Ultrahigh resolution x-ray Fresnel zone plates made by thin film deposition

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In comparison to visible light or electrons, x-ray imaging advantages are the high penetration depth and the low diffuse scattering, allowing for the non-destructive imaging of thick, non-transparent samples. In addition, contrast mechanisms can provide information on the elemental and chemical composition, combined with the very short wavelength of x-rays that gives the potential for imaging with very high spatial resolution. Since the refractive index of matter in the x-ray range is close to unity, refractive optics and mirrors are often problematic for high resolution x-ray imaging. Here, diffractive optics, i.e. Fresnel zone plates (FZPs), are an attractive alternative. The resolution of full-field and a scanning x-ray microscopes is essentially given by the smallest (outermost) line with of the zone plate pattern. Over the past ten years, there been little progress in achieving smaller outermost zone widths. This is related to an intrinsic limitation of electron-beam lithography (EBL), which is the technique to generate practically all FZPs world-wide. While state-of-the-art EBL tools are capable of writing with nanometer spots, the obtainable structure sizes are limited by the range of secondary electrons created in the resist. The exposed pattern is thus blurred, which has a particularly detrimental consequence when writing dense patterns such as FZPs. While isolated lines with widths down to 10nm can be obtained by high resolution EBL, the writing of periodic structures seems to be limited to pitches of 40-50nm. In consequence, no FZPs with lines and spaces below 20-25nm can be written in a straight-forward way.

We have developed a novel technique that combines standard EBL with thin film deposition techniques to prepare FZPs with smaller outermost zone widths and to boost the resolution of x-ray microscopy. The approach is based on the coating of a template structure with a metal layer. The template was prepared by EBL and a highly anisotropic reactive ion process. A uniform coating with iridium was deposited by an atomic layer deposition process. As iridium has a much higher x-ray refractive index as silicon, we obtain a doubling of the effective zone density and subsequent improvement of the resolution by a factor of two. The method was used to fabricate iridium FZPs with line widths down to 12.5nm (Fig. 1). An opaque platinum central stop was added onto the center of the FZP by focused ion induced deposition to block unwanted zero order radiation. The imaging properties of the devices were experimentally demonstrated in a scanning x-ray microscope at the Swiss Light Source using a cross section of a GaAs/AlGaAs heterostructure as a test object. The heterostructure consisted of line pairs of 40nm down to 9nm in width. Line pairs down to 9nm could be resolved (Fig. 2), which represents the best resolution to date achieved in x-ray microscopy. The method has the potential to push the limits of x-ray microscopy even further into the sub-10 nm regime.

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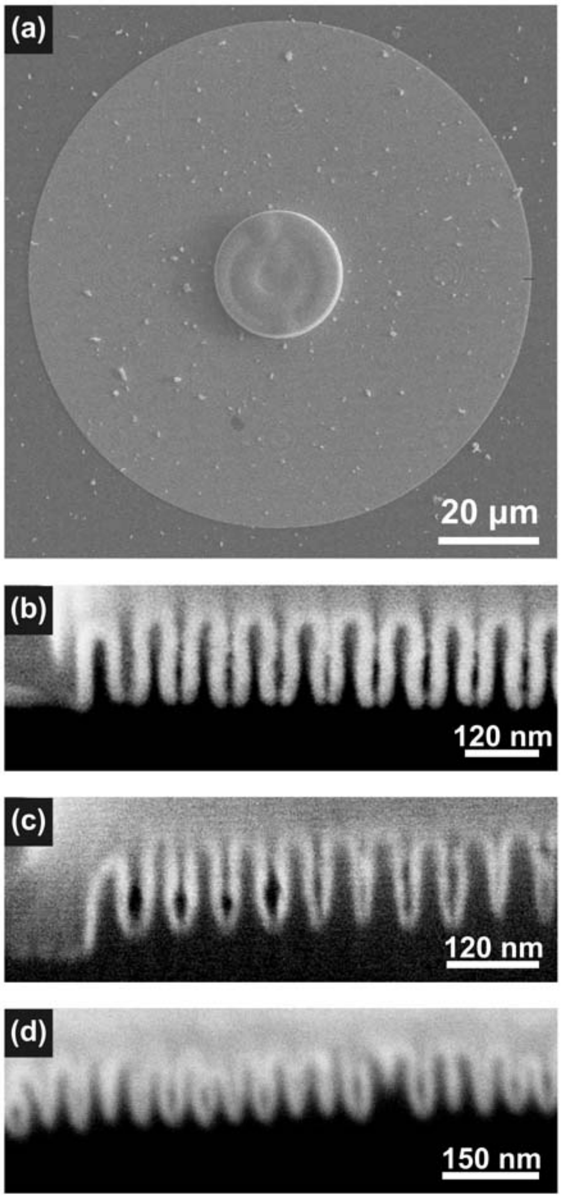

