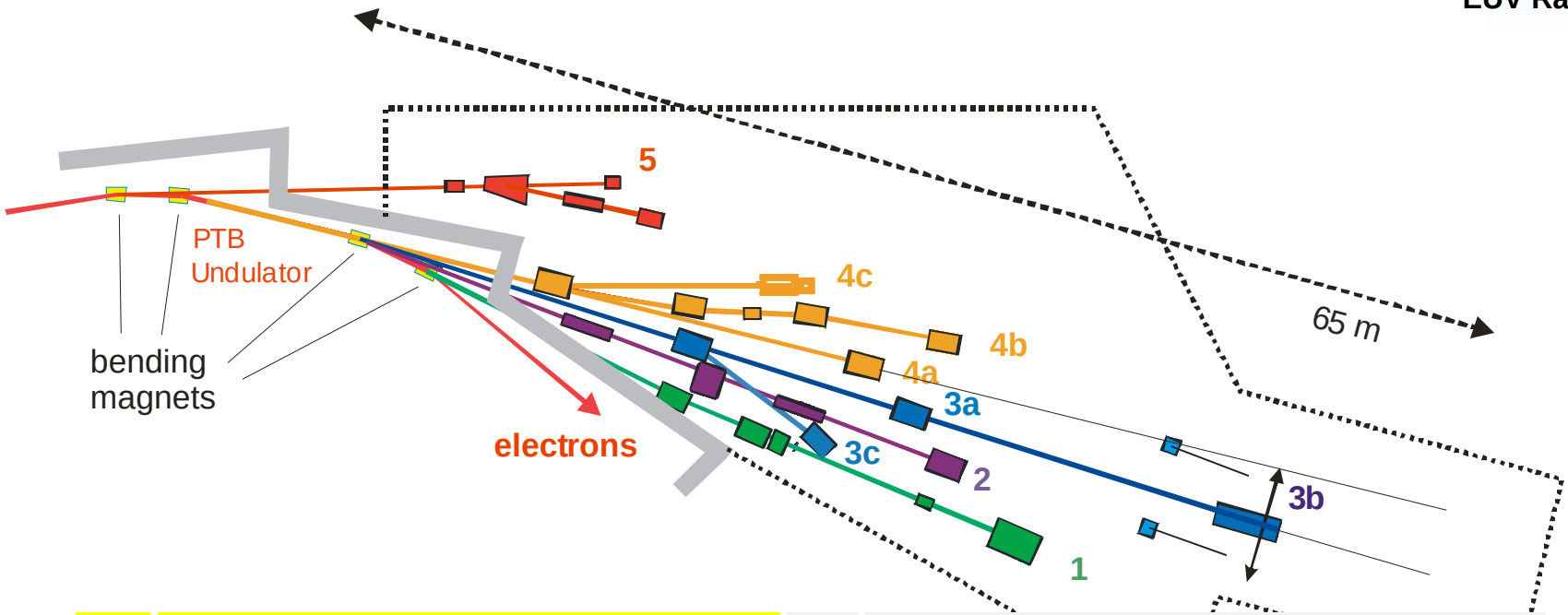
BESSY II
main parameters

electron energy 1.7 GeV

circumference of storage ring: 240 m

PTB Radiometry Laboratory

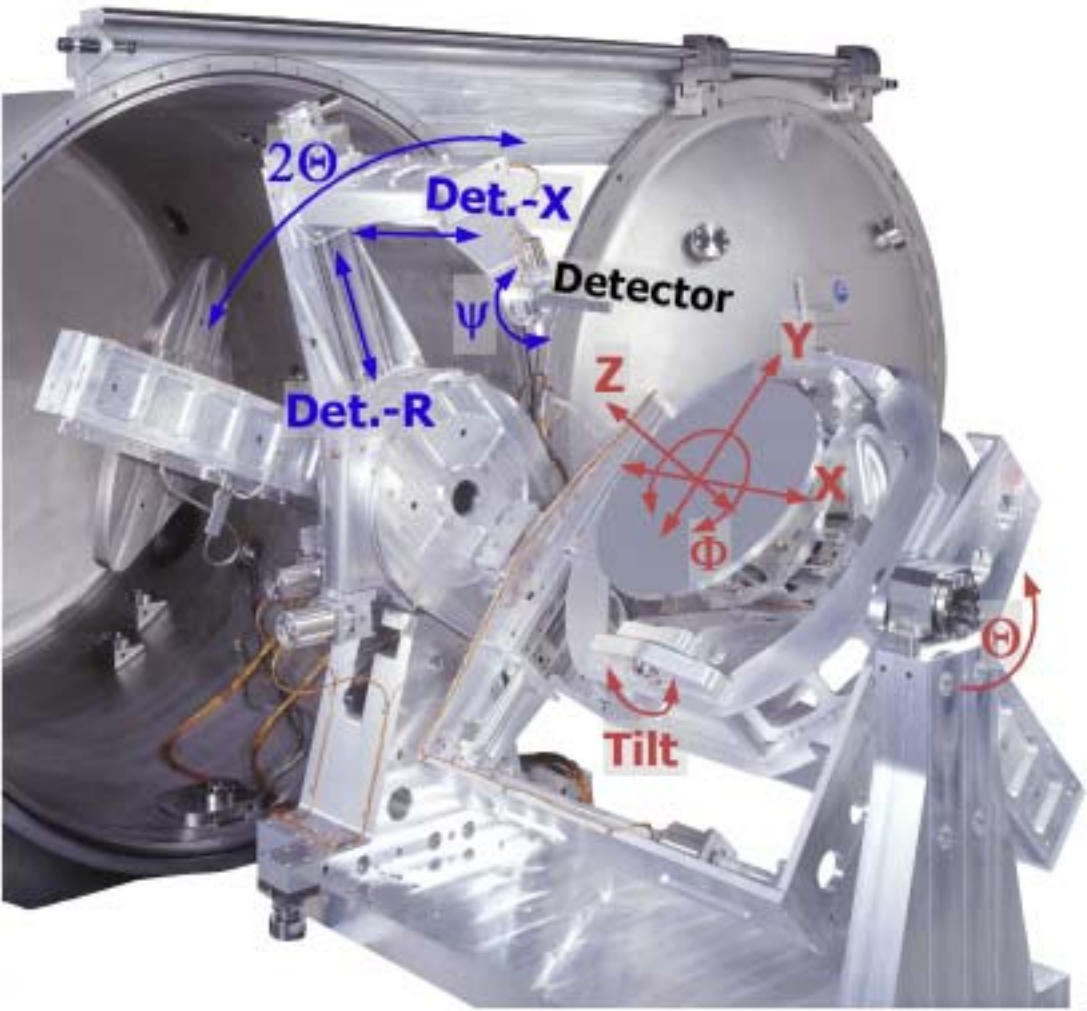
EUV Radiometry



1	plane grating monochromator 30 eV to 1800 eV	4a	undispersed undulator radiation
2	four crystal monochromator 1.75 keV to 10 keV	4b	plane grating monochromator at undulator 20 eV to 1900 eV
3a	undispersed bending magnet radiation	4c	deflected undispersed undulator radiation
3b	normal incidence monochromator radiation source calibration 3 eV to 35 eV	5	normal incidence monochromator detector calibration 3 eV to 35 eV
3c	deflected undispersed bending magnet radiation		

