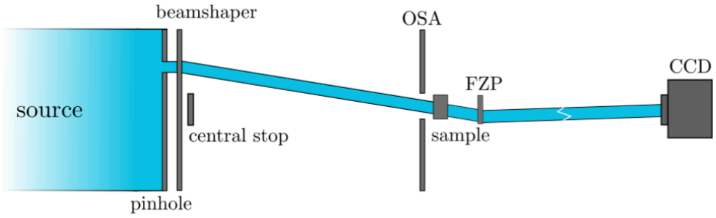


SLS Symposium on

Optics and scanning techniques

Tuesday, Mai 09, 2017

10:00 to 12:15, WBGB/019

10:00 Towards Zone Plates with sub-10 nm Resolution
Benedikt Rösner, B. Watts, J. Raabe, M. Meyer, R. H. Fink and C. David

10:30 Recent developments in high-efficiency kinoform optics for hard X-rays
Maxime Lebugle, F. Marschall, G. Seniutinas, V. A. Guzenko, D. Grolimund, and C. David

11:00 Coffee

11:15 X-Ray Fourier Ptychography
Klaus Wakonig, A. Diaz, A. Bonnin, J. Ihli and A. Menzel

11:45 Scanning-SAXS microscopy: higher dimensionality, information level and reconstruction complexity
Viviane Lutz-Bueno, M. Guizar-Sicairos, A. Diaz, J. Kohlbrecher, O. Bunk and A. Menzel

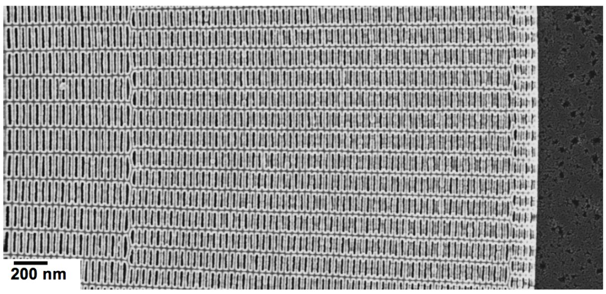
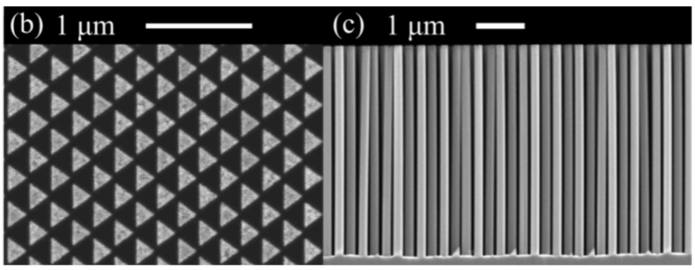


Figure 1: Fresnel zone plate with line-doubled iridium zones of 9 nm line width.



Towards Zone Plates with sub-10 nm Resolution

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Abstract

Fresnel zone plates are widely used as lenses in both full-field and scanning probe X-ray microscopy [1]. The diffraction-limited spot size of a Fresnel zone plate is generally in the order of the outermost zone width (by a factor of 1.22 larger). While conventional lithographic processes for zone plate fabrication break down at feature sizes below 20 nm [2], line-doubling techniques have been developed to produce smaller nanostructures. Thus, zone plates with outermost line widths of down to 12 nm have been demonstrated. [3,4]

Targeting sub-10 nm resolution, zone widths have to be decreased to 8 nm or below. Pushing the limits of electron beam lithography and atomic layer deposition, we have successfully fabricated a set of zone plates with outermost zone widths of 8.8, 8.0, 7.2 and 6.4 nm for use at the L-edges of first-row transition metals, between 700 eV and 1000 eV. All of these zone plates have been characterized at the Pollux scanning transmission X-ray microscope, and showed first-order diffraction efficiencies between 1% and 5%. Whereas detailed analysis is ongoing, the resolution approaches the theoretical limit.

However, a set of new challenges comes along with these highly resolving zone plates. If reasonable working distances should be maintained, the diameter has to be kept above approx. 200-250 µm, and number of zones approaches 10^4. This implies more stringent requirements in terms of monochromaticity as well as in a source size which has to be small enough to ensure coherent illumination. For the latter, the availability of new low-emittance light sources will provide a major benefit for the usability of such highly resolving zone plates.

