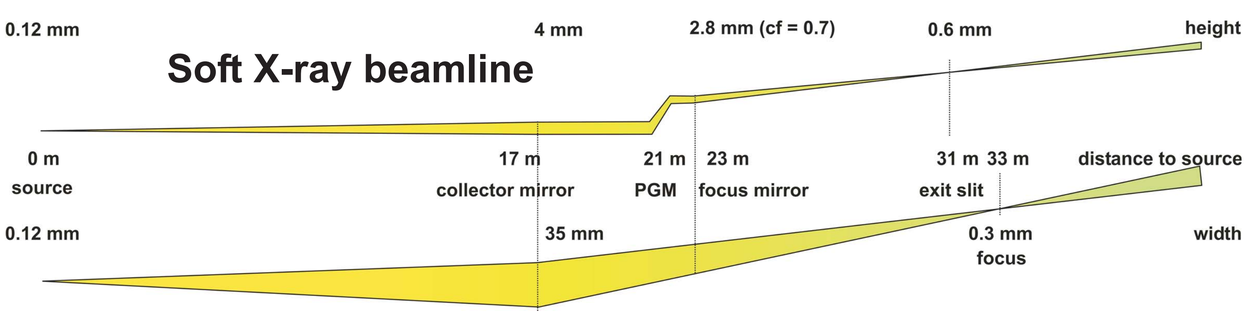
Status of EUV Reflectometry at PTB

Christian Laubis, Annett Barboutis, Martin Biel, Christian Buchholz, Benjamin Dubrau,
Andreas Fischer, Anne Hesse, Jana Puls, Christian Stadelhoff, Victor Soltwisch, and Frank Scholze

Introduction

PTB accompanied the European EUVL development program from beginning with its at-wavelength metrology services. Now several pre-production EUV tools have been set up in the field and the first production tools are scheduled for delivery in 2013. Consequently, the demand for EUV radiometry has grown with respect to volume and variety of the measurement requirements. PTB continuously expanded its measurement capabilities and now offers not only reflectance , transmittance, and sensitivity measurements but also diffusely scattered light measurements for PSD characterization in the spatial frequency region up to 10 µm. Since 2011, a second beamline at the PTB-owed MLS is operational. It complements and expands the measurement capabilities of the Soft X-ray metrology beamline at BESSY II in radiant power, wavelength, variable spot size and variable polarization. We present an updated overview of our capabilities with a focus on the long-term stability of our instrumentation and methods.

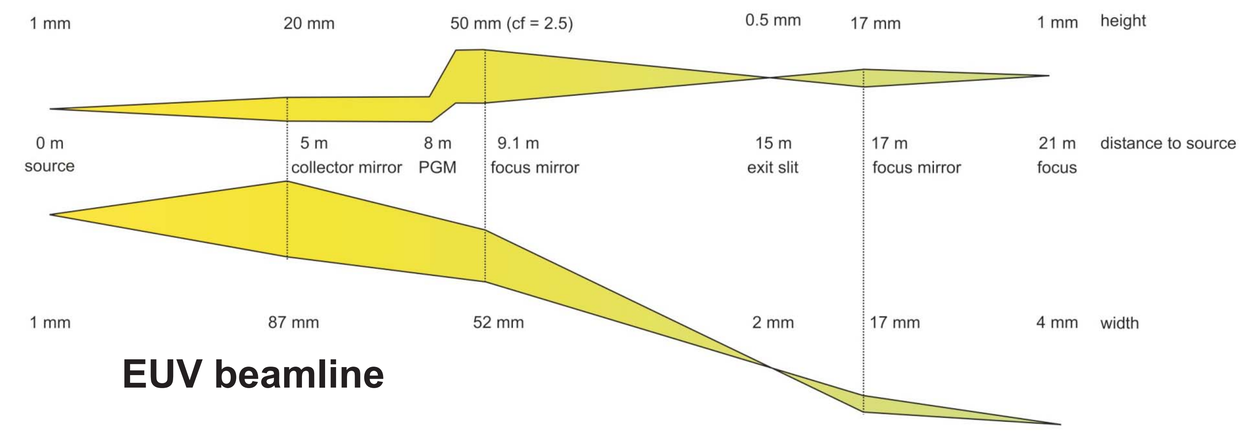
Beamlines



PTB's soft X-ray beamline at BESSY II was designed for maximum stability and a well-collimated beam. The achieveable low beam divergance is most useful for small-angle scattering measurements.

