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# The At-Wavelength Metrology Facility at BESSY-II

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**Abstract:** The At-Wavelength Metrology Facility at BESSY II is dedicated to short-term characterization of novel UV, EUV and XUV optical elements, such as diffraction gratings, mirrors, multilayers and nano-optical devices like reflection zone plates. It consists of an Optics Beamline PM-1 and a Reflectometer in a clean-room hutch as a fixed end station. The bending magnet Beamline is a Plane Grating Monochromator beamline (c-PGM) equipped with an SX700 monochromator. The beamline is specially tailored for efficient high-order suppression and stray light reduction. The versatile 11-axes UHV-Reflectometer can house life-sized optical elements, which are fully adjustable and of which the reflection properties can be measured in the full incidence angular range as well as in the full azimuthal angular range to determine polarization properties.

## 1 Introduction

The At-Wavelength Metrology Facility (Schäfers et al., 2016) consists of an Optics Beamline PM-1 (Sokolov et al., 2014) and a Reflectometer (Eggenstein et al., 2014, 2013) as a fixed end station in a clean-room surrounding. It is dedicated to at-wavelength characterization and calibration of the in-house produced diffraction gratings and nano-optical devices as well as of mirrors and multilayer systems. It is coupled to a versatile 4-circle UHV-Reflectometer as a permanent end station which is located in a moderate clean-room hutch and which allows to carry out Reflectometry experiments on a very high precision level. The Plane Grating Monochromator beamline attached to a bending magnet is operated in collimated light (c-PGM) (Follath, 2001). The SX700 monochromator is equipped by new blazed

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gratings of our own production. The beamline is matched to reflectometry requirements: Over the large operating range from 10 to 2000 eV this bending magnet beamline has very high spectral purity achieved by (1) a four-mirror arrangement of different coatings which can be inserted into the beam path at different angles and (2) by absorber filters for high order suppression. Stray light and scattered radiation is removed efficiently by in-situ exchangeable apertures and slits. The incident beam has a low divergence and a moderate energy resolution.
The main feature of the 11-axes Reflectometer is the possibility to incorporate large samples (up to 4 kg and 360 mm in length) into the UHV-chamber. The samples are adjustable within six degrees of freedom by a novel compact UHV-tripod system. The reflectivity can be measured in the full incidence angular range of 90° for both s- and p-polarization geometry by azimuthal rotation of the sample around the beam direction. A variety of in-situ exchangeable detectors with different angular resolution and dynamic range are available.

## 2 Instrument Applications

- At Wavelength metrology (quality control) of UV, EUV and XUV-optics: Multilayers, mirrors, gratings, zoneplates, crystals, thin films
- Reflectivity, efficiency, transmission, diffraction
- Scattering (specular - non specular)
- Non-destructive investigation and characterisation of optical surfaces
- In depth analysis of internal material structure including buried layers and interfaces
- Optical constants derived from accurate reflectivity measurements

## 3 Source

The source is the bending magnet D1.1 with the following parameters:

| | |
|---|---|
| Electron energy [GeV] | 1.7 |
| Magnetic field [T] | 1.3 |
| Bending radius [m] | 4.35 |
| Power on $1^{st}$ optical element (300 mA) [W] | 20 |
| Critical energy [keV] | 2.5 |
| Source horizontal size ($\sigma_x$) [$\mu$m] | 50 |
| vertical size ($\sigma_y$) [$\mu$m] | 40 |
| Source hor. divergence ($\sigma'_x$) [$\mu$rad] | 130 |
| vert. divergence ($\sigma'_y$) [$\mu$rad] | 2 |

Table 1: BESSY II source characteristics of the dipole section DIP 1.1

## 4 Optics Beamline PM-1: Optical Design

The optical layout of the beamline is described in in Figure 1. M1 is a toroidal mirror which collimates the light vertically and focusses it approximately 1:1 horizontally. The plane mirror M2 is used to vary the deviation angle at the plane grating PG (SX700 monochromator with 600 and 1200 l/mm, respectively (Schäfers et al., 2016). Vertically, the diffracted light is focused onto the exit slit by the cylindrical mirror M3. The subsequent astigmatic refocusing of horizontal and vertical focus onto the

sample position in the reflectometer is performed by the toroidal mirror M4. Two systems for high order suppression provide a wide flexibility for light shaping upstream of the reflectometer:

1. The high order suppression system (HiOS) is a four mirror system with different coatings which can be inserted into the beam under selectable incidence angles to freely determine the high-energy cut-off.
2. The Filter and Slit Unit (FSU) houses a set of 12 absorber filters and slits and pinholes of different sizes upstream and downstream the filters for beam shaping and stray light reduction.

