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# Construction of a scanning transmission X-ray microscope at the undulator U-41 at BESSY II

U. Wiesemann*, J. Thieme, R. Früke, P. Guttmann, B. Niemann, D. Rudolph, G. Schmahl

*Georg-August-Universität Göttingen, Institut für Röntgenphysik, Geiststr. 11, D-37073 Göttingen, Germany*

**Abstract**

A new scanning transmission X-ray microscope for the soft X-ray region is under construction at the BESSY II storage ring. The radiation from the undulator U-41 is monochromatized with a monochromator consisting of a plane mirror and a plane grating with varied line density. For a high resolution image, the zone plate is scanned with a piezoelectric flexure stage. The X-ray flux in the focal spot will be of the order of $10^9$ photons/s. The sample is located in air. A pn-CCD detector is used to measure the transmitted intensity. 

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## 1. Introduction

A scanning transmission X-ray microscope (STXM) acquires an image by scanning the sample with an X-ray microprobe generated by a Fresnel zone plate. In contrast to a directly imaging transmission X-ray microscope (TXM), there is no optical element between the object and the detector, which lowers the radiation dose required for an image. Although it is possible to reach spectral resolutions of a few thousands with a TXM, a STXM achieves this goal with a much simpler optical setup and is therefore a very well suited tool for spectromicroscopy. Using NEXAFS spectra, chemical maps of the sample can be derived. At the undulator U41 at BESSY II, a new STXM is under construction [1]. It will be used for a wide variety of spectromicroscopy applications, including environmental sciences, soil sciences and water chemistry.

## 2. The monochromator

The monochromator consists of a plane mirror and a plane grating without entrance and exit slits [2]. The grating has a varied line density to prevent a loss of monochromaticity due to the divergence of the beam [1]. The mirror adjusts the angle of deflection when changing the wavelength over a larger range. For smaller wavelength changes, e.g. to obtain a spectrum at an absorption edge, only

*Corresponding author. Tel.: +49-0551-39-9429; fax: +49-0551-39-9430.

*E-mail address:* uwiesem@gwdg.de (U. Wiesemann).

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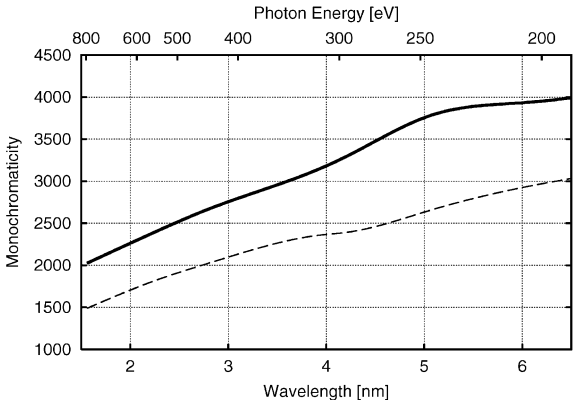


Fig. 1. The expected spectral resolution of the monochromator for a grating of 600 lines/mm (dashed line) and of 1000 lines/mm central line density, calculated with ray tracing simulations.

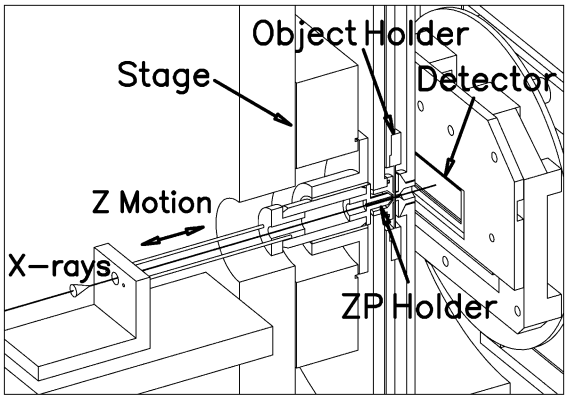


Fig. 2. Schematic of the object area. The object is located in air between the vacuum chambers of the zone plate and the detector.

the grating is rotated. The grating pattern is exposed holographically as an interference pattern of a convergent and a divergent spherical wave. The pattern is transferred into a germanium layer by reactive ion etching. To enhance the grating diffraction efficiency, the germanium layer is coated with nickel. According to ray tracing simulations, the spectral resolution is between 1500 and 3000 for a 600 lines/mm grating and between 2000 and 4000 for 1000 lines/mm (Fig. 1).

