Pure Electron Vortex Beams from a Cylindrical Mode Converter

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Vortex (or donut) electron beams carry an angular momentum and magnetic moment. Therefore they are a switchable magnetic probe, especially for scanning (S)TEM. A widely applicable vortical STEM probe should be (i) straight forward to employ, (ii) of high purity with minimal spurious scattering, (iii) easy and fast to switch between angular states of l=+1, l=-1, and (iv) sufficiently reliable and stable for the duration of a microscopy session. We adopt the well-established method of mutual mode conversion between Hermite and Laguerre Gaussian profiles in laser optics, pioneered by [1]. The optical setup for vortex generation utilizes a diagonal Hermite(1,0) laser source, and a pair of cylinder lenses that has to be mode matched by a convex adapter lens. While the optical path outside the cylinder lenses is not astigmatic, the astigmatism in between results in a relative Gouy shift of $\pi/2$.

Building on the principal experimental demonstration that mode conversion is feasible [2], we propose a versatile electron optical mode converter repurposing a conventional Cs probe corrector (DCOR, CEOS) in combination with a Hilbert phase plate. The phase plate prepares the incoming beam such that its phase structure closely resembles that of a Hermite (1,0) mode, which is then sent to the corrector. If the right aperture is chosen and the condenser lenses are adjusted accordingly, mode matching can be achieved. The quadrupoles of the corrector are utilized to tune the relative $\pi/2$ Gouy shift, while maintaining a non-astigmatic beam on the outside. We perform wave optical calculations to visualize the propagation of the electron beam in the microscope column and the formation of the vortex beam in between the two quadrupoles of the spherical aberration corrector.

The inherent appeal of vortex generation by a mode converter is the full lossless conversion of the entire electron beam and suppression of spurious scattering intensities. In contrast to the light optical mode converter the cylinder lens setup can be easily rotated to establish vortex states with either l =+1 or l =-1 and inverted magnetic moments, respectively. As we only repurpose already well established and widely used hardware for the electron vortex generator, we expect easy and quick adoption of this novel kind of switchable magnetic STEM probe.

[1] Beijersbergen et al, Optics Comm., **96**, 123-132, (1991)

[2] Schattschneider et al, PRL, **109**, 084801, (2012)

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