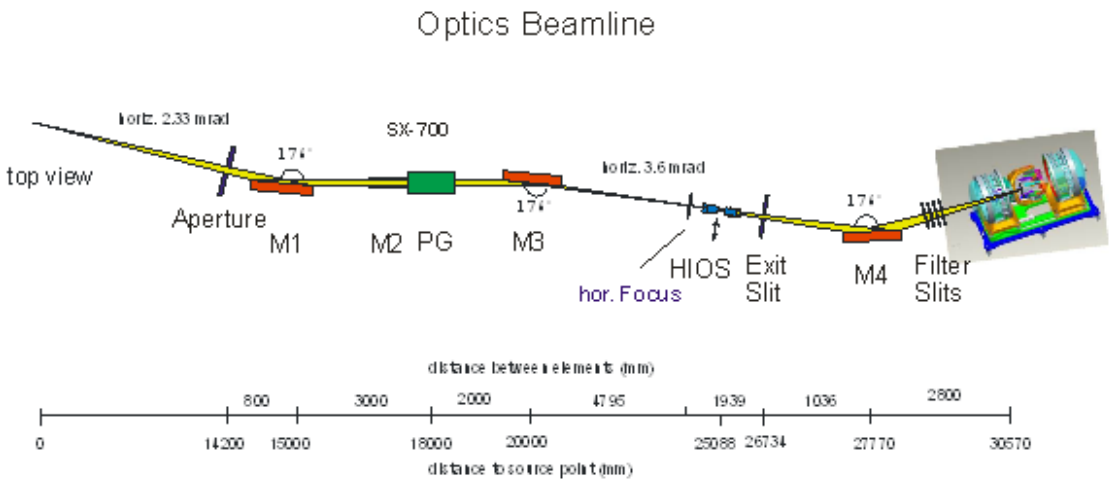


Figure 1: Optical layout of beamline PM-1 with Reflectometer end station

## 5 Beamline all-over Performance Data

| | |
|---|---|
| Location | Section DIP 1.1 |
| Source | Dipole |
| Monochromator (gratings) | SX700 (600 l/mm, 1200 l/mm) |
| Energy range | 10 eV - 2000 eV |
| Energy resolution | E/ΔE= 1000 - 10000 |
| Flux | $10^{10}$ - $10^{11}$ photons/s/100 mA |
| Polarization | horizontal-linear, elliptical |
| Divergence horizontal | 3.5 mrad |
| Divergence vertical | 0.5 mrad |
| Focus size (hor. x vert.) | 0.2 x 0.15 $mm^2$ |
| Fixed end station | 4-circle UHV-Reflectometer |
| Absorption filters | Mg, Al, Be, B, $C_6H_8$, Ti, Cr, Fe, Cu |
| HiOS mirrors coatings | Si, $AlF_3$, C |

Table 2: Performance data of Optics Beamline PM-1

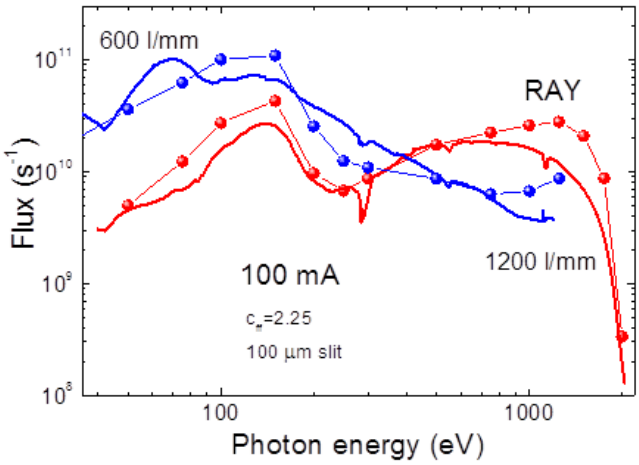


Figure 2: Photon flux at the sample position in the reflectometer, normalized to 100 mA ring current (blue (600 l/mm) and red curve (1200 l/mm)), in comparison with raytrace calculation with RAY (points). Typically BESSY-II runs with 300 mA.