PTB Reflectometer

EUV Radiometry

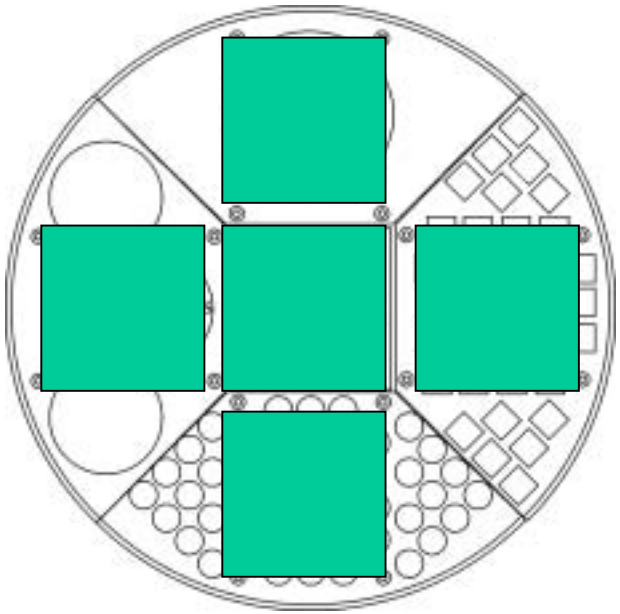


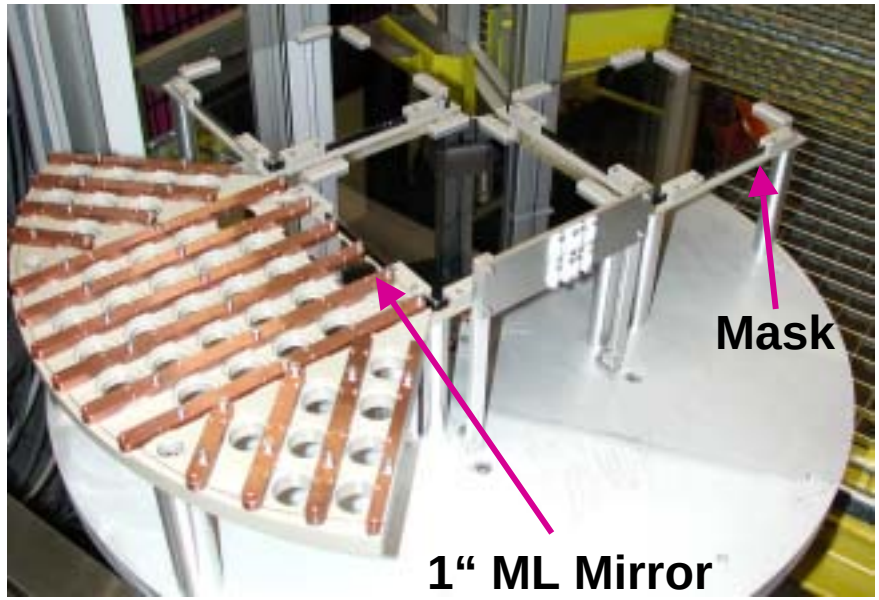
Axis	Range
Θ	-30° to 95°
Tilt	-10° to 10°
Φ	0° to 360°
X	-90 mm to 90 mm
Y	-10 mm to 300 mm
Z	-15 mm to 140 mm
Det. X	0 mm to 120 mm
Det. R	150 mm to 550 mm
Det. Ψ	0° to 180°
2θ	-5° to 190°