Beamline parameters - Soft X-ray beamline at BESSY II:

Wavelength range:	- 0.65 nm to 30 nm
Spot size:	- standard - below 1 mm x 1 mm
Divergence:	- 1.6 mrad x 0.4 mrad (full beam) - see paper
linear Polarization:	- better than 98% in the EUV region
radiant power at 13.5 nm wavelength:	- around 1 µW - also see radiant power figure

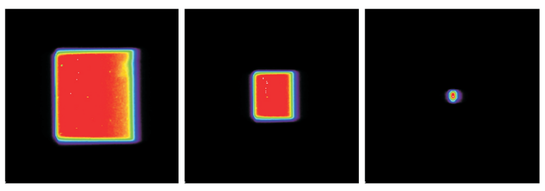


With its available radiant power, adjustable spot size and variable degree of polarization, PTB's new EUV beamline at PTB's own synchrotron light source MLS (Metrology Light Source) extends available measurement capabilities.

Beamline parameters - EUV beamline at MLS:

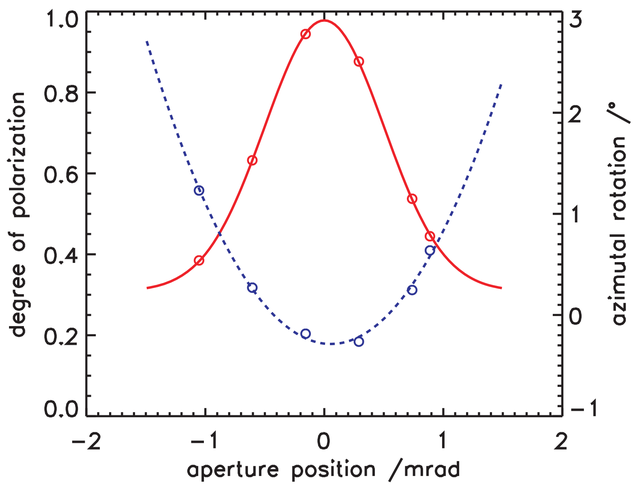
Wavelength range	- 5 nm to 50 nm
Spot size	- 2 mm x 2 mm to 0.1 mm x 0.1 mm (4 mm x 4 mm full beam)
Divergence	- standard - below 4 mrad
linear Polarization	- adjustable between 40% and 98%
radiant power at 13.5 nm wavelength:	- around 20 µW

New Options



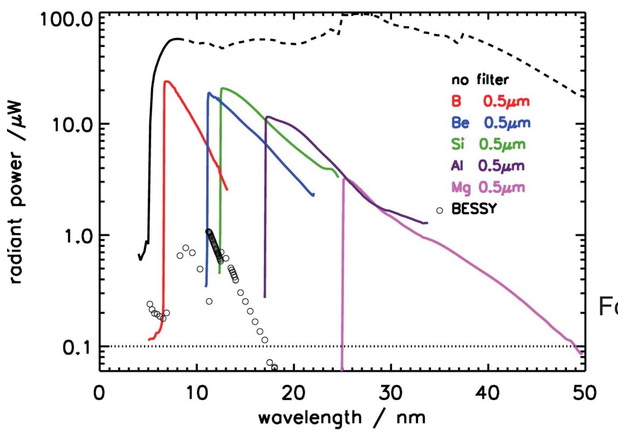
beam spot variable from 2 mm x 2 mm to 0.1 mm x 0.1 mm at experimental distance

Variable Spot Size



Variable Polarization

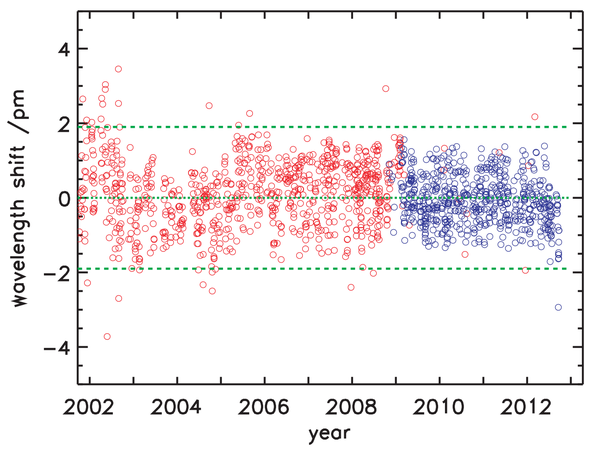
Degree of polarization adjustable from 40% to 98% - depending on the position of the entrance aperture (red).



