Monte Carlo simulation and developing study of resist profile for high aspect ratio Fresnel zone plates

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High aspect ratio Fresnel zone plates (FZPs) as x-ray lenses are the key optical components in X-ray optics with synchrotron light (SL) facilities. Although nanoscale zone plates with high aspect ratio have already been reported [1], the ultimate aspect ratio achievable with certain resolution remains unclear. The profile control in PMMA resist as templates forming metallic zone plates is related not only to the charge distribution by e-beam exposure but also to the developing dynamics which has been rarely investigated in this subject. In this work, we have conducted systematic study of effects of both charge distribution and developing condition on the resist profile control with high aspect ratio configuration. Monte Carlo (MC) simulation by BEAMER simulator supplied by GenISys Ltd was first applied to plot the charge distributions in thick PMMA with and without proximity effect corrections. Dissolution rates of PMMA at various developing time were carefully measured. Based on these results, the resist profiles under various developing time were calculated. Guided by theoretical results, experimental processing study was carried out for achieving high aspect ratio resist profile in PMMA.

Figure 1 shows the contrast curves and the dissolution rates with different development time. Combining the dissolution rates with the charge distribution by MC simulation, the resist profile for the outer zones are obtained as shown in figure 2. In this work, attention was particularly paid on the largest depth achievable by increasing developing time, trying to maximize the aspect ratio. Figure 3 shows the fabricated FZPs in gold with 200 nm outermost zone width and 2 μm height on in-house fabricated Si_3N_4 membranes. High aspect ratio gold pillar and pillar arrays of 400nm in diameter and 2500 nm in height were also fabricated. Figure 4 demonstrates the SEM images of single gold pillar and the measured diffraction pattern by hard X-ray. 12 diffraction rings are clearly observed, indicating the high quality gold pillars. This work provides us with a theoretical guide for achieving high aspect ratio nano structures.

[1] http://www.psi.ch/lmn/ultra-high-resolution-zone-plates

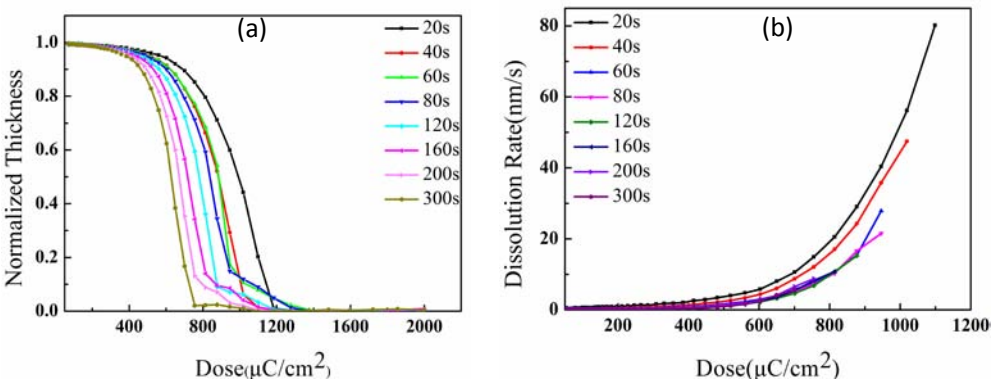

Figure 1. (a) Contrast curves and (b) dissolution rates of 2μm-PMMA with different development time

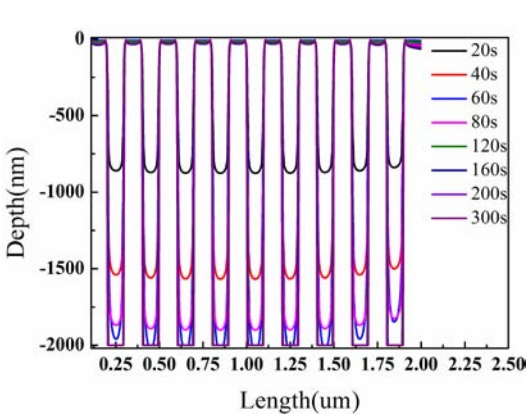

Figure 2. The simulation result of resist profile without proximity effect corrections

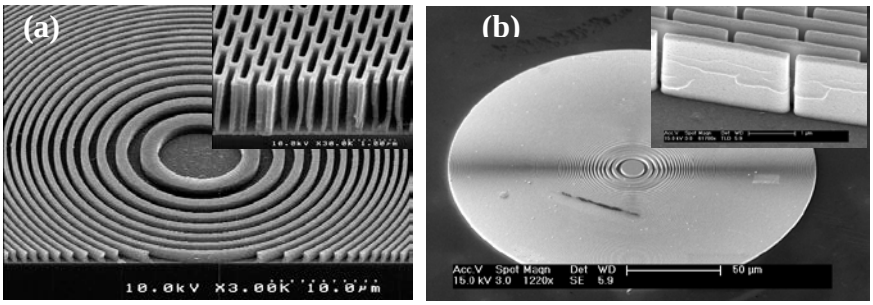

Figure 3. SEM image (a) The profile of Fresnel Zone Plate. (b) Fresnel Zone Plate with gold electroplated.

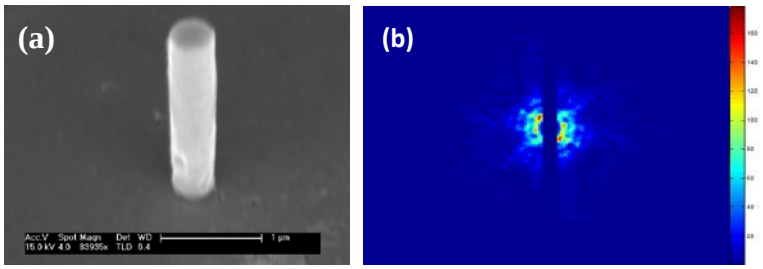

Figure 4. (a) SEM image of single gold pillar on Si_3N_4 membrane. (b) Measured diffraction pattern at X-ray