Volume zone plate development at BESSY

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State-of-the-art Fresnel zone plates can be described by scalar diffraction theory neglecting the three-dimensional shape of the zone structures. According to this theory their diffraction efficiency scales as $1/m^2$ where m is the diffraction order. While keeping the zone height constant, the aspect ratio of the zones increases inversely with decreasing outermost zone width. For photon energies below one keV, it is shown by applying electrodynamic theory that scalar theory is no longer suited to describe zone plates with outermost zone width below 20 nm and aspect ratios of about 10:1 [1,2].

Full electrodynamic theory - which includes forward and backward diffracted as well as evanescent waves - predicts that the diffraction efficiency decreases continuously if the lateral dimensions of the zone width approach the wavelength used for imaging. This result is obtained for zone structures parallel to the optical axis. Unlike the diffraction properties of parallel zone structures, rigorous coupled wave theory (RCWT) predicts for zone structures tilted to the optical axis according to the local Bragg condition that the diffraction efficiency can be up to 50 % [3]. In addition, RCTW calculations show that similar diffraction efficiency values can be obtained in any high order of diffraction $m > 1$.

The resolving power of zone plates scales with the order of diffraction m. By applying high orders of diffraction, it is possible to increase the resolution without the need for manufacturing increasingly smaller outermost zone width far below 20 nm. Applying high orders for imaging requires manufacturing tilted zone structures with aspect ratios of about 20:1 [2]. To overcome the extremely difficult problem of manufacturing tilted zones with high aspect ratios of 20:1, we propose to manufacture zone plates on top of each other with slightly decreasing zone radii [3]. In good approximation – depending only on the number of layers – the zones can be tilted according to the local Bragg condition and each single layer requires only moderate aspect ratio structures (see Fig. 1C). However, the overlay accuracy for e-beam writing is in the nanometer range. Theoretical results on the dependency of the number of layers and their required overlay accuracy will be presented. We will also present the current status of the zone plate development at BESSY.

Fig. 1: A) Zone plate with zones parallel to the optical axis, B) Zone plate with tilted zones, C) Zone plate where the local tilt angle of the zones is approximated by 5 layers.

[1] J. Maser, in: X-ray Microscopy IV, Bogorodskii Pechatnik Publishers (1994) 523
[2] G. Schneider, Appl. Phys. Lett. 71 (1997) 2242
[3] G. Schneider, S. Rudolph, S. Rehbein, *Volume diffraction zone plates: A new generation of x-ray optics for sub-10 nm resolution*, in preparation