Accuracy: 10µm or 0.01 °

Diameter: 2 m
Length: 2.1 m
Weight: 3 t

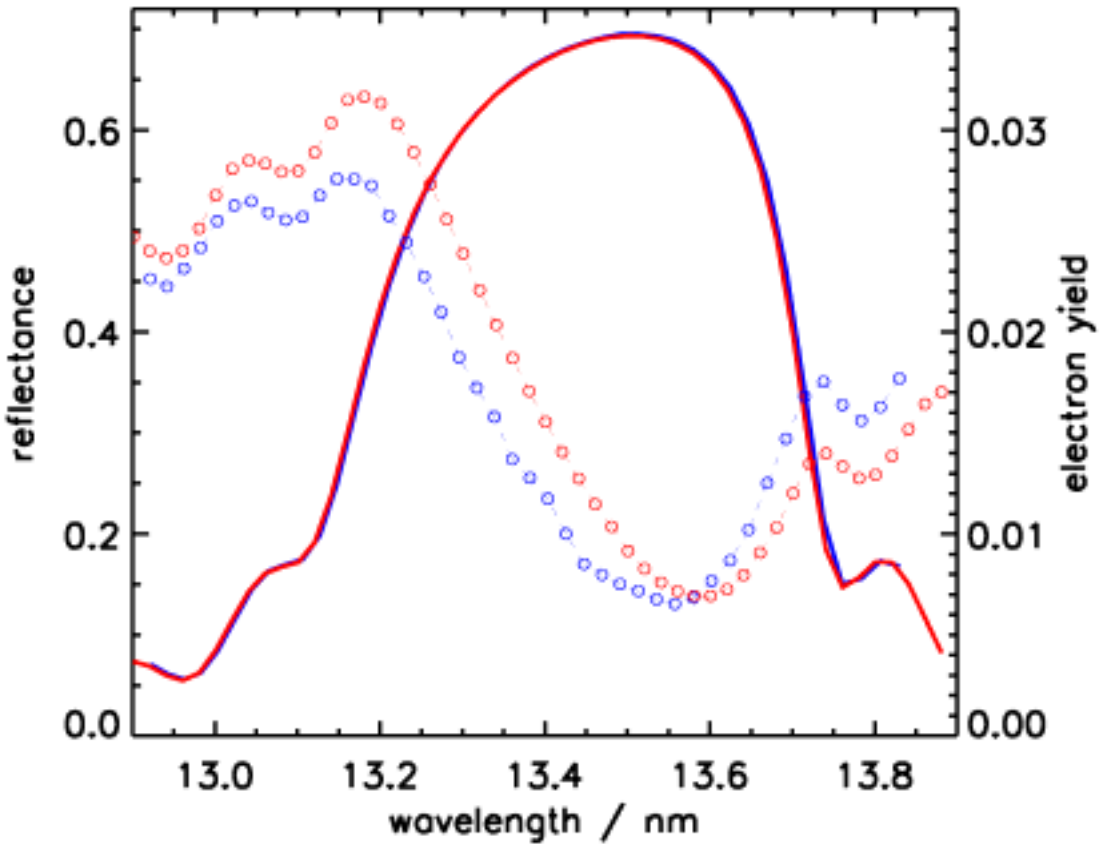
PTB Reflectometer Sample Holder





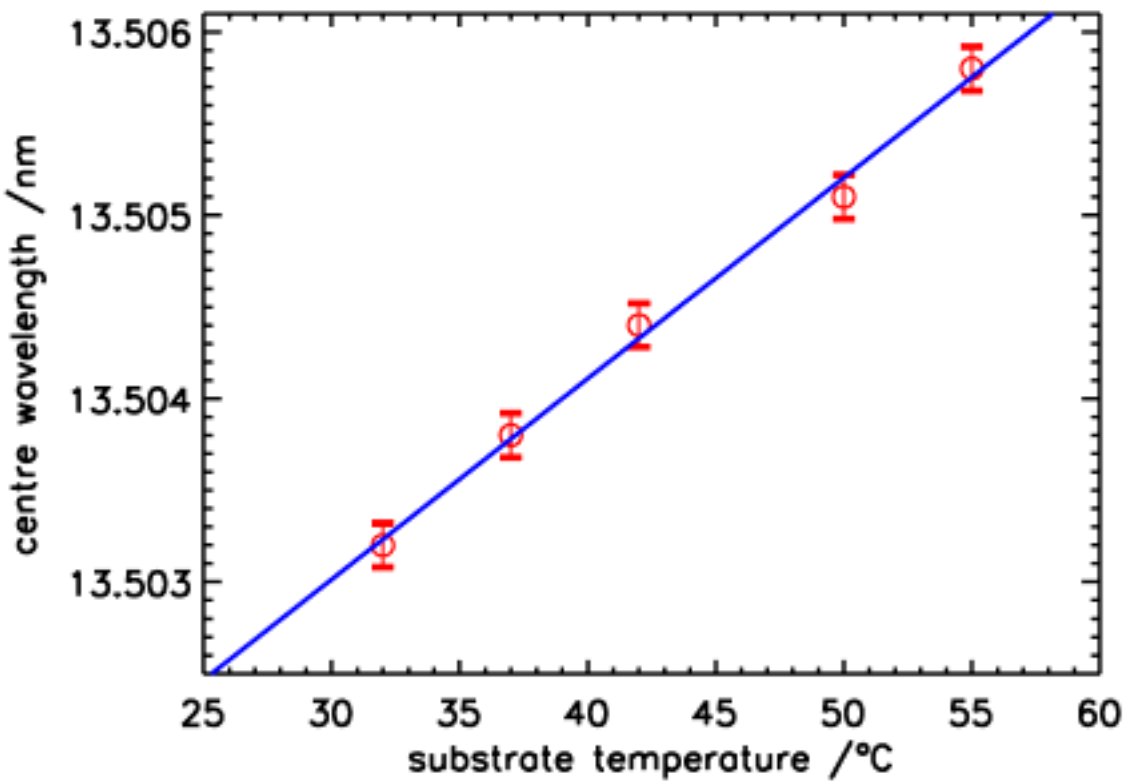
Transfer with robot

Simultaneous photocurrent and reflectance measurement



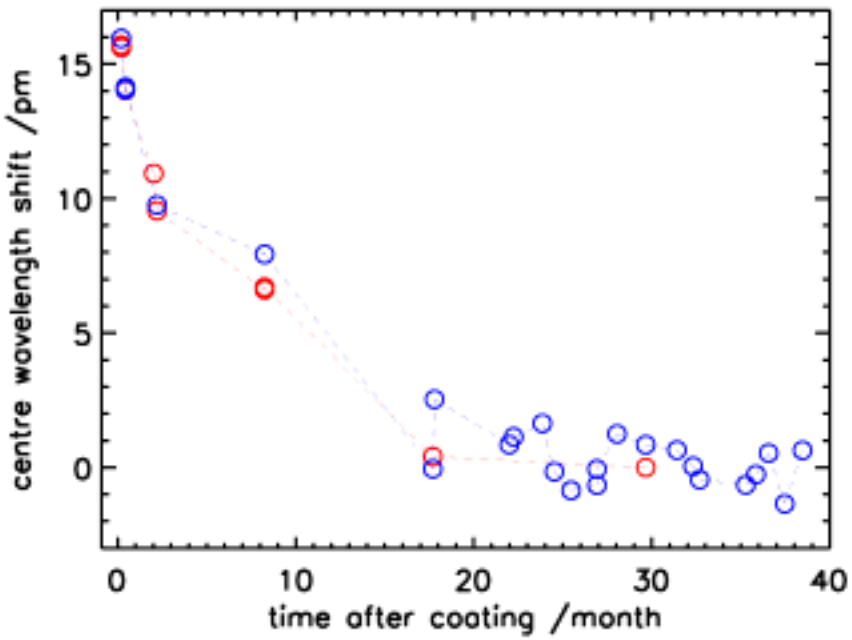
Reflectance of a mirror measured in **March 2002** (blue) and **August 2004** (red).
The line is the spectral reflectance, left scale. The circles are the photocurrent signal, right scale.
The reflectance curve is almost identical, the phase-shift of the photocurrent curve indicates an increase in top layer thickness by about 0.2 nm.