## 6 Reflectometer

The reflectometer is coupled permanently to the Optics Beamline as a fixed end station. It is located in a moderate clean-room hutch. The UHV-optical bench comprises a four circle goniometer (two sample circles and two detector circles). The vacuum vessel has a diameter of 1 m and it can handle large samples up to 360 mm length and 4 kg weight. Smaller samples (e.g. wafers) will be mounted via a load lock system without breaking vacuum. Three circles are realized by HUBER-goniometers to set (1) the azimuthal angle $\Phi$ (s- or p-polarisation, respectively), (2) the incidence angle $\Theta$ and (3) the detector arm $2\Theta$. For off-plane sample scans (-4° - +4°) another motorized stage is hooked up onto the $2\Theta$-goniometer to realize the 4th circle. The six axes sample adjustment and positioning system is based on a compact UHV-tripod system. It allows a two-dimensional scan of the sample surface within a range of approximately +/- 15 mm while maintaining all rotational degrees of freedom within +/- 1°. A pointing stability of this system of better than 50 $\mu$m and 0.025° was reached. A couple of photodiode detectors with and without pinholes or apertures are available.

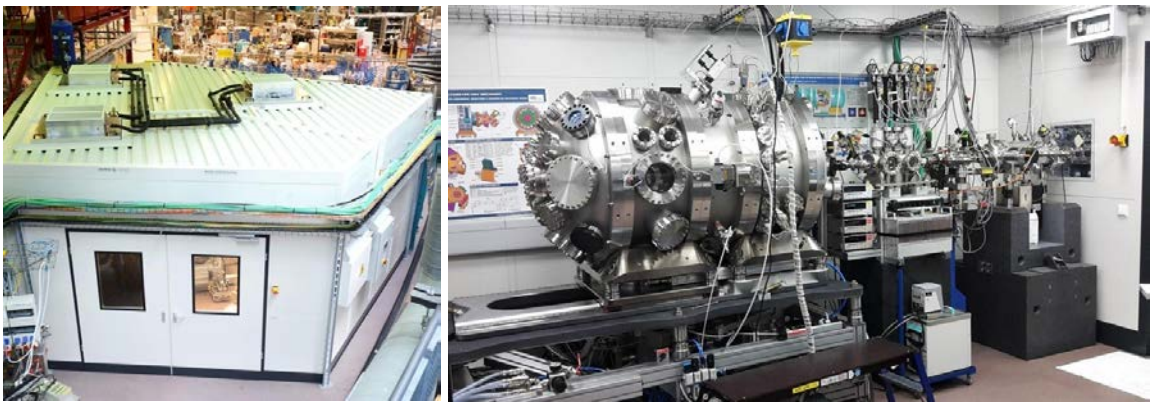

Figure 3: The clean-room hutch at the experimental floor of BESSY-II with the M4-mirror chamber, the Filter and Slit Unit (FSU) and the Reflectometer inside (Light comes from the right side).

## 7 Reflectometer all-over Performance Data

| | |
|---|---|
| Monochromator | Optics Beamline – PM1 |
| Experiment in vacuum | $10^{-9}$ mbar |
| Max. sample size | 360 x 60 x 60 $mm^3$ |
| Max. sample size for Load-lock | 50 x 50 x 10 $mm^3$ |
| Max. sample weight | 4 kg |
| Sample surface scan | 15 x 15 mm |
| Incidence angle scan range | $-180° \leq \Theta \leq 180°$ |
| Azimuthal angle scan range | $0° \leq \Phi \leq 360°$ |
| Detector scan range (in plane) | $-180° \leq 2\Theta \leq 180°$ |
| (off-plane) | $-4° \leq \Theta_D \leq 4°$ |
| Min. step size for all motors | 0.001° |
| Sample – Detector Distance | 310 mm |
| Detector | GaAsP-photodiode with Keithley electrometer 6517B |
| Detector size | 4 x 4 $mm^2$, slits or pinholes: 0.14 – 4 mm |

Table 3: Performance data of the reflectometer

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