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IM4-P-2584 Simplified electron vortex generator with aberration correction

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The principle of astigmatic mode conversion (MC), known from light optics [1a], has been successfully applied in electron optics to form a singular and high-purity electron vortex beam [1b]. Such a vortex generator is based on a quadrupole (QP) doublet. The drawback of this setup is the fact that the QP doublet must be "borrowed" from the aberration corrector, which is then out of function. Ideally, separate QPs in front of the aberration correcting elements should be used. In the case of the NION C3/C5 aberration corrector [2], employed e.g., in the NION UltraSTEM instrument, there is a set of quadrupoles to couple the beam coming from the condenser into the first octupole, which can be repurposed for MC.

Furthermore, it is shown that the standard mode converter geometry as described in [1a] can be simplified inasmuch as the Hilbert phase plate (HPP) can be positioned inside the QP doublet. For a proof of principle experiment, an optical setup is proposed where the HPP is placed in the sample holder in between two astigmatic line foci produced by the QP component of the first QP/octupole element, see Figure 1. Wave optical simulations of the propagation of the electron through the optical elements of the proposed configuration show that the characteristic azimuthal vortex phase and ring like intensity distribution can be produced, see Figure 2. It turns out that the currents for the appropriate focal widths of the QPs in order to function as a vortex generator lie all within the accessible range for the NION UltraSTEM.

Even though the proposed setup leaves the probe corrector in operation, there are two major drawbacks. Firstly, the extremely low convergence angle (~70 µrad) produces a rather large STEM probe of ~43 nm (which facilitates beam testing in a proof-of-principle experiment). Secondly, the sample stage is occupied by the HPP. Future directions include the placement of the HPP in an upgraded condenser aperture holder. This enables STEM imaging with the MC vortex probe and enhance the achievable convergence angle to roughly one mrad. However, for atomic resolution imaging as well as e.g., testing new quantum computation schemes [3] a dedicated QP doublet with demagnification- and magnification-stage is proposed.

[1] a) Beijersbergen et al., Astigmatic laser mode converters and transfer of orbital angular momentum, Optics Communications, 96, 123-132 (1993), b) T. Schachinger et al., Experimental realization of a π/2 vortex mode converter for electrons using a spherical aberration corrector, Ultramicroscopy, 229, 113340 (2021)

[2] O.L. Krivanek et al., An electron microscope for the aberration-corrected era, Ultramicroscopy, 108, 179–195 (2008)

[3] S. Löffler et al., A quantum logic gate for free electrons, (2022), submitted

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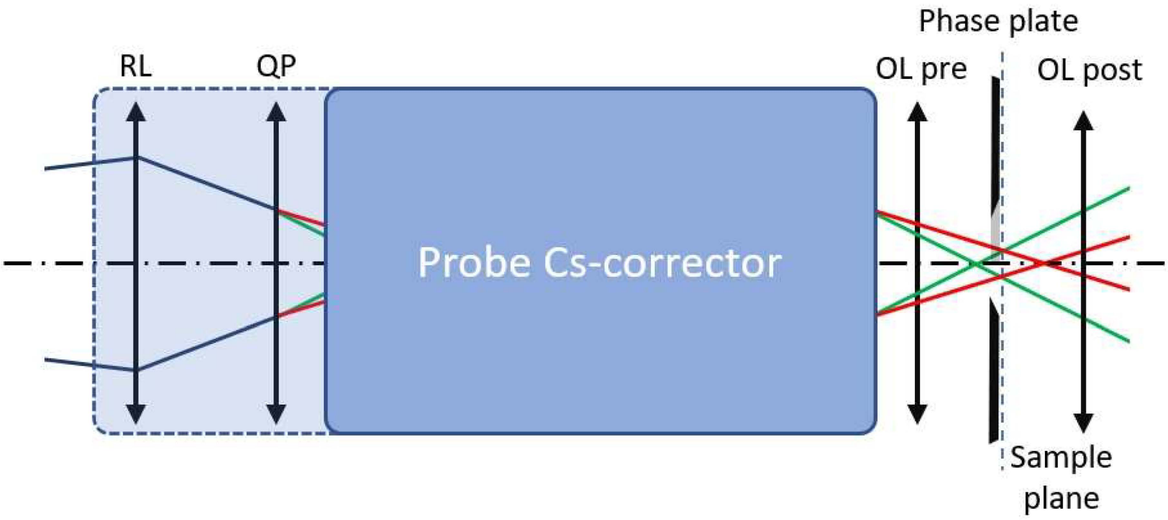

Fig. 1: Schematics of a vortex generator realized in a dedicated STEM instrument with operational probe corrector. The round lens (RL), formed by QPs in the corrector, prepares an astigmatic low convergence angle beam in the objective lens (OL) with the OL being switched off. A HPP is placed in between the two astigmatic line foci to facilitate MC.

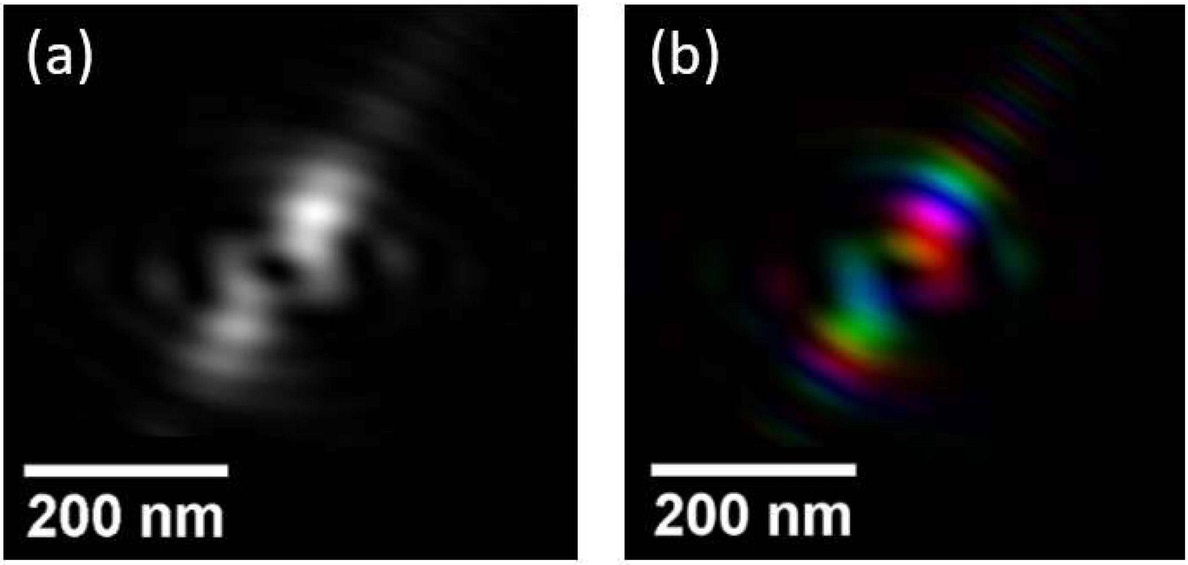

Fig. 2: Wave optical electron beam simulation results showing the intensity distribution (a) and (b) hue color coded phase of the vortex probe for the MC setup proposed in Figure 1.