The PolLux Microspectroscopy Beamline at the Swiss Light Source

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Abstract. The optical design and performance expectations of a Fresnel zone plate based scanning transmission x-ray microscopy (STXM) beamline at a bending magnet of the Swiss Light Source is described. The instrument allows microspectroscopy in polymer science in the water window and the study of magnetic materials with circularly polarized light. The beamline is based on a spherical grating monochromator with two gratings at a constant deviation angle and covers a photon energy range from 200 eV to 1000 eV.

Keywords: X-rays, microscopy, beamline optics, grating efficiency, zone plates
PACS: 07.85.Qe, 42.79.Dj

INTRODUCTION

PolLux is a new microspectroscopy facility at the Swiss Light Source (SLS). It is a joint project between SLS and German universities to offer spectroscopy with sub-micron spatial resolution for polymers, environmental science and magnetism. The beamline has been installed in spring 2006, first test experiments are scheduled for summer 2006.

During the last decade a number of reports appeared about zone-plate based scanning transmission x-ray microscopy (STXM) beamlines at other synchrotron's [1-5] which show the feasibility of the technique and instrumentation. Most of them use an insertion device to profit from the high brightness of the undulator source. This appears obvious since the spatial resolution of the zone plate is limited by the coherent phase space [6]. Winn et al. [4] showed the full spatial resolution of a zone plate is preserved for a phase space parameter $p \leq 1$.

$$p = \frac{s\,\theta}{\lambda}$$

s is the source width, θ the full acceptance angle of the zone plate and λ the wavelength.

We followed the basic concept of a comparable beamline of Warwick et al. [7, 8] at the Advanced Light Source (ALS BL 5.3.2). ALS successfully demonstrated the possibility to built a competitive instrument at a bending magnet without the complexity and costs of an insertion device beamline.

Our beamline has an extended energy range to give access to absorption edges of magnetic materials and the option to use circular polarized light. The monochromator mechanics is a new design, developed and built in house. The microscope is a commercialized version of Kilcoyne et al. [9] built by ACCEL. More details of the hardware can be found in the accompanying papers by Henein et al. [10] and Wiesemann et al. [11].

OPTICAL DESIGN

Two gratings in a simple spherical grating monochromator (SGM) in horizontal dispersion with constant deviation angle ($2\theta = const. = 175^\circ$) and stationary slits cover a photon energy range from about 200 to 1000 eV. The beamline layout is shown in Fig. 1. The toroidal mirror focuses the source to the entrance- and exit-slit respectively. The drawback of defocusing, unavoidable with the simple monochromator geometry, can be kept in a tolerable limit by a careful design of the geometrical parameters.

We consider the focusing term in the optical path function:

$$F_{200} = \left(\frac{\cos^2\alpha}{\overline{S_1G}} - \frac{\cos\alpha}{R}\right) + \left(\frac{\cos^2\beta}{\overline{GS_2}} - \frac{\cos\beta}{R}\right)$$

CP879, *Synchrotron Radiation Instrumentation: Ninth International Conference*,
edited by Jae-Young Choi and Seungyu Rah

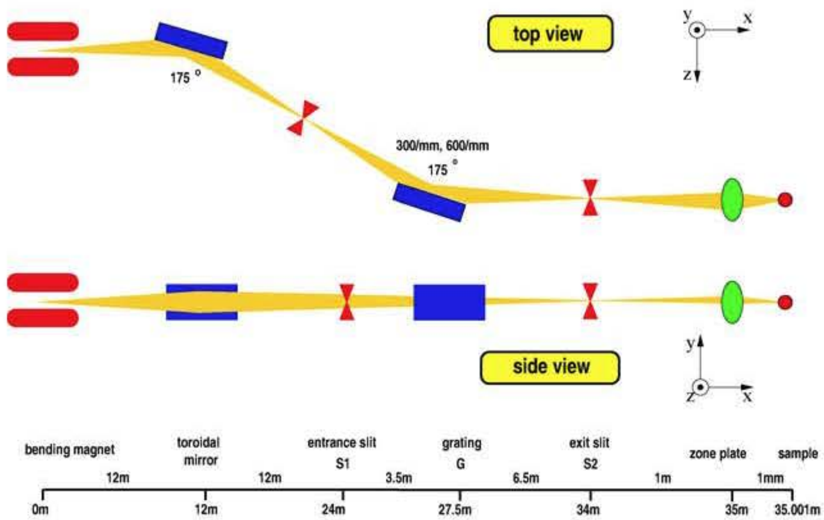

FIGURE 1. Layout of the PolLux beamline.