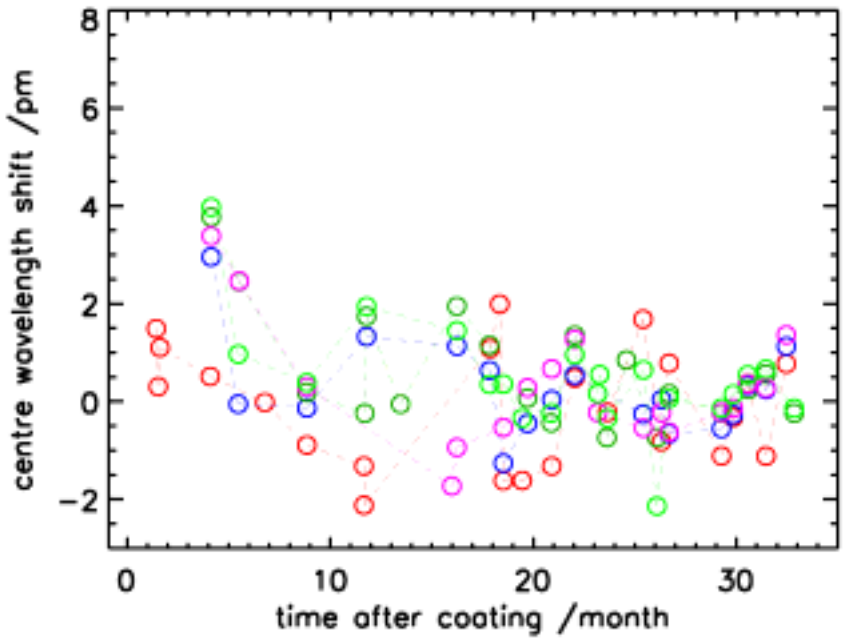
Repeatability of wavelength



- Measured shift of the centre wavelength of a mirror with 60(Mo/B_4C/Si/C) layers as function of substrate temperature.
- The contribution of pure signal statistics to the uncertainty is only 0.06 pm (1σ). A 2σ -range is indicated by the error bars.
- The suspected linear relation holds within this uncertainty.
- The line shows a linear fit with a thermal expansion coefficient of $8.1(4)10^{-6}$ K^{-1}.

