Status of EUV Metrology at PTB

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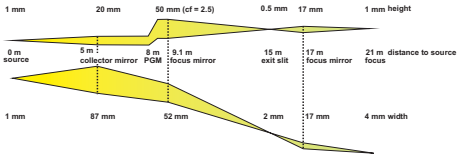
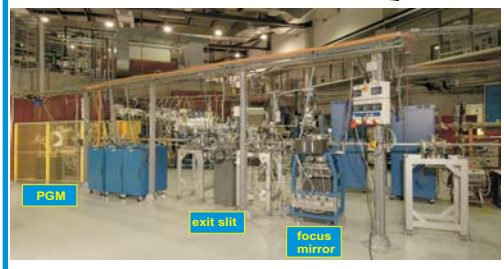
PTB at its synchrotron laboratory in Berlin has been supporting EUV technology from its very beginning almost 30 years ago, with metrology using synchrotron radiation for at-wavelength reflectometry. Here we give an overview of the present status of PTB's measurement capabilities which evolved with the technology requirements. Now, PTB operates two beamlines which both cover the wavelength bands of 13.5 nm and also 6.5 nm for future EUV generations. The second beamline, operational from end 2011, was particularly designed for smaller measurement spot sizes down to 100 µm by 150 µm width, providing higher radiant power at the same time for the investigation of small EUV detectors as used in EUV lithography machines. Our present reflectometer allows us to measure the presently largest mirrors manufactured for EUV lithography. A new ellipsometer-scatterometer, scheduled for delivery in October 2012, is capable of measuring 6-inch-square substrates under arbitrary polarization geometry in a strictly fat-free environment.

New EUV Beamline

There are 3 main goals with the new beamline:

- sufficient power for detector calibration
- expansion of the measurement capabilities in the EUV spectral range - e.g. small spotsize
- closing the spectral gap between the soft X-ray [2] and VUV [3] beamlines



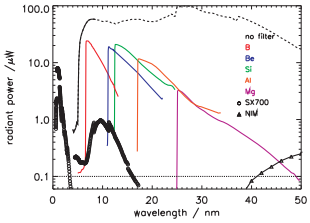


Picture of PTB's new EUV beamline. From left (synchrotron side) via monochromator (PGM), exit slit and focus mirror to the experimental side on the right.

Spatial resolution

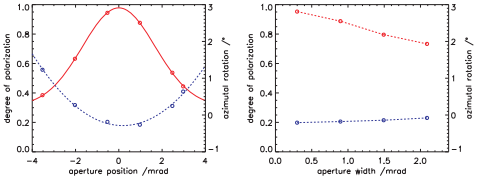
CCD images (4 mm square image area) of the beam (2 mm)^2, (1 mm)^2 and (0.1 mm)^2 in size. Note the sharp contour and the top-hat profile.

Radiant power



Radiant power at the new EUV beamline (colour).

Polarization

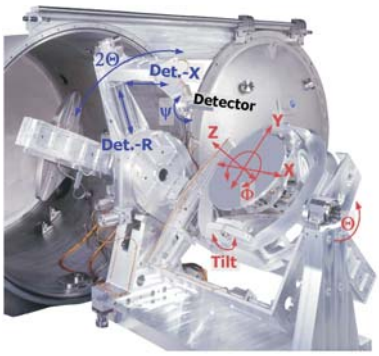


Linear degree of polarization for different vertical acceptance angles of the beamline. The entrance aperture was centered in the orbital plane.

Instrumentation

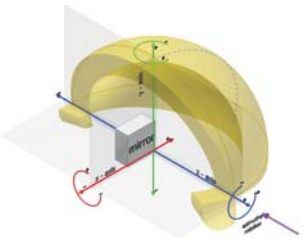
Flexibility and highest accuracy in measurements require - in addition to stable and well optimized beamlines - instruments which offer all necessary degrees of freedom of movement and which are well characterized to provide calculable placement on optical samples.

Large Reflectometer



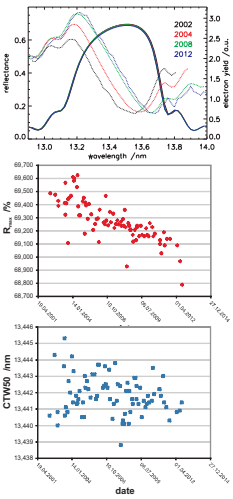
PTB reflectometer with movements indicated [1].
Red: Sample movements
Blue: Detector movements

New Scatterometer



Kinematic scheme of PTB's New Scatterometer [5]. Here the detector can be freely positioned in a quarter of the full sphere around the sample, allowing any rotation of the plane of reflection.

