Optimization of Fresnel zone plate layout for high diffraction efficiency by e-beam lithography

Shanshan Xie, Jianpeng Liu, Sichao Zhang, Yifang Chen*

Nanolithography and Application Research Group, State Key Laboratory of ASIC and Systems, School of Information Science and Engineering, Fudan University, Shanghai 200433, China

Email: shanshan_xieahu@163.com

Keywords: Fresnel zone plate, e-beam lithography, diffraction efficiency, zone width ratio, X-ray optics

Fresnel zone plates (FZP) are one of the key components in X-ray microscopes owing to its focusing/imaging ability in nanoscale through diffraction of lights. However, the limited diffraction efficiency (1 or 4 over π^2 in theory and about 5% in most of practical cases) hinders its applications. To enhance the focusing efficiency, two aspects are most concerned, one is the zone height and the other is the ratio of gold-zone width over air-zone width. So far, substantial efforts have been made to achieve high aspect ratio of zone-height over zone-width for high imaging contrast, few reports have been seen to tackle the zone width issue. This work addresses the optimization of FZP layout with the outermost ring of 100 nm, trying to control the zone width ratio for maximizing the transmission efficiency through the plates.

Figure 1 illustrates the relationship between the zone width and the transmitted intensity by coherent interference. It is clear that, for a phase ZP, when the phase difference between two adjacent zones ϕ approaches π, corresponding to the case that two zone widths are close, the diffraction efficiency is up to the maximum. Therefore, the problem turns out to be the control of zone widths in electron beam lithography (EBL). To this end, high resolution EBL was carried out by a state-of-the-art JEOL6300 FS to generate FZP layout (Fig. 2), with careful correction of proximity effect by the serial software of Layout BEAMER/TRACER/LAB based on Monte Carlo simulation. The continuous change in zone width can be obtained by controlling the exposure dose as shown in Fig.3 and Fig.4 after electroplating of Au. By using the optimized processing parameters in the designed zone-widths and developing condition, high zone-width control can be achieved. The optimized FZP layout for the most coherent situation can be figured out through adjusting the exposure dose. Figure 5 shows the fabricated FZP in gold with high aspect ratio in height/width.

In summary, enhancing the diffraction efficiency of FZPs was addressed by optimizing the zone layout. The key point to the success of fabricating high efficiency ZPs is the careful control of zone width in EBL. The processing window for the highest efficiency of diffraction was worked out, in which both the zone-width design and the lithography condition should be the deciding factors. The developed methodology should be applicable to not only 100 nm zone plates, but also all sized ones as a whole.

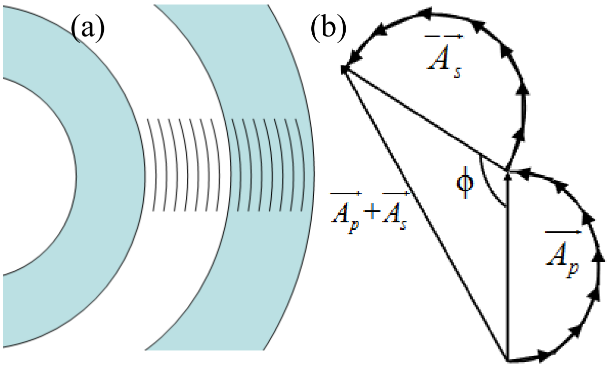

Figure 1: (a) Illustrations of the vector sum of the wavelets; (b) Total amplitude from one pair of zones. $\overrightarrow{A_p}$ is the amplitude of bright zone, $\overrightarrow{A_s}$ is the amplitude of dark zone, ϕ is the phase difference of the dark zone.

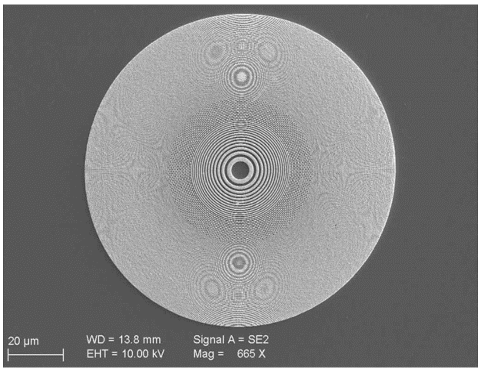

Figure 2: The SEM image of the fabricated gold Fresnel zone plate.