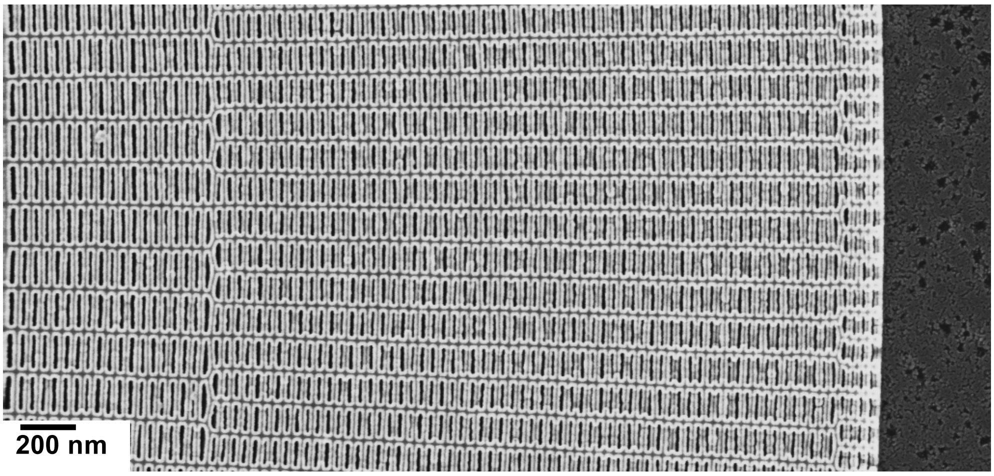

Figure 1: Fresnel zone plate with line-doubled iridium zones of 9 nm line width.

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Recent developments in high-efficiency kinoform optics for hard X-rays

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High-efficiency diffractive optics for hard X-ray photons with energy in the range 7-20 keV are notably difficult to realize. Most materials present a low refractive index contrast, making it difficult to efficiently manipulate light since the required material length to obtain significant phase shift is long. Additionally, binary gratings are often used, which have a maximum efficiency of 40.5% for the 1st diffraction order. To circumvent these limitations we recently developed optics based on the kinoform phase profile, which theoretically can diffract up to 100% for lossless material (see Fig. 1(a)) [1]. This class of optics provides a continuous phase profile for diffraction, here approximated by periodic arrays of triangular elements (see Fig. 1(b) and (c)).
In this talk I will describe recent developments in kinoform lenses for a high-efficiency microfocus module currently under commissioning at the PXII beamline (SLS). Our module is based on 2 crossed kinoform 1D lenses made of silicon, which provides high flexibility in the focusing conditions and generates a focal spot size in the micrometer range with total efficiency of ~25% at 12.4 keV. Recent results on kinoform beamsplitters [3] will also be presented, which are splitting gratings with dynamical splitting ratio and tunability in photon energy. Experiments realized at the microXAS beamline (SLS) showing hard X-rays splitting with high efficiency (more than 60% at 12.4 keV) and high extinction ratio (less than 1%) will be shown.

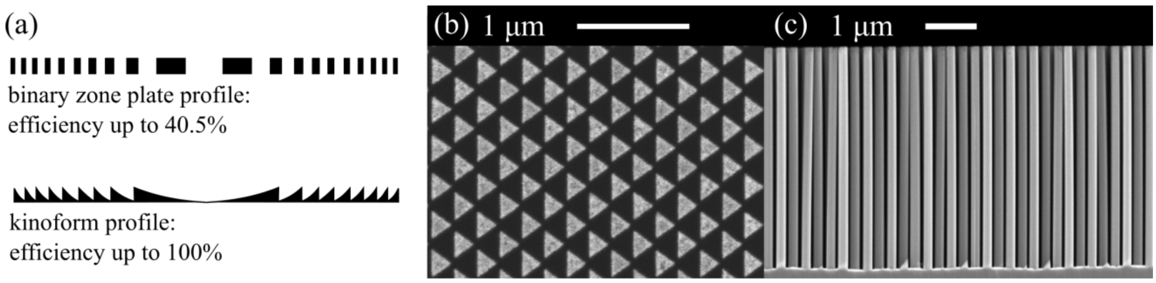

Fig. 1: (a): Binary and kinoform phase profiles sketches. (b,c): Scanning electron micrograph of kinoform lenses with 200 nm pitch, showing the (a) top view and the (c) cross section of triangular kinoform elements in silicon.

