# Fabrication of hard X-ray zone plates with very high aspect-ratio by X-ray lithography

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The fabrication of hard X-ray zone plates has always been a challenging task, for on one hand, zone plates have to be thick enough to yield high efficiency in this range of wavelength, on the other hand, the outermost zone width has to be as small as possible for high resolution of focusing or imaging. These two factors result in a very high aspect ratio of the zone plate structure, which is a major challenge to the fabrication technology.

The 'buttress' structure has been proven helpful, even essential in improving the aspect ratio of zone plates when only electron beam lithography(EBL) or EBL combined with dry etching of tri-layer resist was employed. [1,2] In this report, we integrate the 'buttress' structure into the fabrication of hard X-ray zone plates by X-ray lithography. Compared to EBL-based approaches, XRL is capable of exposing a thicker resist layer while maintaining a high resolution. However, the realization of XRL's potential in obtaining high aspect ratios was usually prevented by resist collapse. With the help of the buttress structure, resist collapse was reduced and we were able to achieve developed resist structures with an aspect ratio of 15, whereas the thickness of the resist is 3 um and the outermost zone width is 200nm. (Fig. 1) Using said resist structure as the plating mold, we fabricated gold zone plates with an aspect ratio of 14. (Fig. 2, 3)

The X-ray lithography mask was fabricated by electron beam lithography and electroplating gold onto a polyimide membrane supported by a silicon frame. The X-ray lithography process is carried out at the National Synchrotron Radiation Laboratory, Hefei, China. The substrate stack comprises a silicon wafer, 1μm polyimide, 5 nm Cr, 10 nm Au, and 3μm PMMA, where as the Cr and Au act as the electroplating base. After electroplating, the silicon under the zone plate area was removed by wet etching as the final step.

The 2.8-um-thick zone plate can be used for focusing and imaging with up to 25 keV hard x-rays with the efficiency well above 20% (Fig. 4) and the theoretical resolution is better than 250 nm.

References:

[1]. Yan Feng, Michael Feser, et al, Nanofabrication of high aspect ratio 24 nm x-ray zone plates for x-ray imaging applications, J. Vac. Sci. Technol. B 25(6) (2007)
[2]. Yu-Tung Chen, Tsung-Nan Lo, et al, Full-field hard x-ray microscopy below 30 nm: a challenging nanofabrication achievement, Nanotechnology 19, 395302 (2008)

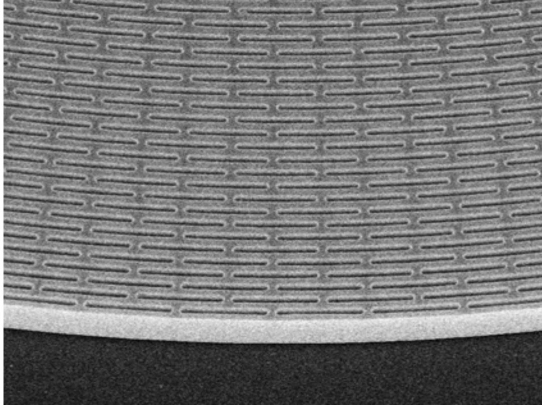

*Fig.1 SEM of the PMMA resist acting as the electroplating mold for the zone plate.* The resist is exposed by X-ray lithography. The outermost zone width is 200nm and the thickness is 3µm. A very high-aspect ratio profile can be seen from the sidewall of the pattern.

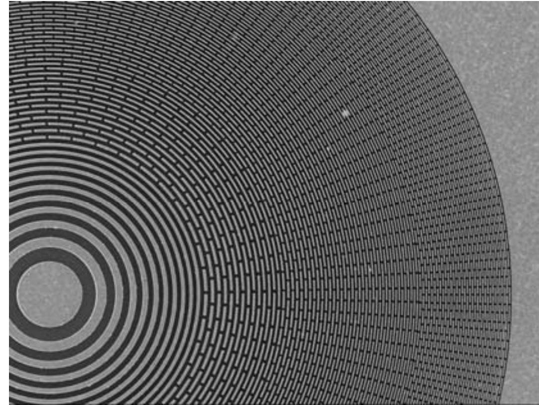

*Fig.2 SEM of the electroplated gold zone plate* . The diameter of the zone plate is 160 µm, the outermost zone width 200nm and the thickness 2.8µm. Thus the aspect ratio is 14 for the outermost zones.

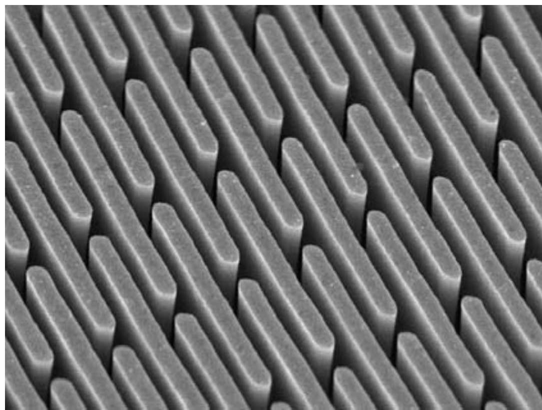

*Fig.3 SEM of the outermost zones of the electroplated zone plate.*

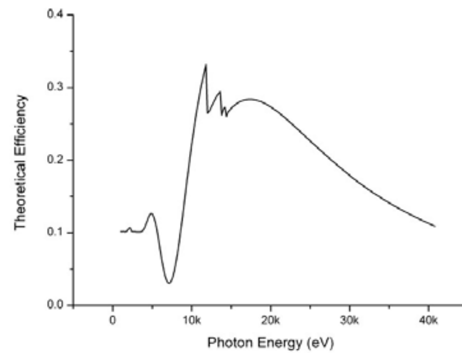


*Fig.4 The theoretical efficiency of the 2.8-μm-thick gold zone plate* . According to the calculation, the zone plate can be used for photon energies between 10k and 20k eV with the efficiency well above 20%