α, β are the angles of the incident and outgoing beam to the grating normal, $\overline{S_1G}$, $\overline{GS_2}$ the grating to slit distances and R the grating radius. To calculate the actual contribution to the path length, F_{200} has to be multiplied by $\frac{1}{2}w^2$, w is the aperture coordinate on the grating surface. This corresponds to a wavelength error:

$$\Delta\lambda = \frac{d}{m} w F_{200}$$

with the grating constant d and the diffraction order m. The results are shown in Fig. 2. Above 250 eV the absolute value of the defocusing is $< \pm 5$ nm and the related resolving power > 5000 for full illumination of the gratings. A summary of the parameters of the optics is given in Table 1.

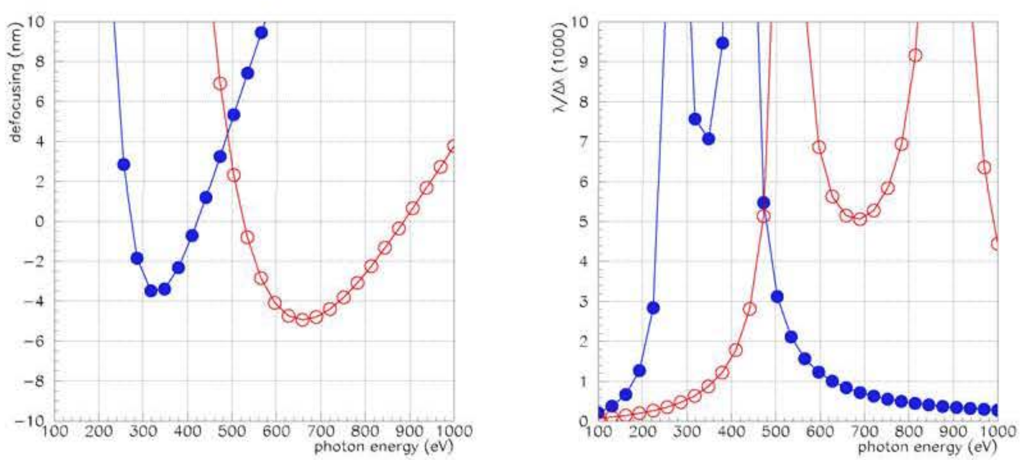

FIGURE 2. Defocusing and corresponding limit to the resolving power for the 300/mm grating (solid circles) and 600/mm grating (open circles), illumination: ± 45 mm.

TABLE 1. Selected data of the optical elements.

parameter	unit	mirror	grating 1	grating 2
shape	-	toroidal	spherical	spherical
position	(m)	12	27.5	27.5
heat load	(W)	30	< 2	< 2
max. heat load density	(mW/mm^2)	< 31	< 1	< 1
max. footprint (4σ)	(mm^2)	180×20	90×5	90×5
geom. surface size	(mm^2)	200×30	100×40	100×40
opt. surface size	(mm^2)	180×20	90×15	90×15
bulk material	-	Si	Si	Si
roughness (rms)*	(nm)	0.49	0.12	0.11
tangent error long axis (rms)*	(μrad)	1.63	0.47	0.48
tangent error short axis (rms)*	(μrad)	8.6	0.6	0.76
coating (thickness: 30 nm)	-	Pt	Ni	Au
source distance	(mm)	12000	3500	3500
image distance	(mm)	12000/22000	6500	6500
total deflection angle	(°)	175	175.035	175.035
direction of deflection	-	right	left	left
radius*	(mm)	275050/680	114900	114700
line density	(1/mm)	-	300	600
groove depth*	(nm)	-	27	10
groove width to period ratio*	-	-	0.53	0.74

