Nanofabrication of High-Aspect-Ratio Zone Plates for Hard X-rays

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Scientific Thrust Area: Nanofabrication and Devices

Research Achievement:

Zone plates are diffractive lenses composed of concentric rings of phase-shifting material whose period changes along the radius. The focal spot size is proportional to the outermost ring width. In the hard x-ray region, no effective refractive lens is available due to weak interaction between materials and hard x-rays. Zone plates are among those few optics which can focus to the diffraction limit for hard x-rays. The optimal efficiency of a zone plate, however, is determined by the thickness of the phase-shifting layer, which ranges from hundreds of nanometers to several microns, depending on the material and working x-ray wavelength. Therefore, it is challenging to fabricate hard x-ray zone plates with better than 50-nm resolution due to the high aspect ratios required. Our current work focused on taking advantage of the capabilities of our 100-KeV electron beam lithography system for the development of nanofabrication techiques for hard x-ray zone plates.

Current commercial hard x-ray zone plates [1] are fabricated by using electron beam lithography (EBL) to pattern the a thin resist layer, and the use oxygen reactive ion etching to transfer the pattern into a thicker underlying layer that acts as a mold for gold electroforming. We have demonstrated the ability to use hydrogen silsesquioxane (HSQ) as a negative resist for high-aspect-ratio patterning using 100 KeV EBL [2]. We then employed HSQ and EBL to directly pattern the molds for gold electroforming hard x-ray zone plates, which is relative simply compared with commercial process. 1-μm-thick gold zone plates with 80-nm-wide outermost zone were successfully fabricated with this process. While higher resolution zone plates could be patterned, their aspect ratio was limited by electron scattering effects.

A multi-pass technique was initially developed for high-resolution (below 20-nm) soft x-ray zone plate fabrication [3], in which odd- and even-numbered rings are patterned and electroplated separately. The success of this technique relied upon a unique customized EBL system that has sub-pixel overlay alignment capability. Our numerical simulation shows the performance of a zone plate made with multi-pass technology is not very sensitive to alignment accuracy. A zone plate with alignment error no larger than half of the outermost zone width can keep most of the resolution and more than 90% of the efficiency. With our well-calibrated, state-of-the-art commercial EBL system, the overlay alignment can be controlled to 10 nm or less. It is a maximal misalignment budget good for the zone plates with 20 to 30 nm outermost zone width, which can be a breakthrough for hard x-ray zone plates.

By combining the multi-pass technique with an "in-situ" electroplating technique [4] and a resist contrast enhancing technique, we have successfully demonstrated the nanofabrication of gold zone plates with 30-nm-wide outermost zones and 500-nm-thick phase shifting layer. The best alignment error was determined to be about 10 nm. The outermost zone width and thickness have not yet reached the limit of the fabrication technology and with room to improve the aspect ratio of hard-x-ray zone plates.

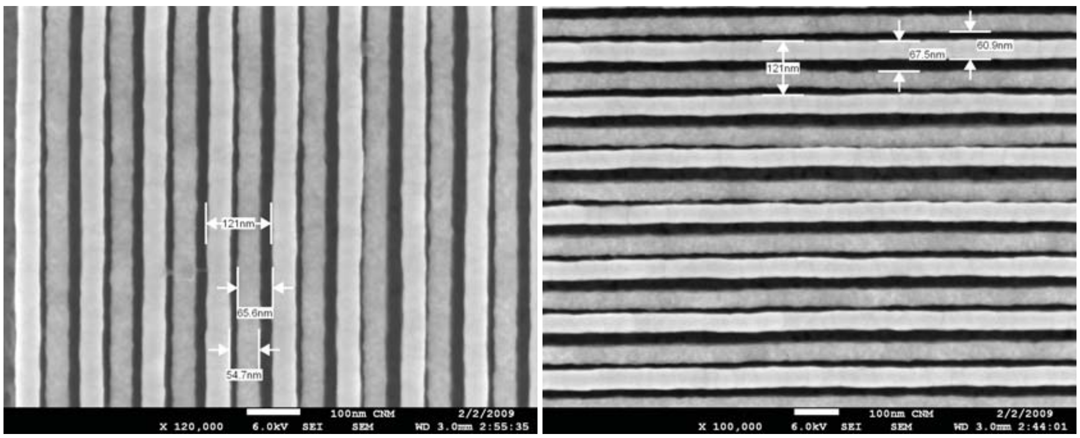

Fig. 1. SEM micrographs of a 500-nm-thick zone plate with 30 nm nominal outermost zone width. The measured misalignment error is about 6.5 nm (5.5 nm at X-direction and 3.3 nm at Y direction).

Future Work:

We will continue to advance the state-of-the-art of hard x-ray zone plate fabrication by employing new methods and materials for high-aspect-ratio nanopatterning of zone plate structures.

References:

1. W. Yun, M. Feser, A.F. Lyon, F. Duewer, Y. Wang, "Pathways to sub-10nm x-ray imaging using zone plate lens," in "Design and Microfabrication of Novel X-Ray Optics II," Proc. SPIE 5539, 133–137 (2004).
2. L.E. Ocola and V.R. Tirumala, "Nanofabrication of super-high aspect ratio structures in HSQ from direct-write e-beam lithography and hot development," presented at EIPBN 2008.
3. W. Chao, B.D. Harteneck, J.A. Liddle, E.H. Anderson and D.T. Attwood, "Soft X-ray Microscopy at a Spatial Resolution better than 15 nm," Nature, 435, 1210-1213 (2005).
4. R. Divan, D. Mancini, N. Moldovan, B. Lai, L. Assoufid, Q. Leonard, and F. Cerrina, "Progress in the fabrication of high-aspect-ratio zone plates by soft x-ray lithography," in "Design and Microfabrication of Novel X-Ray Optics," Proc. SPIE 4783, 82–91 (2002).

Publications:

M. Lu, L. E. Ocola, R. Divan, D. C. Mancini, "Fabrication of high-aspect-ratio hard x-ray zone plates with HSQ plating molds," in "Nanoengineering: Fabrication, Properties, Optics, and Devices V," Proc. SPIE 7039 (2008).

M. Lu, R. Divan, L. E. Ocola, D. C. Mancini, "Fabrication of High Resolution Hard X-ray Zone Plates Using Multi-pass Technology with a Commercial Electron-beam Lithography Tool," to be presented at HARMST 2009 and to be submitted to Microsystems Technologies.