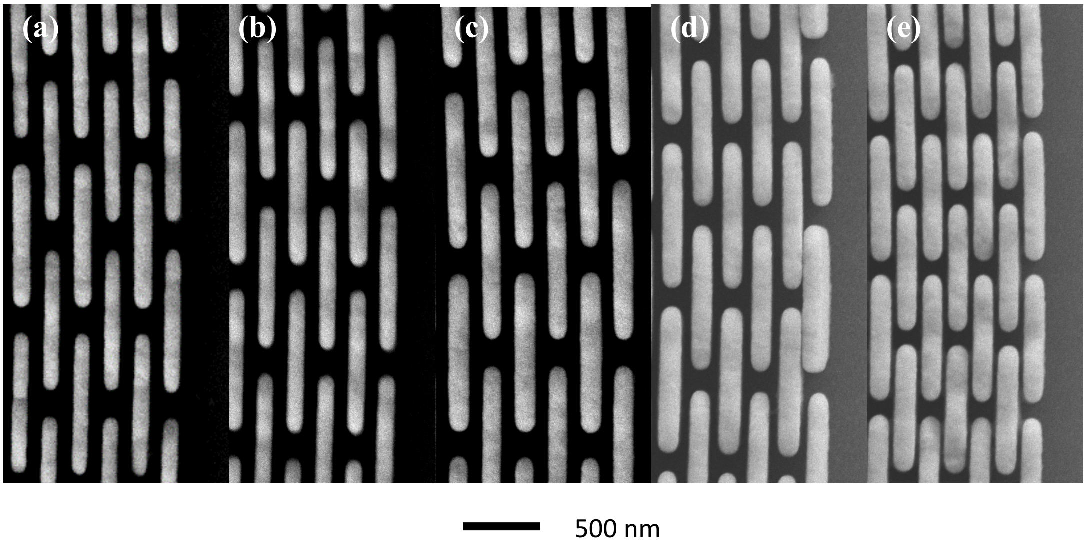

Figure 3: SEM images of the zone widths under different exposure dose.

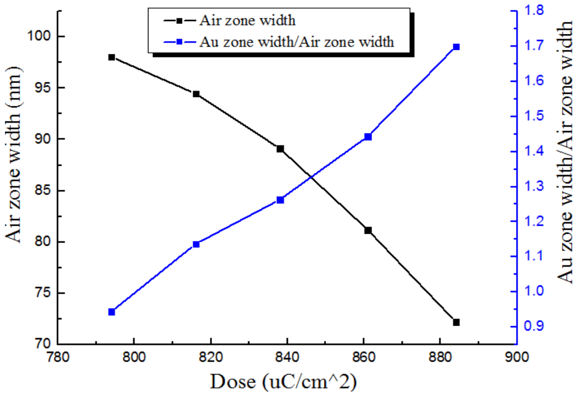

Figure 4: The zone widths and their ratio controlled by the exposure dose.

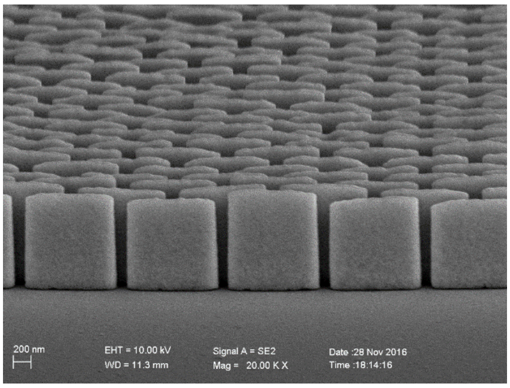

Figure 5: The fabricated zone plate with high aspect ratio.