First differential phase contrast results from PolLux

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Abstract. We report on the design and performance of the PolLux soft x-ray scanning transmission x-ray microscopy (STXM) instrument, which has been installed at the X07DA bending magnet beamline of the Swiss Light Source. Although PolLux started routine user operation in 2006, new features like differential phase contrast imaging have recently been implemented to broaden the experimental possibilities.

1. Motivation

X-ray microscopy has developed into a routine technique at many synchrotron facilities. In the soft x-ray regime, scanning-transmission x-ray microspectroscopy (STXM) allows combined spectroscopy and microscopy of soft matter, environmental samples and mesoscopic magnetic structures. In addition to elemental and chemical imaging, linear or circular polarization is routinely used to visualize molecular orientation, and magnetic order.

Differential phase contrast (DPC) is an additional feature now available at the PolLux STXM. This provides significant enhancement of image quality, reduced radiation damage and allows observation of minute differences in the refractive index that are not detectable in pure absorption experiments. Although DPC is quite common in hard x-ray imaging with coherent beams, it is rarely used in soft x-ray microscopy, mainly due to complications in the detection of soft x-rays. DPC is implemented in the STXM X1A at Brookhaven [1] using a segmented x-ray detector, and in the TWINMIC end station at ELETTRA via a fast read-out CCD camera [2]. We have realized a DPC setup similar to that at TWINMIC for the PolLux instrument and present here the current performance of PolLux with first examples of DPC detection.

2. PolLux Beamline and Experimental Station

In the PolLux STXM a Fresnel zone plate (FZP) focuses the x-rays to a diffraction limited focus ($\varnothing_{\text{focus}}$ ~ tens of *nm*). Images are acquired by raster-scanning the sample through the focus while measuring the transmitted intensity, I_{trans}, with a relatively large x-ray detector ($\varnothing_{\text{detector}}$ ~ hundreds of μm). Variation of the photon energy, E, the polarization, $\vec{P}$, or sample parameters such as the temperature, T, allows recording multidimensional datasets, e.g. $I_{trans}(x, y, E, \vec{P}, T,\ldots)$. These are analyzed by comparison to the well-known absorption edges of the elements and to reference samples, thus providing quantitative information about the elemental composition, chemical bonding, sample morphology and magnetic order.

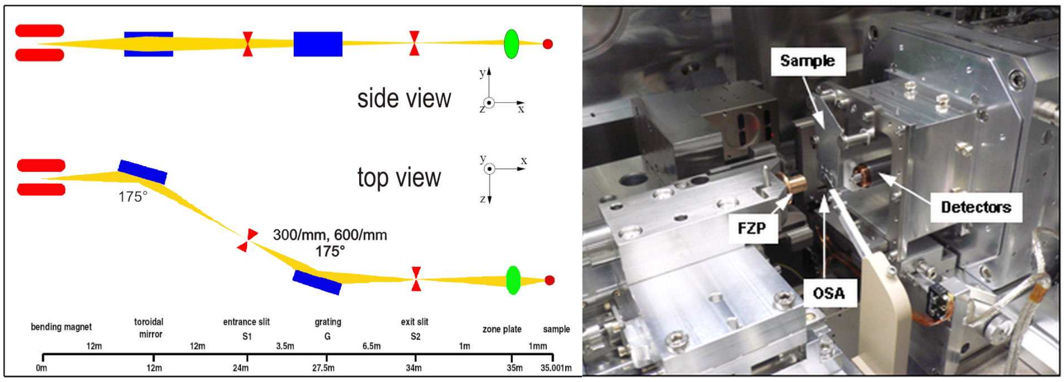

Figure 1. Left: Sketch of the beamline layout, based on a spherical grating monochromator. Right: Image of the microscope interior with the major components labelled.

The PolLux instrument is installed at bending magnet beamline X07DA of the Swiss Light Source (Villigen, Switzerland). Its design is based on the STXM installed at BL 5.3.2 of the Advanced Light Source (Berkeley, USA) but includes several substantial improvements. The beamline allows a choice of two monochromator gratings in order to provide an extended photon energy range (200 - 1400 *eV*), while still providing high flux and resolution for the study of transition metal samples and their magnetism. The SLS provides excellent stability of the electron beam in terms of intensity, through its top-up mode, and in terms of position, via a fast orbit-feedback system. The user can introduce local vertical tilt of the storage ring orbit to provide circularly polarized light, without disturbingother beamlines. The helicity can presently be switched (both left or right) within less than 1 *sec* which greatly reduces long term drift effects between images.

