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Multilayer Fresnel Zone Plates for X-ray Microscopy

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Scanning transmission X-ray microscopy (STXM) is a powerful technique that allows chemical, structural and elemental specific characterization of materials with resolutions down to about 10 nm where the quality of the focusing optic is the limiting factor. The setup of a STXM is shown schematically in Figure 1.

Among all optics the Fresnel zone plates (FZP) are one of the most popular optics in X-ray microscopy. A Fresnel zone plate, in its simplest form, is a set of concentric rings of alternating transparent and opaque nature. These rings constitute the zones of the FZP whose radii follow the relationship $r_n = \sqrt{n\lambda f + n^2\lambda^2/4}$ where r_n is the radius of the nth zone, λ is the wavelength and f the focal distance. The resolution = R depends on the outermost zone width, Δr_n.

With the improvement of the FZPs and new X-ray sources, laboratory size X-ray microscopes, which do not need synchrotron radiation, recently became available. However to be able to compete with synchrotron sources, laboratory size X-ray microscopes need better focusing optics with higher efficiencies and resolutions at high energy radiation. The standard e-beam lithography based techniques for the FZP fabrication fail to deliver the needed high aspect ratios for high efficiencies and high resolutions at harder X-rays. Our research is focused on a new fabrication method that can deliver the required aspect ratio. In this method a nanometer smooth bare glass fiber is coated with alternating layers of materials to serve as opaque and transparent zones, by using the atomic layer deposition technique (ALD). The ALD is a very precise thin film deposition technique that can handle the extremely fine layer positioning accuracy required for this application. Virtually unlimited number of Multilayer FZPs (ML-FZPs) can be sliced out of the fiber by using a focused ion beam. This is depicted in Figure 2a and 2b. The ML-FZP thicknesses can be varied and optimized to the desired X-ray energy.

We recently resolved 21 nm structures of a test sample as well as the innermost 30 nm structures of a Siemens Star test structure (see Fig. 3a) with an Al_2O_3-Ta_2O_5 FZP of outermost zone width, $\Delta r = 35$ nm and diameter, d = 38 μm at 1.2 keV [3]. This is, to date, the highest imaging resolution achieved by a ML-FZP to the best of our knowledge. In the hard X-ray range at 7.9 keV a sub-30 nm FWHM (full-pitch) resolution, was deduced from an autocorrelation analysis [3]. Besides improving the resolution by fabricating thinner zones, our research also covers new material couples for higher efficiencies that would compensate the efficiency losses due to volume effects for $\Delta r < 25$ nm. Furthermore, higher efficiency would also allow higher signal to noise ratio and faster imaging. In this work we also discuss the performance of such a new material couple, Al_2O_3-HfO_2. The calculated efficiency of a lens made out of Al_2O_3-HfO_2 as a function of X-ray energy and ML-FZP thickness is shown in Figure 3b.

References:

[1] D.T.Attwood, "Soft x-rays and extreme ultraviolet radiation: principles and applications", Cambridge Univ Press, New York (2000).

[2] M. Mayer *et al*., Ultramicroscopy **111** (2011) 1706-1711

[3] K. Keskinbora *et al*., Optics Express, **22** (2014), 18440-18453.

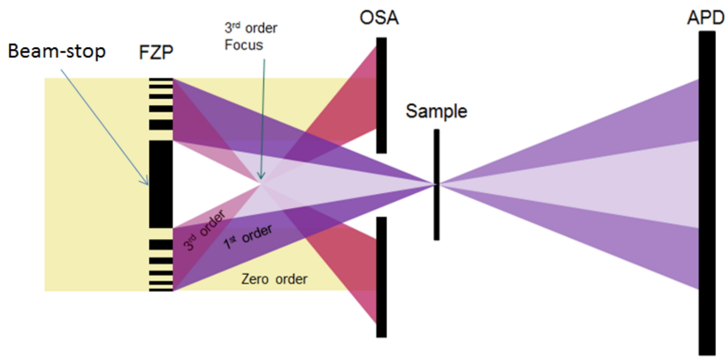

Figure 1. Schematic of STXM imaging setup. The order selecting aperture OSA eliminates unwanted diffraction orders. The sample is raster scanned and the transmitted light is collected by an APD.

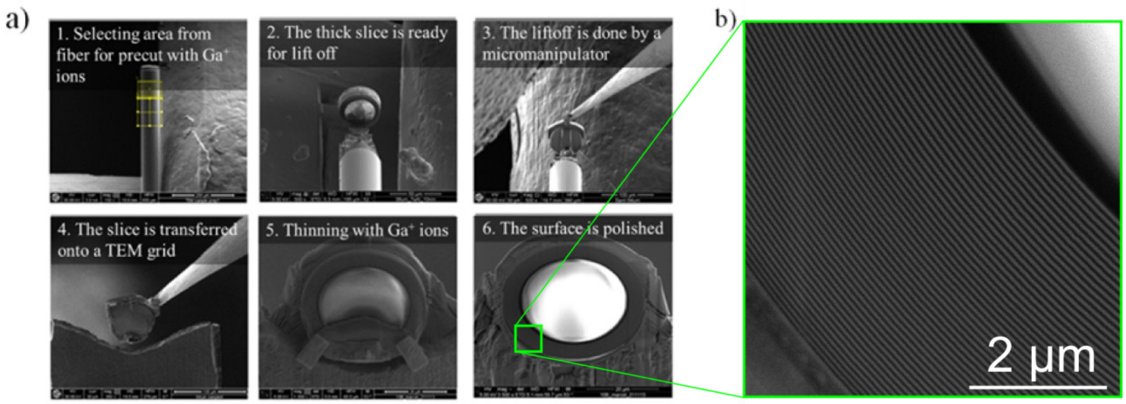

Figure 2. a) 6 step FIB slicing and polishing of ML-FZPs and **b)** SEM image showing excellent surface and zone quality.

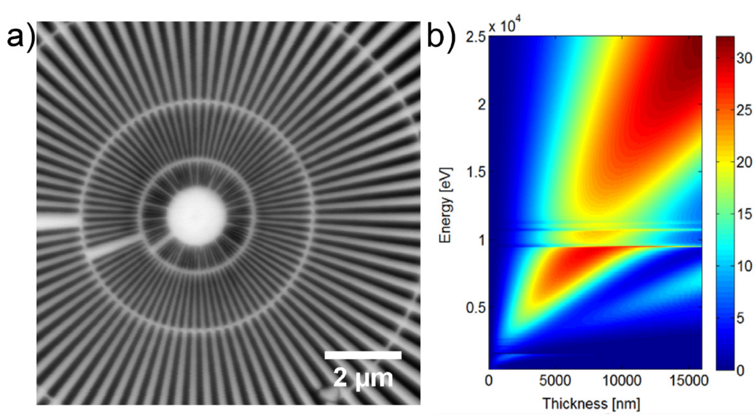

Figure 3. a) STXM image of a Siemens Star test pattern. The 30 nm features of the inner circle are clearly resolved. **b)** Calculated efficiency of an HfO_2-Al_2O_3 FZP.