* measured values

Circular Polarized Light

Circular polarized light is available without readjusting mirrors or apertures, it will be generated by a localized angular steering of the electron beam within the dipole magnet [12]. This is accomplished by means of the SLS fast orbit feedback system which allows to stabilize the electron beam to the micrometer level up to frequencies of 100 Hz. Due to the adapting coupling compensation involving dedicated adjacent skew quadrupoles this steering becomes practically transparent for the other beamlines. Polarization switching at a few Hz should be feasible.

Grating Optimization

We developed a two- step method where we first calculated the diffraction efficiency of the multi- parameter space of laminar and blazed gratings[1] with an adaptive grid. The evaluation of the results with a quality function of flux and higher order contribution etc. is done in a separate step. This approach decouples the time consuming efficiency calculations from the evaluation process and is a significant advantage over direct optimization. Thus, different quality functions[2] can be tested easily and in an efficient way. In addition one has access to the complete parameter space for "manual" verification or to produce cuts and overview maps. The results of step 1 can be reused for other gratings which may have completely contrary requirements. In our case we optimized for high average flux in combination with low higher order average. The results are summarized in Fig. 3. The figure shows the predicted relative transmittance of the beamline[3] in different diffraction orders and the higher order ratio for the selected gratings. The calculation includes the spectral distribution of the source with a fixed acceptance[4]. Geometrical losses at apertures and slits are not considered.

[1] Depending on the grating type and monochromator geometry one can optimize the coating material, blaze angle, groove depth, groove width to period ratio and total included angle (not all of them are always available or independent parameters).
[2] The quality function may depend on the photon energy.
[3] Without microscope i.e. vacuum window and zone plate.
[4] We choose (0.2 H $\times$ 0.4 V) mrad which corresponds to the phase space limited acceptance of the zone plate at 200 eV. Electron current: 400 mA.

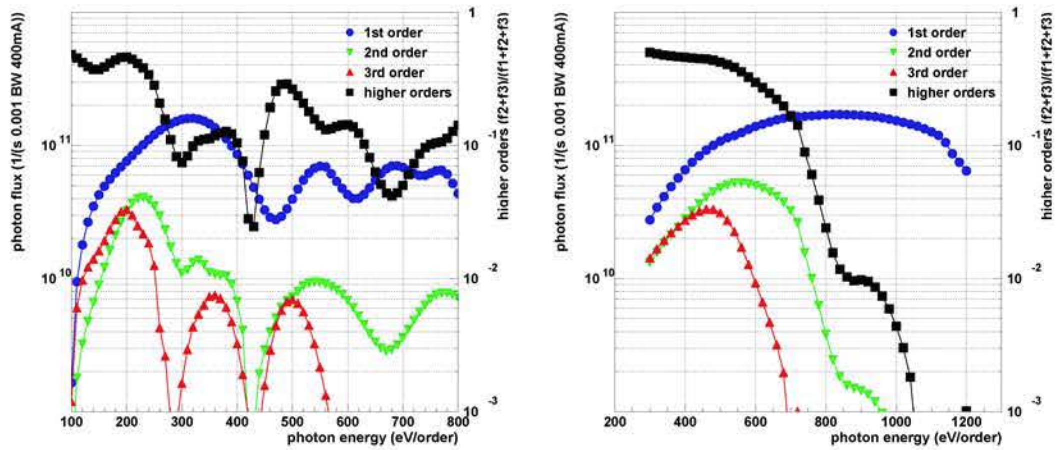

FIGURE 3. Predicted relative transmittance in different diffraction orders and higher order content of the beamline. 300/mm grating (left) and 600/mm grating (right).

ACKNOWLEDGMENTS

We acknowledge financial support through BMBF (project 05KS4WE1) and BaCaTec and thank BESSY for the permission to use their grating efficiency code REFLEC [13].

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