The New Scanning Transmission X-Ray Microscope at BESSY II

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Abstract. A new scanning transmission X-ray microscope (STXM) is under construction and will be operated at the undulator U41 of the BESSY II storage ring. In the monochromator without entrance or exit slits, a plane grating with variable line density is used. A spectral resolution of 2200 to 6500 is expected in the energy range of 680 eV to 200 eV. The sample is located in air so it can be exchanged easily. The photon rate in the focus will be of the order of $10^9$ s at a monochromaticity of 3000. A pnCCD capable of handling this rate will be used as a detector.

INTRODUCTION

Scanning transmission X-ray microscopes obtain images by scanning the sample with a scan spot generated by a Fresnel zone plate. The illumination of the zone plate has to be monochromatic and spatially coherent in order to get a diffraction limited focal spot size, so a source of high spectral brilliance is needed. Existing scanning microscopes are used in a wide variety of applications, including environmental science, materials science and biology. A summary of these applications can be found in [1]. A new STXM will be installed at the BESSY II storage ring. The schematic of the microscope is shown in Fig. 1. Planned research activities are among others in environmental and soil sciences, water chemistry and geochemistry.

THE SOURCE

The new microscope will be operated at the undulator U41 which is installed at a low beta section of the BESSY II storage ring [2]. The undulator covers a photon energy range of 172 eV to 596 eV in the first and 518 eV to 1340 eV in the third harmonic. Its spectral brilliance is about $10^{18}$ photons / s mm$^2$ mrad$^2$ 0.1% BW. The size of the source is $\sigma_x = 84.3 \mu$m in the horizontal and $\sigma_y = 21.7 \mu$m in the vertical direction. The microscope is located at a distance of 37 m from the undulator. Due to the small source size and the long distance between the zone plate and the source, a zone plate with a diameter of 200 $\mu$m is illuminated coherently, so there is no need to form a smaller source with a pinhole.
THE MONOCHROMATOR

The monochromator is very similar to the one used in an earlier STXM at BESSY I [3]. It consists of a pre-mirror and a plane grating (Fig. 2). To prevent a loss of monochromaticity due to the divergence of the beam, the line density of the grating is varied. The diffraction order -1 is used because of its high dispersion and the reduction of the vertical beam diameter. To acquire a spectrum of a small wavelength range, only the grating is turned. To adjust the angle of incidence when scanning over a larger range, the mirror is moved. It is suspended excentrically under the axis of the grating, so it does not have to be shifted along the beam axis. The undulator emits radiation in higher harmonics in addition to the desired wavelength. A part of this unwanted radiation is diffracted by the grating and the zone plate in higher orders of diffraction and also illuminates the sample. To prevent this spectral pollution, the mirror is coated with nickel which has a low reflectivity at shorter wavelengths.
The small source size of the undulator U41 and the variable line density of the grating make it possible to have a setup without entrance or exit slits. This keeps the alignment procedure. Ray tracing simulations show that monochromaticities of several thousands can be achieved (Fig. 3). The measured slope error of the grating substrate is 0.36". Even at higher slope errors, the spectral resolution is still sufficient for NEXAFS measurements and to illuminate the zone plate with a monochromaticity higher than the number of zones. Due to the limited area of the grating illuminated by the beam, the monochromaticity is limited to about 6500.

**THE MICROSCOPE UNIT**

The sample is located in air and thus can be exchanged easily. It is possible to remove the detector vacuum chamber and insert a visible light microscope for optical alignment, sample inspection and focusing. The object can be moved with step motors to obtain a large, low resolution X-ray image and to move it to an interesting location for a high resolution scan. The high resolution scan is performed by moving the zone plate in vacuum by a piezo driven X-Y flexure stage, which can be shifted along the beam axis for focusing. An order sorting aperture (OSA) is used together with a central stop to prevent light of the 0th order of diffraction of the zone plate from reaching the sample (Fig. 4).
The OSA is identical with the exit window. It does not have to be scanned together with the zone plate. This setup restricts the area for a high resolution scan to approximately 20×20 μm². In order to have comfortable working distances between zone plate and the object, large zone plates with long focal lengths are used (Tab. 1). The total length of the beam path in air is only a few hundred micrometers. The estimated photon rate in the focus is about 10⁹/s. The scanning motion of the zone plate, the object stage, the detector, the monochromator and the vacuum system will be controlled by computers running the Linux operating system with the RTLinux real time extension.

### THE DETECTOR

The transmitted photons are detected using a back illuminated pn-charge coupled device (pnCCD) developed by the MPI für Extraterrestrische Physik [4]. A whole line of the CCD is read out in parallel to allow very fast readout with low noise. The gate structures on the CCD chip are isolated from the light sensitive silicon by pn-junctions instead of SiO₂, which improves the radiation hardness. The detector is read out in a continuous mode, where one CCD line is read every 25 μs. If an area of 10 × 10 pixels is illuminated, the detector is able to detect 10⁹ photons/s with a noise level below 10 electrons per CCD pixel.
An advantage of the position resolution of the pnCCD is the option to use it as a configured detector [5]. It is possible to reconstruct images with different contrast mechanisms from the data obtained in a single scan. One can implement phase contrast imaging by taking the intensity difference between the left and the right detector part as the signal. By counting only the photons outside of the bright field cone, a dark field image is generated.

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