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A monochromator for scanning X-ray microscopy beamlines at third-generation synchrotron light sources

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A concept for a plane-grating monochromator for use at scanning X-ray microscopy beamlines at third-generation synchrotron light sources is presented. The design of the monochromator is optimized for a scanning transmission X-ray microscopy beamline at BESSY II. Ray-tracing calculations are presented which include geometric aberrations of the optics used in the beamline.

Keywords: monochromators; X-ray microscopy; beamline design; third-generation synchrotron light sources.

1. Introduction

Scanning X-ray microscopes for application in X-ray microscopy and microspectroscopy require X-radiation of high spectral brilliance. Therefore, undulator radiation provided by third-generation electron storage rings is well suited for these instruments. The monochromator described in the following was designed to be used for a scanning transmission X-ray microscope at BESSY II. To test its performance, the monochromator was combined with the scanning X-ray microscope at BESSY I.

To obtain the smallest possible X-ray microprobe the diffraction-limited focus of a micro-zone plate is used. The diameter of such a focal spot is limited by the width of the smallest zones of the zone plate. Preconditions to obtain a diffraction-limited focus are that only the spatially coherent part of the synchrotron radiation is used and that the aberrations of optical components in front of the zone plate are sufficiently small.

The performance of the optical system of the scanning X-ray microscope, comprising the monochromator and the micro-zone plate, was calculated by ray-tracing.

2. The monochromator

For high-resolution X-ray imaging in X-ray microscopes, as well as for submicrometer X-ray microprobes in scanning X-ray microscopes, micro-zone plates have, until now, been unsurpassed optical elements. Micro-zone plates need quasi-monochromatic radiation with $\lambda/\Delta\lambda \simeq N$ (where N is the number of zones of the zone plate). This results from the wavelength dependence of the focal length of a zone plate ($f \propto \lambda^{-1}$). For high-resolution X-ray microscopy, zone plates with N = 500–1000 are used. Some applications, however, require a higher monochromaticity; for XANES and EXAFS, for example, $\lambda/\Delta\lambda \gtrsim 1000$ is necessary. It is possible to meet these requirements with a fairly simple monochromator comprising two optical elements, namely a plane mirror and a plane grating. The optical set-up is shown in Fig. 1. The mirror prevents the grating from being illuminated directly with undulator radiation, and, in particular, cuts off short wavelengths. Additionally, the mirror offers the possibility of compensating for the deflection of the beam by the grating so that the optical axis of the microscope is not changed and the monochromator set-up can be incorporated in a straight beamline. A knife edge approaching the grating at its axis of rotation limits the effective area of the grating and thus allows the bandwidth of the radiation illuminating the zone plate to be adjusted (Sandström, 1957). The grating is used in the −1. diffraction order.

3. Ray-tracing calculations

To achieve a diffraction-limited focal-spot size of the zone plate, the illumination has to be spatially coherent. An undulator with a period length of 41 mm in a low-β section of BESSY II (J. Bahrdt, personal communication; BESSY, 1989) used as light source meets this condition. The coherently illuminated area at a distance of 30 m from the source is significantly larger than the size of the zone plate. To determine the optical performance of a beamline such as that shown in Fig. 1, ray-tracing calculations have been

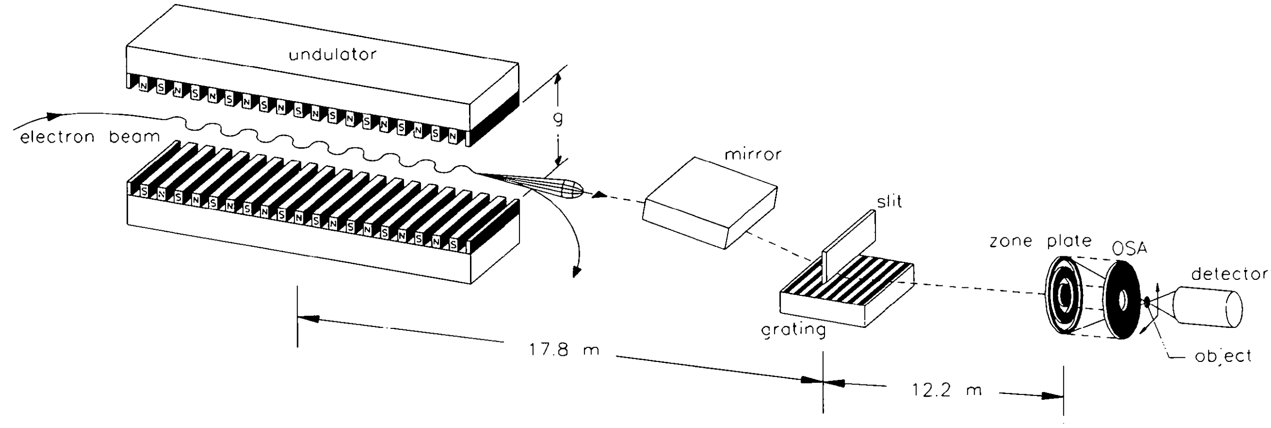

Figure 1
Optical set-up of the scanning transmission X-ray microscope.

Table 1
Geometric conditions for the ray-tracing calculations.

Source size ($\sigma_x \times \sigma_y$)	(82 × 30) μm²
Source divergence ($\sigma'_x \times \sigma'_y$)	(27 × 14) μrad²
Distance from undulator to grating	17.8 m
Distance from grating to zone plate	12.2 m
Grating-line density	600 lines mm⁻¹
Slit height	65 μm
Zone-plate diameter	56 μm
Smallest zone width of the zone plate	30 nm
Focal length of the zone plate at λ = 2.4 nm	701 μm

performed. Table 1 gives a list of the geometric conditions on which the calculations were based.

First, a grating with an ideal plane surface was assumed and then a slope error up to 2″ was introduced. The ray-tracing calculations yield the result that, at a total angle of deflection of 5°, a monochromaticity of $\lambda/\Delta\lambda$ = 1600 at λ = 2.4 nm can be achieved even with such slope errors. In addition, the ray-tracing calculations show that the geometric focus dimensions are much smaller than the diffraction-limited spot size.

Experiments with such a monochromator at a bending-magnet beamline at BESSY have shown that the theoretically estimated resolution and photon flux have been achieved (Irtel von Brenndorff, 1996; Thieme *et al.*, 1996). For the case of BESSY II we estimate diffraction-limited resolution and a photon flux of 10^9 photons s^{-1} in a focal spot of 30 nm.

4. Conclusions

The small source size and the long distance between the source and the experimental end station at third-generation synchrotron light sources like the ALS or BESSY II allow a very simple monochromator design for a scanning X-ray microscope. The use of a single plane grating with constant line density already fulfills the requirements of the experiments. The design of the slit, which is realized by a single knife edge approaching the grating at the center, greatly enhances the ease of alignment.

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