

Design and fabrication of dual-helicity orbital angular momentum zone plates for nano-angle-resolved photoemission spectroscopy

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Orbital angular momentum (OAM)-resolved nano-angle-resolved photoemission spectroscopy (nARPES) is a soft X-ray experimental technique that enables sensitivity to orbital symmetry, but requires precise phase control at nanometer length scales. By providing a controlled orbital angular momentum degree of freedom at the nanoscale, these optics introduce an additional tunable parameter in nARPES that can be used to probe photoemission matrix elements and potentially reveal electronic features not accessible with conventional polarization control alone. Diffractive zone plate lenses offer a compact approach to generating OAM-carrying beams [1], although systematic helicity comparisons are often limited by alignment and reproducibility.

We present the design and nanofabrication of a matched pair of Fresnel zone plates for nARPES with topological charges of +1 and -1, fabricated on a single chip to minimize errors from tilt, drift, and misalignment. The zone plates were designed using in-house software incorporating nARPES constraints, including a photon energy of $E = 92$ eV, focal length $f = 4.36$ mm, numerical aperture $NA = 0.086$, and a target focal spot diameter of 80 nm. The helical wavefront phase terms are encoded in the zone plate pattern, enabling helicity control without additional optical elements.

Adjacent, complementary zone plates with a center-to-center separation of 4 mm, enable rapid helicity switching under identical illumination conditions. The outermost zone width is 80 nm for both zone plates. Fabrication was performed by electron-beam lithography followed by gold electroplating, yielding an average zone height of 65 nm. The calculated first-order diffraction efficiency is $\eta = 14.5\%$ for these lenses.

This single-chip, dual-helicity platform provides a robust optical element for helicity-dependent nARPES experiments, enabling direct comparison of opposite OAM states with reduced systematic uncertainty. The approach is compatible with existing nARPES endstations and can be extended to higher topological charges and more complex phase profiles for advanced soft X-ray spectroscopy.

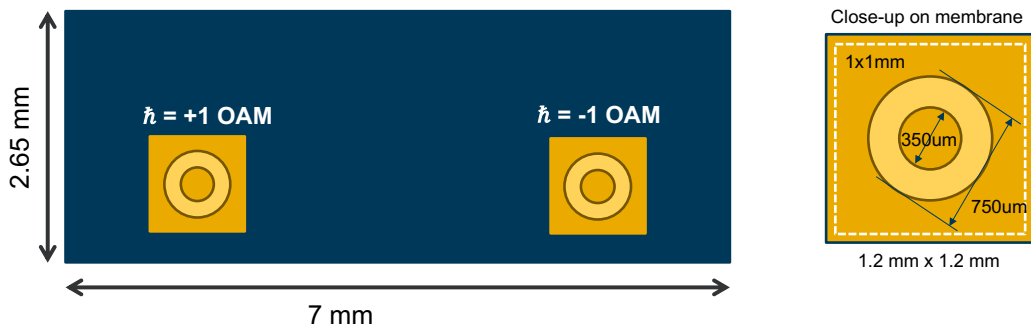


Figure 1: Schematic view of the designed dual-helicity zone plate chip and close-up on membrane region. The zone plate lenses have an annular pupil with a 350 μm central stop to facilitate the use of an order-sorting aperture downstream.

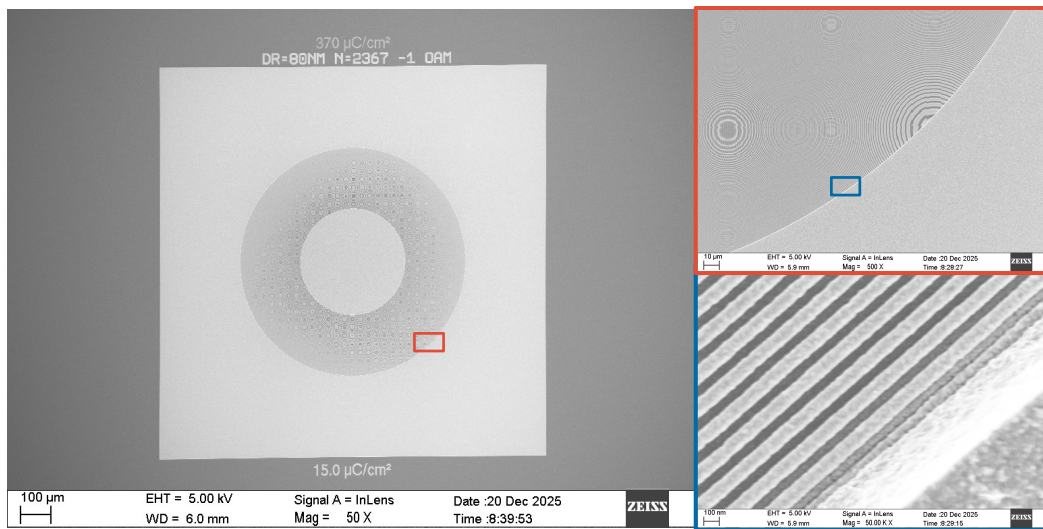


Figure 2: SEM images of a fabricated OAM zone plate with detailed view on outer zone region.

References:

- [1] Rouxel, J.R., Rösner, B., Karpov, D. *et al.* Hard X-ray helical dichroism of disordered molecular media. *Nat. Photon.* **16**, 570–574 (2022).
<https://doi.org/10.1038/s41566-022-01022-x>