Towards high-resolution high-diffraction-efficiency soft x-ray zone plate lenses: sub-15 nm pattern transfer to tungsten using HSQ and cryogenic RIE

J. Reinspach, F. Uhlén, H. M. Hertz, and A. Holmberg
Biomedical and X-Ray Physics, Dept. of Applied Physics, Royal Inst. of Technology, S-10691 Stockholm, Sweden

The development of zone plate lenses is crucial for the progress of high-resolution soft x-ray microscopy. As the resolution achievable in imaging is proportional to the outermost zone width of the lens, narrow zones have to be nanofabricated. An issue with such high-resolution zone plates is their low diffraction efficiency, a problem that originates from the difficulty of making narrow zones with high aspect-ratio. For state-of-the-art sub-13-nm soft x-ray zone plates this results in theoretical diffraction efficiencies below 2%.[1,2]

Recently we have reported on efficiency-enhanced 13-nm nickel-germanium zone plates with a theoretical efficiency of 4.7% (@ λ=2.48 nm).[3] In the present contribution, we present a new fabrication process for thick tungsten zone plates with narrow zones which can provide significantly higher diffraction efficiency than has been achieved before. Electron-beam-patterned HSQ in combination with a salty development process[4] in an aqueous NaOH/NaCl solution was used to provide high resolution. The HSQ pattern transfer to the tungsten layer was achieved by cryogenic reactive ion etching with SF_6/O_2 using chromium as intermediate hard mask. The anisotropy of the tungsten etch was controlled by the substrate temperature, and straight sidewalls were achieved at -50 °C. Good-quality periodic tungsten gratings with half-pitches down to 12 nm and a tungsten height of 90 nm were fabricated (cf. Fig. 1). For a zone plate with corresponding parameters this would result in a diffraction efficiency of 9.6% (@ λ=2.48 nm), which will be a significant improvement compared to present high-resolution soft x-ray zone plates.

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[2] J. Reinspach, M. Lindblom, O. v. Hofsten, M. Bertilson, H. M. Hertz, and A. Holmberg, J. Vac. Sci. Technol. B **27**, 2593 (2009).
[3] J. Reinspach, M. Lindblom, O. v. Hofsten, M. Bertilson, H. M. Hertz, and A. Holmberg, J. Vac. Sci. Technol. B. **29**, 011012 (2011).
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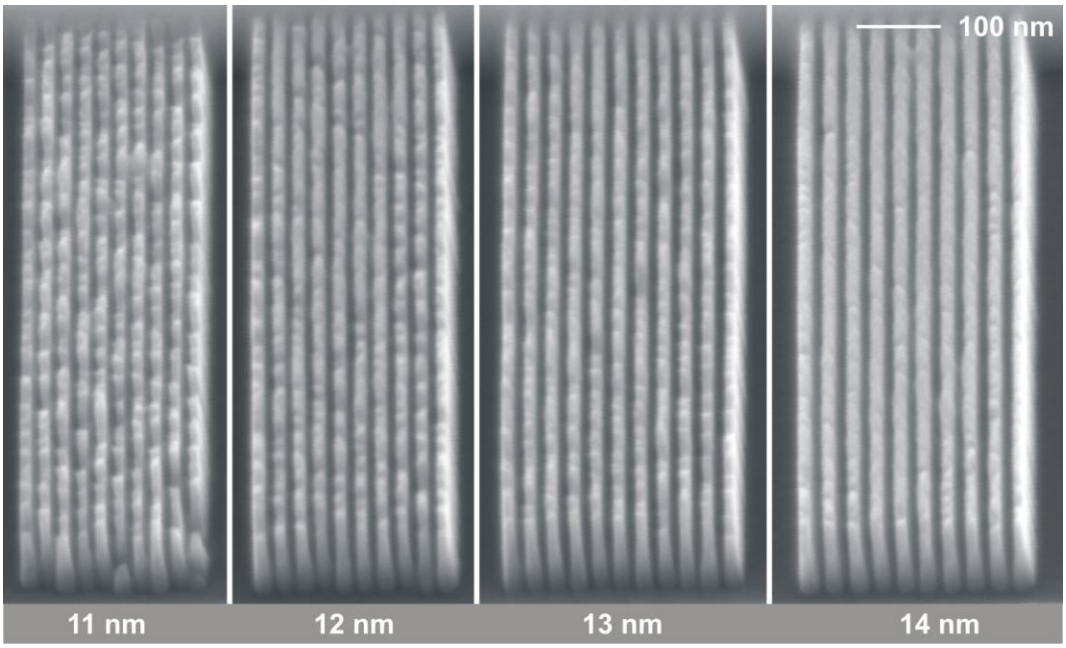

Figure 1: Tungsten gratings with half-pitches of 11, 12, 13 and 14 nm. The thickness of the tungsten is 90 nm. The pattern quality is good for half-pitches down to 12 nm.