Radiant Power

Radiant power measured at the PTB EUV beamline. Normalized to 150 mA stored electron current. For comparison, values of the PTB soft X-Ray beamline for 200 mA are shown as open circles.

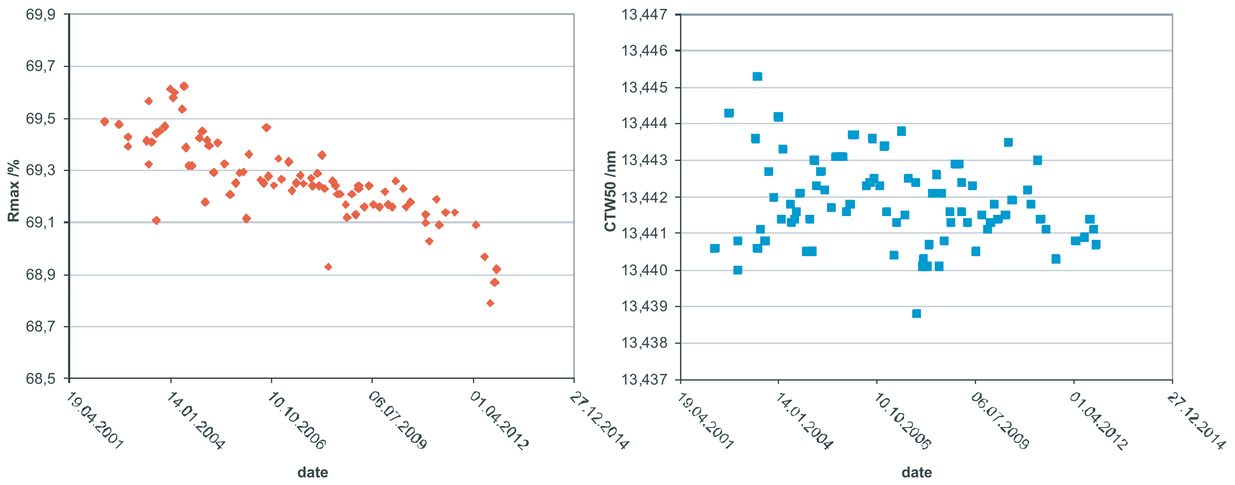
Long-Term Stability



History of wavelength calibration. Shown are daily results of wavelength control using the absorption edge of the Be (red) and Si (blue) spectral purity filters in the soft X-ray beamline. In 2009, we switched from the Be filter as the main reference to the Si filter because of the better stability of Si.
For comparison, the full vertical scale is 10 pm - as in the wavelength-graphs below.

To put the long-term repeatability of our measurements to the most rigorous test, we regularly perform reflectance measurements on a set of our own samples. To arrive at the same results over time, all relevant variables like wavelength, angle of incidende, the sample itself and our normalization to beam intensity need to be stable simultaneously. Please note the absolute scale in the figures below.

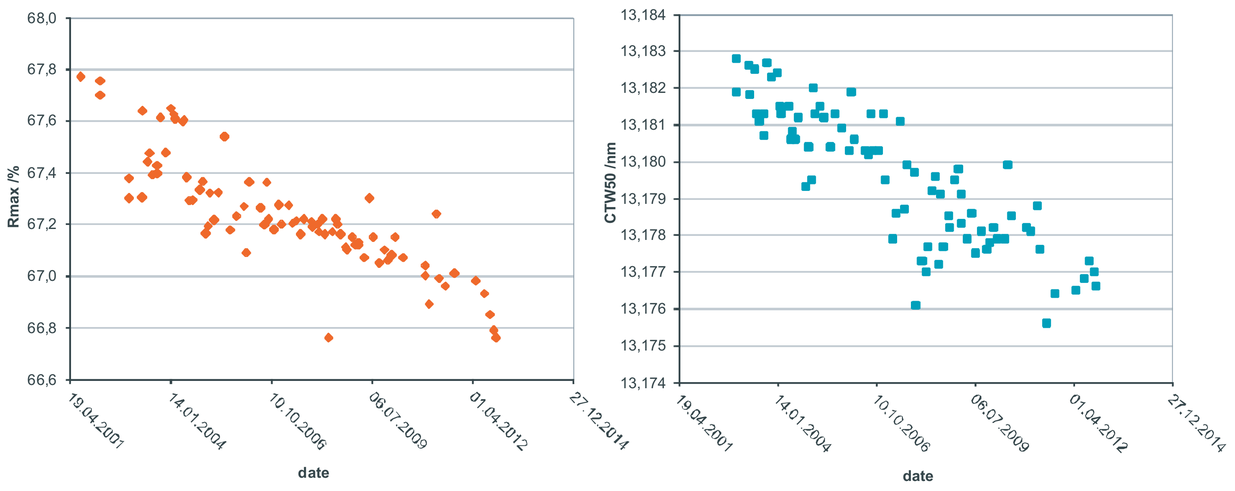
Multilayer Mirror with Diffusion Barrier