Reflectometry

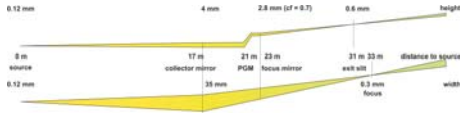


Reflectance of a mirror measured in March 2002 (black), Aug. 2004 (red), July 2008 (green) and Sept. 2012 (blue). The lines are the spectral reflectance, left scale. The dashes are the photocurrent signal, right scale. The reflectance curves are almost identical. The phase shifts of the photocurrent curves indicate an increase in top layer thickness by about 1 nm from 2002 to 2012.

The lower panels show the trend for all measurements on this mirror over the 10-year period. The wavelength remained stable, while the reflectance continuously decreased.
Note that the variation of the data is partly due to inhomogeneity of the mirror.

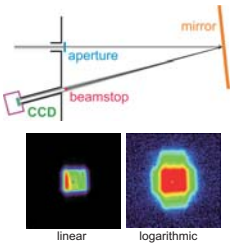
Soft X-ray Beamline

optimized for small divergence

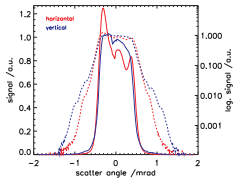


Optical scheme of the PTB soft X-ray beamline at BESSY II. Optical elements and apertures are indicated.

Angular resolution

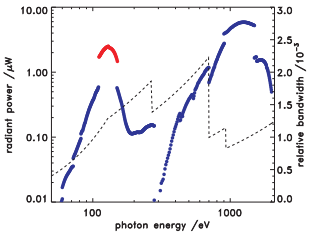


Experimental setup for scatterometry experiments where high angular resolution is needed.

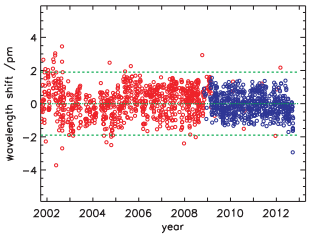


Picture of the beam after reflection as above. The visible beamsize from the CCD calculates to a beamdivergence of below 0.5 mrad.

Radiant power



Radiant power (colour) and spectral resolution (black) at the soft X-ray beamline .



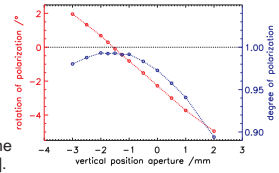
History of the wavelength calibration. Shown are the daily results of the wavelength control with the absorption edge of the Be (red) and Si (blue) spectral-purity filters in the beamline.

Polarization

Left scale: The rotation of the polarization ellipse of the beamline radiation (red).

Right scale: The degree of polarization of the beamline radiation.

Both over vertical position of the beamline entrance aperture [4].



Peak reflectance	Uncertainty contribution u /%		Peak wavelength	Uncertainty contribution u /pm	
	NI	OI		NI	OI
Here considered for an AOI of:	1.5°	20°		1.5°	20°
Stability of normalized 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		Sample temperature (? T = 5 K)	0.6	
Polarization	0.0015	0.30	Incidence angle (? Ê = 0.02°)	0.1	1.6
Total uncertainty of peak reflectance	**0.10**	**0.31**	**Total uncertainty of peak wavelength**	**2.0**	**2.6**

Compilation of measurement uncertainty contributions for peak reflectance and peak wavelength

Acknowledgement

We gratefully acknowledge the substantial support given by the HZB BESSZ and MLS teams and the EUV radiometry team of PTB. The performance of the beamlines is owed largely to their reliable operation of the storage rings and instrumentation.

References

[1] J. Tümmler et al., Proc. SPIE **5037** 265-73 (2003)
[2] F. Scholze et al., Metrologia **40**, S224-S228 (2003)
[3] A. Gottwald et al., Meas. Sci. Technol., **21**, 125101 (2010)
[4] C. Laubis et al., Proc. SPIE **7636** 76362R-1 (2010)
[5] C. Laubis et al., Proc. SPIE **8322** 832236-1 (2012)

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