Figure 1. Scanning electron microscopy images of zone-doubled Fresnel zone plate (a) Top view of zone-doubled Fresnel zone plate. The central region is covered with a central stop deposited by focused ion beam induced deposition. The individual zones cannot be resolved at this magnification (b), (c), (d) Cross-sections of the outer regions of zone-doubled Fresnel zone plates showing outermost zone widths of 20 nm, 15 nm and 12.5 nm, respectively. The samples were cross-sectioned by focused ion beam milling.

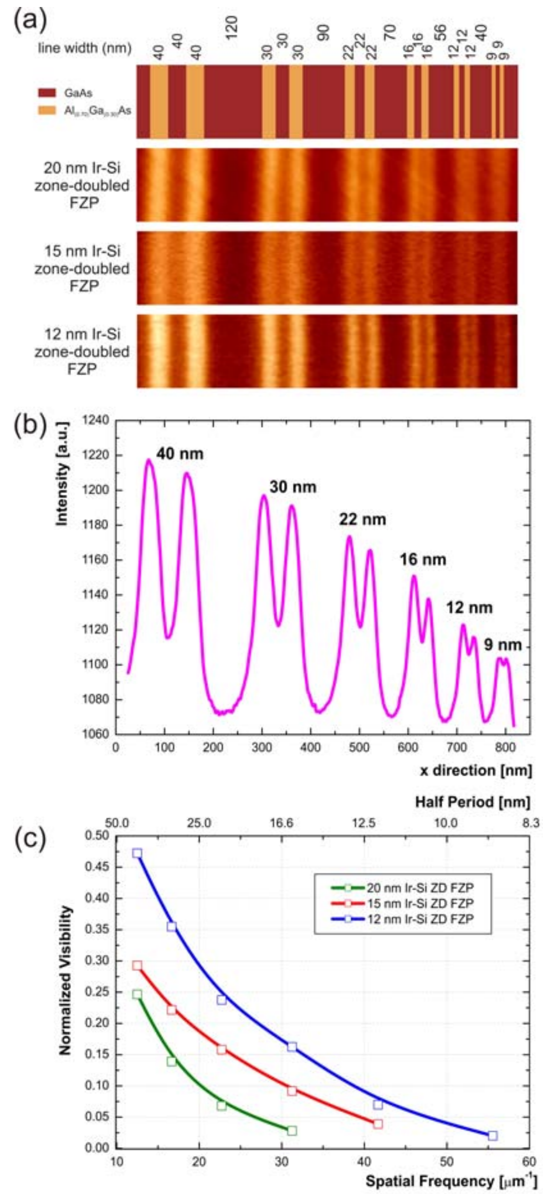

Figure 2. (a) Scanning transmission x-ray microscopy images of GaAs/AlGaAs heterostructure obtained at 1.2 keV photon energy by using zone-doubled Fresnel zone plates of 20, 15 and 12.5 nm outermost zone width as focusing elements. The line widths range from 40 nm down to 9 nm. Notice that the 12.5 nm Fresnel zone plate allows to resolve the set of three lines of 9 nm width. (b) Linear profile of the GaAs/AlGaAs heterostructure by using the 12.5 nm Fresnel zone plate. (c) Normalized modulation transfer function for the three Fresnel zone plates. As expected, the Fresnel zone plate with smallest outermost zone width is able to provide better visibility.