Nanofabrication of high aspect ratio 24nm X-ray zone plates for X-ray imaging applications

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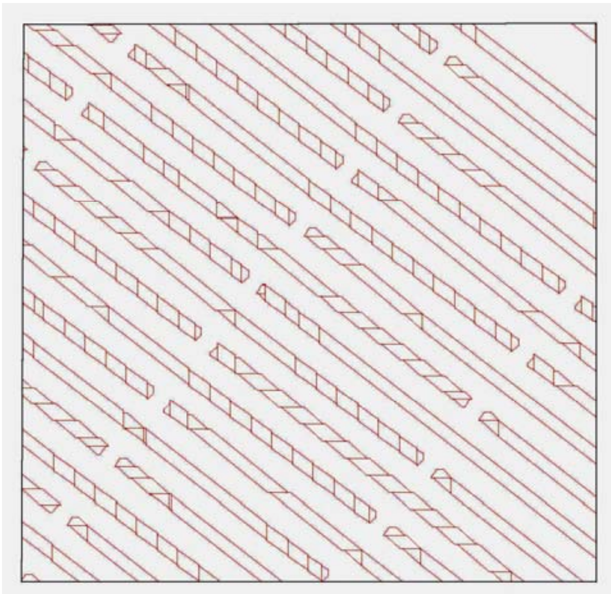
ASTRACT

X-ray imaging techniques have long been recognized for their capabilities of deep penetration and high resolution not limited by the wavelength of X-rays. In recent years, due to availability of high resolution electron beam lithography systems, progress has been made in nanofabrication of high resolution X-ray imaging zone plates, which play a central role in high-resolution X-ray imaging systems. Zone plates are circular diffraction gratings that focus X-rays by means of diffraction and not refraction. The challenge for making high-performance X-ray zone plates lies in the fact that the achievable imaging resolution is approximately equal to the finest feature size that can be fabricated. In addition the efficiency of these X-ray optics demands large feature heights that result in high aspect ratios. We are presenting work on fabrication of 24nm grating bar width structures with a height exceeding 200nm.

A typical process sequence for X-ray zone plate fabrication consists of design pattern generation, patterning of structures by electron beam lithography, deep pattern transfer by a tri-level resist process using reactive ion etching, and electrochemical plating of metal. We are discussing several developments in these steps crucial to the fabrication of high aspect ratio zone plates, in particular:

1. At pattern generation step, a number of procedures were implemented to reduce excessive fracturing of non-rectangle features as shown in figure 1, which causes high defect density in resist patterning. Figure 2 shows an example of improved pattern fracturing.
2. The tri-level reactive ion etching resist process was refined and optimized to produce mold for gold plating in aspect ratios as high as 20 for 35nm wide zones and 12 for 24nm wide zones. Figure 4 shows a SEM picture of a finished zone plate with 133µm diameter, 24nm wide and 200nm thick outmost zones.
3. In order to increase aspect ratio of zone plate further, a technique of stacking two zone plates and hence doubling its aspect ratio is developed at Xradia. Two zone plates were aligned and bonded together face-to-face permanently in X-ray. Depending on X-ray energy and application, the diffraction efficiency of the stacked zone plates can be as high as doubled or tripled efficiency of the single zone plate.

We will present detailed discussion of achieving high aspect ratio for high resolution zone plates, fabrication problems and limitations. We will also present measurement results of X-ray diffraction efficiency of single and stacked zone plates.



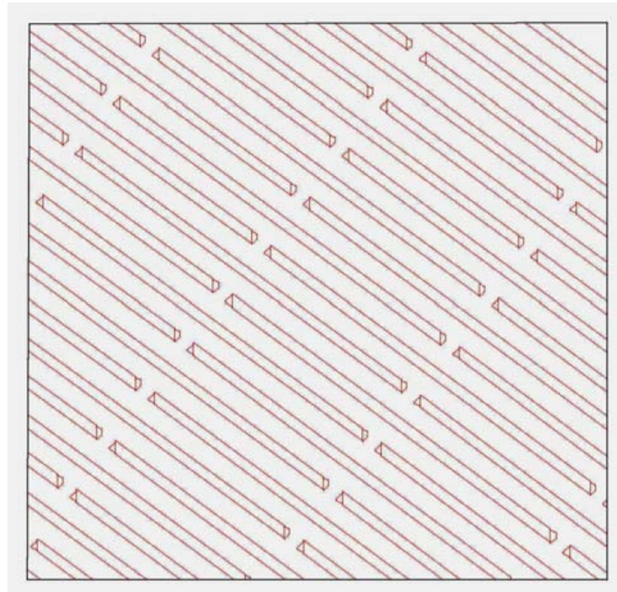
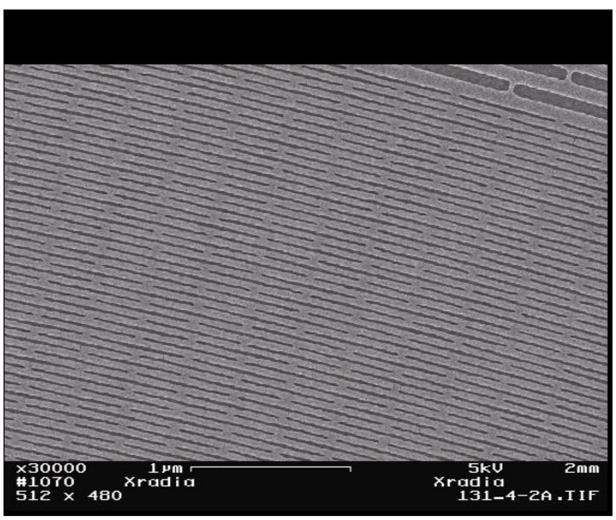


Figure 1. Zone plate patterns were sliced into many x and y trapezoids by the CATS fracturing software before ebeam exposure. This kind of excessive slicing caused too many pattern defects after resist developing.

Figure 2. In the same area of the zone plate patterns as in figure 1, the number of shapes was drastically reduced after implementing a special procedure in the CATS fracturing software.



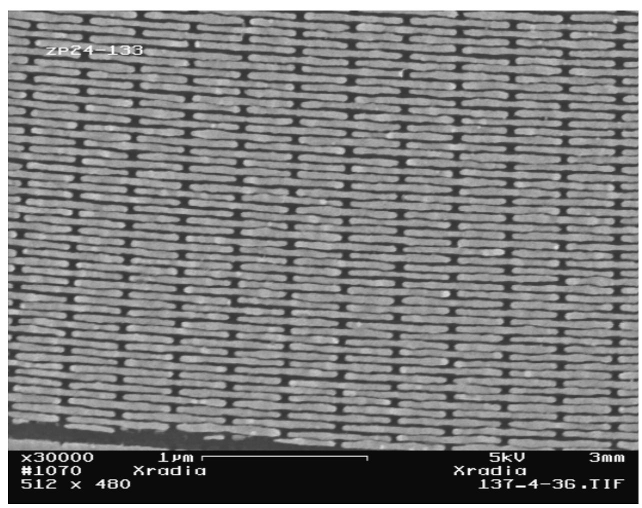


Figure 3. SEM image of ZEP resist pattern of 24nm zone plate. The resist was developed in amyl acetate developer. The exposed line width was 16nm and 48nm pitch.

Figure 4. SEM image of the outmost zones of a gold zone plate with 133μm diameter, 24nm zone width and 200nm zone height.