A downtrend is visible. Regarding the absolute values, this slight decrease in reflectance can be explained by about 1 nm of carbonaceous surface contamination.

Looking at the minute spread in actual numbers, long-term measurement stability is verified. Standard deviation of these values is 1.2 pm.

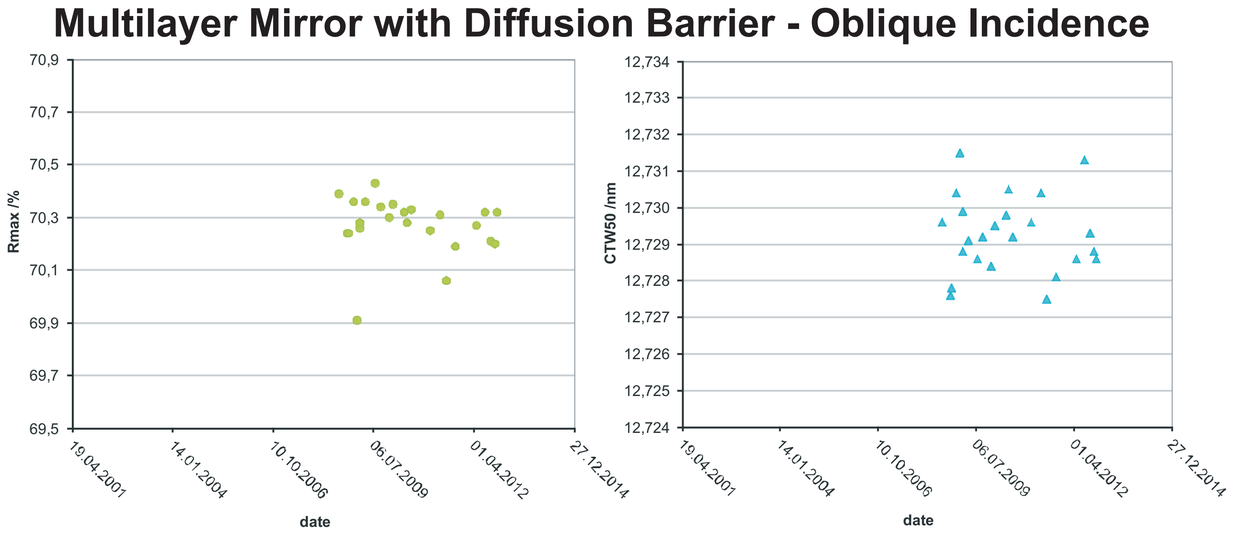
Multilayer Mirror without Diffusion Barrier



The downtrend can be explained by surface contamination together with multilayer interdiffusion.

The downtrend is explainable by multilayer interdiffusion, which shrinks the multilayer period.

Multilayer Mirror with Diffusion Barrier - Oblique Incidence



Measurement at oblique incidence (20° AOI). Standard deviation of these values is 0.11 %.

Measurement at oblique incidence (20° AOI). Standard deviation of these values is 1.1 pm.

Conclusion

PTB uses two dedicated complementary beamlines which cover the wavelength range from 0.65 nm to 50 nm - both beamlines are optimized to achieve temporally stable normalized radiant power and excellent wavelength reproducibility with out-of-band radiation below 10^{-3} relative. Characterizations which require a small beam footprint down to 0.1 mm x 0.1 mm are feasible. For polarization-dependent characterizations we can either rotate the plane of reflection to measure in S or P polarization geometry (or any composition in between) - or we change the degree of linear polarization of the beam itself. For scatterometric measurements, a low divergence beam of below 0.5 mrad beam divergence is available to extract results very close to the specular reflex.
Our reference sample measurement history proves the long-term reproducibility of PTB's reflectance measurements over a 10 year term - our claimed measurement uncertainties are verified by these long-term measurement series.

contact: christian.laubis@ptb.de