## 3. The object area and the scanning stage

Fig. 2 shows a schematic of the object area of the microscope. The object is located in an air gap of a few hundred $\mu$m between the vacuum chambers of the zone plate and the detector. The object holder can be moved with stepper motors to acquire an overview image of the sample and to move it to an interesting position for a high resolution scan. The detector chamber can be moved out and a visible light microscope can be inserted for previewing and optical alignment. High resolution images are obtained by scanning the zone plate with a Queensgate NPS-XY-100A piezoelectric flexure stage. The scanning motion is continuous, because the settling time of the stage is longer than the projected scan speed of 1 ms/pixel. For an image of 40 nm resolution and a step size

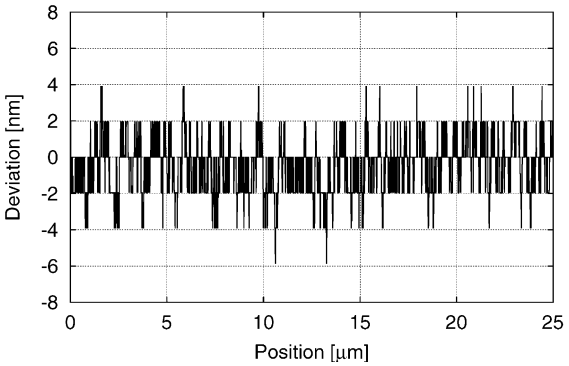


Fig. 3. Repeatability of the scanning stage: Difference between two subsequent scan lines.

of 20 nm, this means an acceptable decrease of resolution of 2 nm.

To test the accuracy of the stage motion, the x position was measured during a scan using a Heidenhain position encoder with 2 nm resolution. The repeatability, measured as the position difference between two consecutive lines, determines the resolution and the signal-to-noise-ratio of the image. Non-linear but repeatable deviations of the scanner from the commanded position appear as distortions of the image and can be corrected. The repeatability is about 1.5 nm RMS (Fig. 3), the maximum deviation from the linear motion is about 30 nm (Fig. 4).

Zero order light from the zone plate is blocked from the object using an order sorting aperture

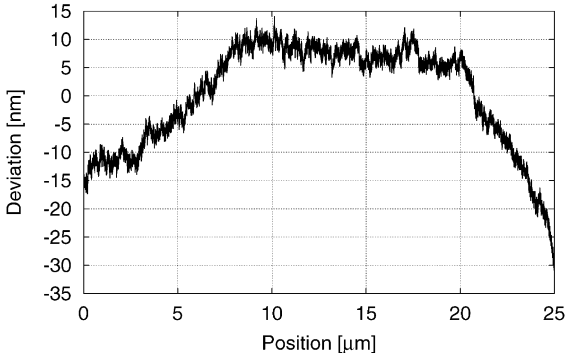


Fig. 4. Non-linear residuals of the scanning stage: Difference between the commanded and the measured position of one scan line.

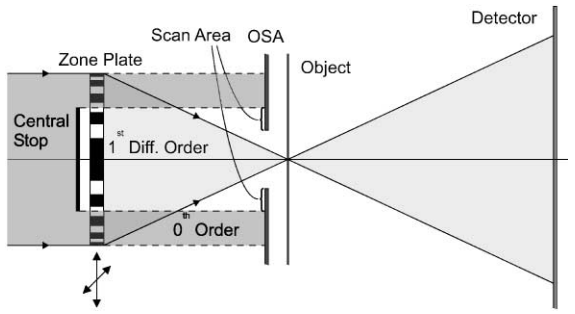


Fig. 5. Schematic optical setup of the microscope. The OSA is fixed, so the high resolution scan range of the zone plate is restricted to about $20 \times 20\ \mu m^2$.

(OSA) together with a central stop on the zone plate. The fixed exit window acts as OSA. This setup restricts the image field for a high resolution scan to about $20 \times 20\ \mu m^2$ (Fig. 5), but this construction has the advantage that the OSA does not have to be scanned together with the zone plate. The photon rate in the focal spot is expected to be of the order of $10^9$ photons/s. The microscope and the monochromator are controlled by standard personal computers using the RTLinux real time operating system.

## 4. The detector

The transmitted intensity is measured using a back-illuminated pn-CCD detector developed by the MPI für Extraterrestrische Physik [3]. Its transfer electrodes and on-chip read out circuits are insulated using pn-junctions instead of MOS structures to reduce radiation damages. The detector is operated in a continuous mode, where one of the 200 lines with 64 pixels each is read out every 25 μs. Typically, a spot of $10 \times 10$ pixels is illuminated, which means a minimum pixel dwell time of the microscope scan of 0.25 ms. In this case, the detector can measure the expected $10^8$ photons/s (assuming 10% transmission of the object) with an extremely low noise level of below 10 electrons. An advantage of the position resolution of the CCD is the possibility to use it as a configured detector for dark field or phase contrast imaging [4].

## Acknowledgements

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