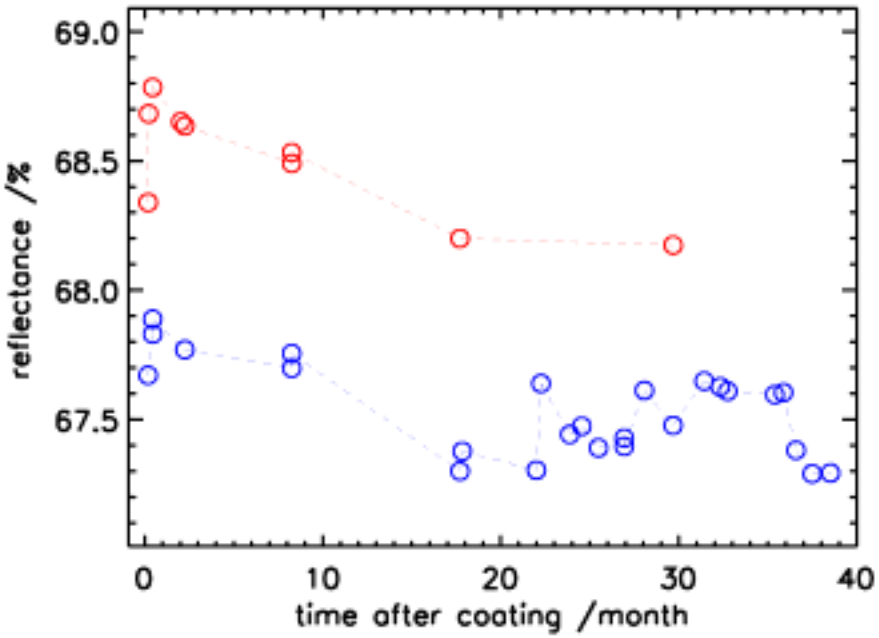
Long-term reproducibility of wavelength

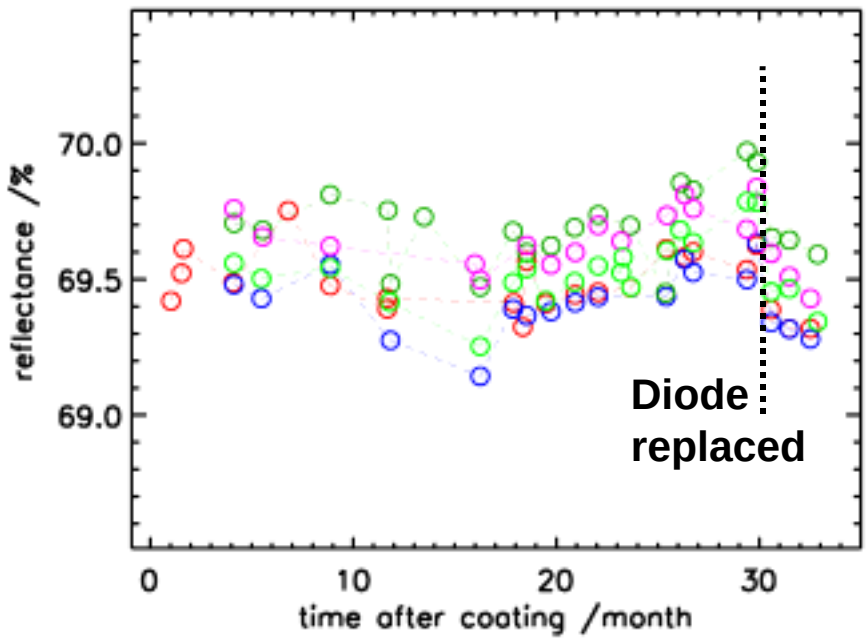




Measured shift of centre wavelength of EUV mirrors after coating by Fraunhofer IWS in Dresden, Germany. The data are normalised to the asymptotic value.
Left: Two mirrors with 65 (Mo/Si) bi-layers coated in June 2001.
Right: Five mirrors with 60(Mo/B_4C/Si/C) layers coated in December 2001.

