A.10: Fabrication of Fresnel Zone Plates for X-ray focusing

Focusing of x-rays is difficult, as the refractive index (n) approaches unity in this regime. The refractive index of a material for x-rays is defined as n = 1 - δ + iβ, where δ is the refractive index decrement, responsible for the phase shift in the transmitted beam, and β is the absorption responsible for the amplitude losses. As δ and β are very small, for significant refraction, multi-element type of optics such as Fresnel zone plates (FZP), compound lenses, and multilayer mirrors are used in the x-ray regime. In the wavelength region 0.3-5 nm, FZPs are the most efficient optics. FZPs consist of a series of concentric rings (zones), where alternate zones are open and rest are either absorbing (light is not transmitted, amplitude ZPs), or changes the phase by π radians (phase ZPs).

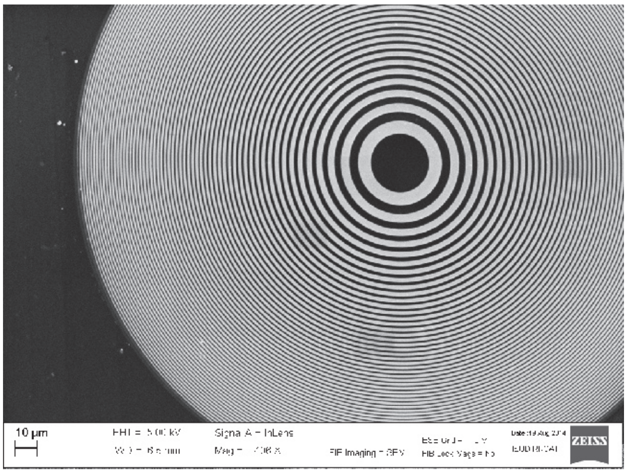

Fig. A.10.1: FZP fabricated in chromium on glass, designed for 8 keV x-rays, f=80 cm, D= 150 µm, N=120, Δr_n = 400 nm. The dark part is chromium.

The construction of FZP is such that over a pair of zones, the phase changes by 2π (path by λ) and each time when path change is λ/2, a new zone starts such that $r_n = \sqrt{(n\lambda f + n^2\lambda^2/4)}$, where r_n is the radius of n^{th} zone and f is the focal length of the FZP for wavelength λ. For nλ << f, this can be approximated as $r_n = \sqrt{n\lambda f}$ and here all zones have equal areas and contribute equally to the irradiance at the focus. The choice of material for a phase FZP should be such that it should have a small value of β/δ in the wavelength range of interest, the material thickness necessary for π phase shift must be comparable to the outer zone width, and fabrication should be possible such that freestanding structures have adequate mechanical strength. Ideally, for extreme ultra violet and soft x-rays, to minimize absorption, there should be no substrate at all. The open zones should be totally open. For hard x-rays, the aspect ratio required is large, for example at 8 keV for silicon t = 12 µm and for Au t = 1.5 µm. So different processes are evolved for hard x-ray FZPs (Fig. A.10.1) and soft x ray FZPs (Fig.A.10.2).

Free standing structures or very thin substrates are necessary for fabrication of soft x-ray FZPs. We have developed a process to fabricate FZP in thick PMMA stack on ultra-thin titanium film. A cleaned glass substrate is used for carbon deposition, leaving 2 mm edges on all the sides, followed by titanium deposition by sputtering all over. A resist stack is spin coated such that the total thickness is 2.3 µm, out of which the top 300 nm layer is PMMA. A pattern having an outer zone width of 1.3 µm, and diameter of 800 µm, designed at a wavelength of 46.9 nm, with 25 mm as focal length, was written using Raith Elphy multi-beam pattern generator on Zeiss Auriga electron beam machine. Interconnects are added in the design for mechanical stability of the free standing structure.

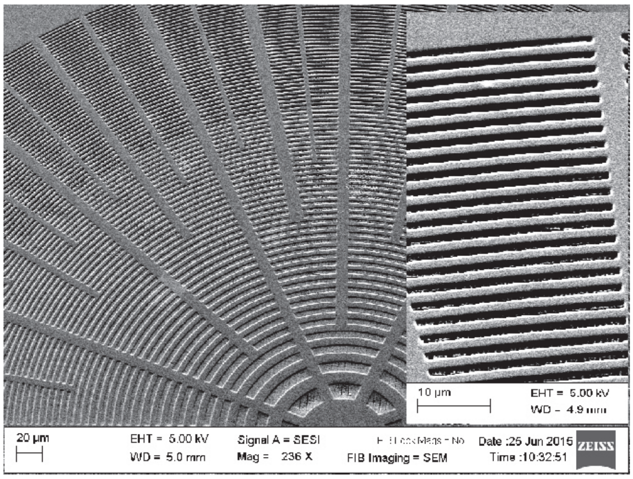

Fig.A.10.2: Soft x-ray FZP (λ=46.9 nm) supported on ultra-thin Ti, fabricated in 2300 nm thick PMMA, with N=165, Δr_n = 1340 nm, f=25 mm. Inset picture shows the outer zones.

Cold and diluted development is utilized to transfer the pattern in the resist stack. The sample is then mounted on a steel ring and edges are cut along the ring using a sharp knife. The standalone FZP in PMMA on Ti thin film mounted on the ring is thus obtained. An aspect ratio of 2 has been achieved in these structures and they are amplitude zone plates in the range 30-200 eV and 300-800 eV.

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