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X-Ray Fourier Ptychography

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The low efficiency of X-ray zone plates with high numerical apertures is an unavoidable limitation of state-of-the-art X-ray microscopy setups. Although Fresnel zone plates can be used to acquire images of nanometer resolution[1], the delicate fabrication of increasingly smaller outermost zone widths and their high absorption are limiting their usability. For enhanced contrast, especially in case of weakly absorbing materials, Zernike phase contrast is widely used. However, the additional accommodation and alignment of phase dots or phase rings in the imaging setup further complicates matters.

In visible-light microscopy, promising results have been achieved using Fourier ptychography, a recently developed imaging technique, to extend significantly the numerical aperture of conventional optical lenses[2]. In contrast to a Zernike microscopy setup[3,4], no additional optical elements have to be used to acquire images of both phase and absorption contrast. Existing X-ray microscopy setups could therefore be modified to host two different imaging methods: conventional X-ray (Zernike) microscopy for fast acquisition with lower resolution and X-ray Fourier ptychography for samples whenever high resolving power is needed.

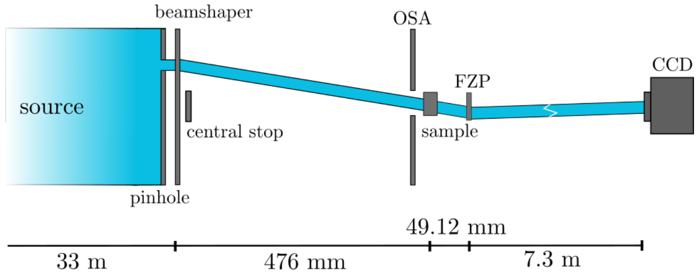

Figure 1: Schematic drawing of a Fourier ptychographic setup at the cSAXS beamline. A 1 mm beamshaper and a 100 µm Fresnel zone plate were used as condenser and objective lens of the X-ray microscope respectively. The condenser was illuminated with a coherent beam at 8.7 keV.

Here we present a proof-of-principle study[3] and demonstrate how X-ray Fourier ptychography can be used to create a large synthetic Fresnel zone plate while providing phase contrast without major changes to a modern X-ray microscopy imaging system.[4,5] This is achieved by acquiring series of images at predefined illumination angles, as shown in figure 1. Established ptychographic iterative reconstruction algorithms[6,7] are then used to obtain both phase and amplitude of the sample transmissivity with a resolution much better than that obtained in each single measurement.

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Scanning-SAXS microscopy: higher dimensionality, information level and reconstruction complexity

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Nature builds materials with excellent mechanical properties from weak building blocks. This hierarchical structuring is applied successfully in materials science for artificial and bio-mimetic materials. Visual analysis of such samples through microscopy is fundamental to discover relationships between structure, shape and function of multiphase hierarchical materials. A current limitation of microscopy is the poor differentiation, identification and quantification of phases and building blocks without non-destructive contrast enhancement of the sample. The lack of methodology to automatically classify and quantify sample composition and its phase distribution hinders the understanding and tuning of structure-property relationships. The signal of small-angle X-ray scattering SAXS is originated from the interaction of matter with light, as a signal sensitive to the sample's electronic composition and structure, covering the length scale range – from a few Angstroms to a few micrometers – ideal to probe hierarchical materials. In this talk we show the development of microscopy and tomography for scanning-SAXS methods at cSAXS, including data analysis routines for automated phase identification, segmentation and quantification. Improvements in synchrotron brilliance, detector acquisition and data science are part of our essential "toolbox" to deal with large data sets, especially for scanning measurements, which still require a compromise between resolution, sample size and feasible measurement times. To improve the beamline efficiency, we discuss an approach to reduce the number of projections needed for SAXS tensor tomography reconstruction, as the tomogram is reconstructed iteratively during measurements, so that the decision on data amount is performed online, avoiding measuring more projections than necessary.