Long-term reproducibility of reflectance



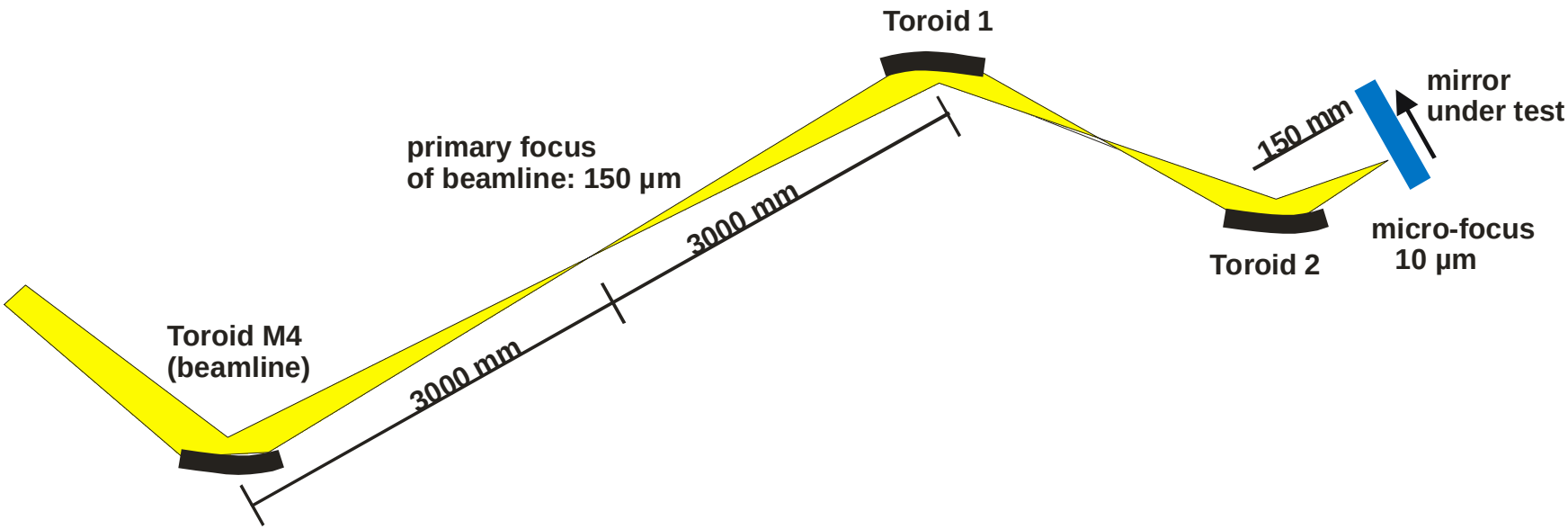


Measured peak reflectance of EUV mirrors after coating by Fraunhofer IWS in Dresden, Germany.
Left: Two mirrors with 65 (Mo/Si) bi-layers coated in June 2001.
Right: Five mirrors with 60(Mo/B_4C/Si/C) layers coated in December 2001.

Compilation of uncertainties

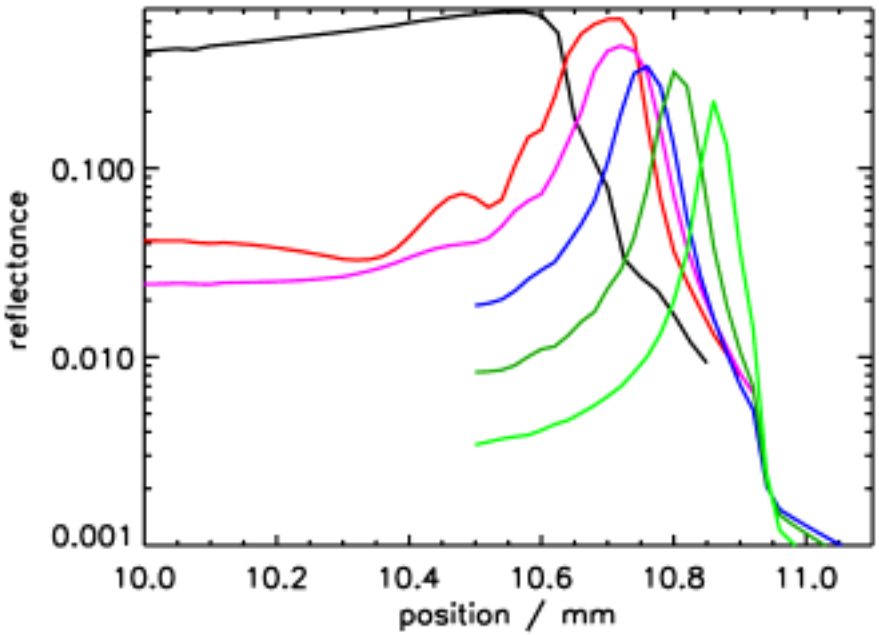
Peak reflectance	Uncertainty contribution u /%	Peak wavelength	Uncertainty contribution u /pm
Stability of normalised intensity	0.02	Repeatability of wavelength	0.06
Inhomogeneity of the detector	0.04	Reproducibility of wavelength (reference to Be K-edge)	1.1
Higher diffraction orders	0.02	Kr resonance wavelength	1.6
Diffuse scattered light	0.08		
Total uncertainty of peak reflectance	**0.1**	**Total uncertainty of peak wavelength**	**2.0**