The optical layout of the beamline is shown in *Fig. 1 (left)*. A horizontally deflecting toroidal mirror creates a horizontal focus of the source at the entrance slit, *S1*. In the vertical direction the source is imaged by the toroidal mirror onto the exit slit, *S2*. The monochromator, with either of ist two spherical gratings (300 *lines/mm* and 600 *lines/mm*), creates dispersion in the horizontal plane. The exit slit (*S2*) is the source for the Fresnel zone plate (FZP). Details of the design and performance are provided in refs. [3],[4].

A photograph of the PolLux instruments sample environment is shown in *Fig. 1 (right)*. The FZP focuses the light into a diffraction limited spot. Higher diffraction orders are filtered out using an order-sorting aperture (OSA), located between the FZP and the sample. Samples are usually prepared on either semitransparent silicon nitride membranes, or transmission electron microscope grids. The intensity of the transmitted x-ray beam is measured by a detector behind the sample. For standard absorption measurements two detectors are available, a photodiode and a photomultiplier (coupled to a scintillator). The instrument has already demonstrated spatial resolution below 20 nm [5].

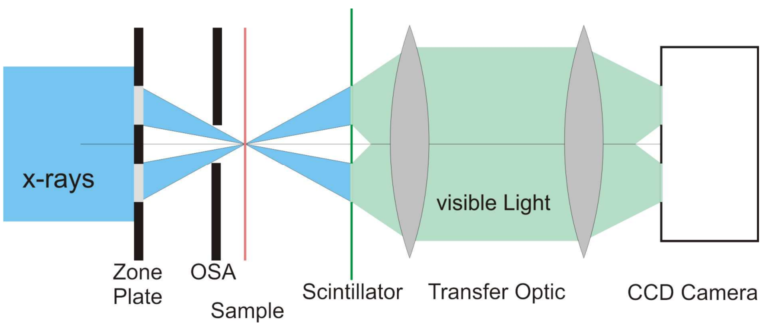

Figure 2. Optical layout of the DPC mode showing the scintillator and the transfer optics used to image the x-ray image on a CCD camera with high read out speed.

3. Differential Phase Contrast Imaging at PolLux

In the standard mode of operation, a STXM records the integrated intensity of the transmitted x-rays, thus providing the local absorption coefficient of the sample at each pixel. Extending the detection system to a spatially resolved detector provides access to phase contrast. At PolLux this is realized by

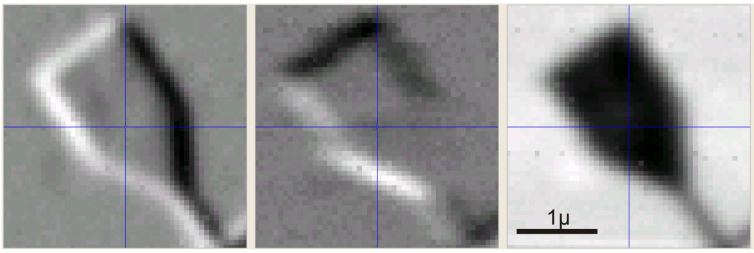

Figure 3. Image of a test pattern (100 nm thick Gold on a silicon nitride membrane), recorded at E = 1 keV. Images on the left and in the centre show differential phase contrast in the horizontal and vertical direction, respectively. The right image shows the conventional absorption contrast.

first converting x-ray image transmitted by the sample into visible light via a scintillator. This image is then transferred onto a CCD camera using intermediate optics (Fig. 2). For a homogenous sample the image on the CCD has the shape of a bright ring, representing the zone plate with its central stop. In the presence of a phase gradient in the sample, this ring is deflected. We calculate this deflection by defining four areas on the detector and by performing a four-quadrant detection in software. The two asymmetry signals measure the horizontal and the vertical phase gradient of the sample, respectively. Details on the realization of a segmented detector and the calculation of the asymmetry signals can be found in [1] for a segmented diode, and in [2] for segmentation in software using a CCD detector. The standard absorption signal is given by the integrated intensity of the CCD detector (Fig. 3).

It should be noted that the CCD image contains even more information about the sample structures in the x-ray focus. This diffraction information can be obtained by application of phase retrieval algorithms [7] and will be the focus of further work on the PolLux instrument.

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