Micro reflectometry

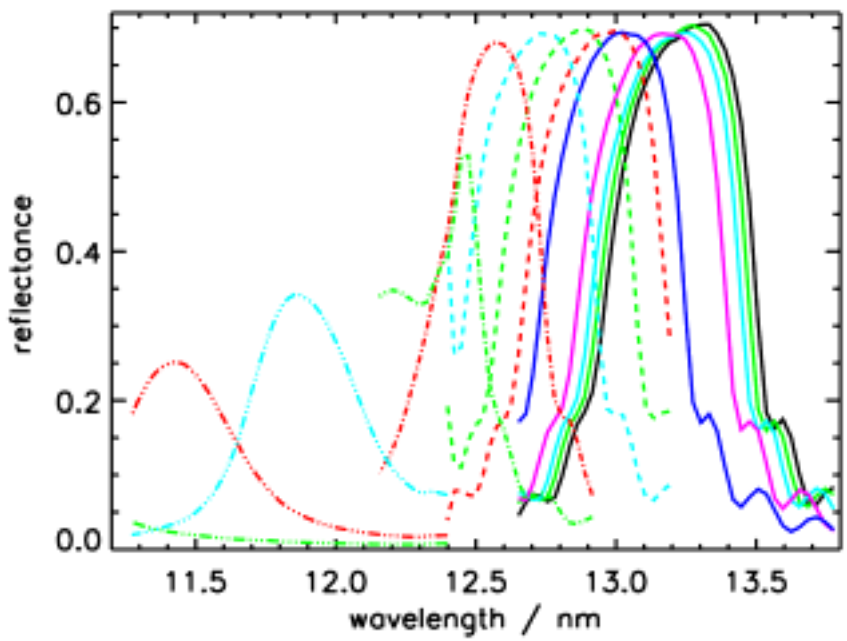


At the undulator beamline of PTB, a refocusing unit with 10 µm focal spot is installed. Using a reflectometer for sample sizes up to 160 mm, micro-reflectometry with about 10 µm spatial resolution can be done at mirrors and masks.

Micro reflectometry

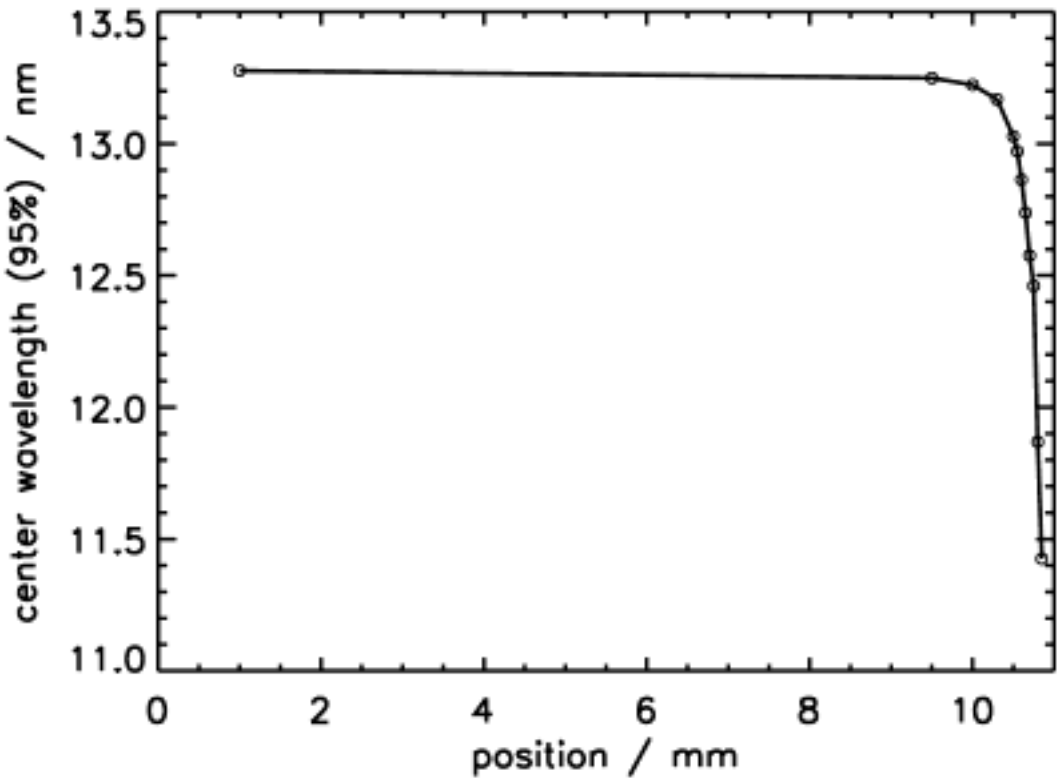


Reflectance close to the edge of the substrate measured at wavelengths of 12.942 nm (black), 12.524 nm (red), 12.398 nm (magenta), 12.155 nm (blue), 11.808 nm (dark green), and 11.271 nm (light green).
The physical edge of the coating is at 10.9 mm, where all curves converge.



Reflectance as function of wavelength measured at positions of 1 mm, 9.5 mm, 10 mm, 10.3 mm, 10.5 mm, 10.55 mm, 10.6 mm, 10.65 mm,. 10.7 mm, 10.75 mm, 10.8 mm, and 10.85 mm, from right to left, respectively.

Micro reflectometry



Variation of the peak wavelength
(measured as centre wavelength for 95% threshold) as function of position on the mirror.

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