The role of spatial coherence for the creation of atom size electron vortex beams

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Electron vortex beams, which carry quantized orbital angular momenta (OAM) L, promise to reveal magnetic signals even down to the atomic level [1].

In order to produce single electron vortex beams, we recently developed a method which allows to generate user-defined OAM beams [2]. We implemented two types of apertures, a 50 μm fork-type aperture and a 100 nm aperture into the condenser lens system of a FEI Titan[3] 80-300 microscope equipped with a probe spherical aberration corrector and a Wien-type monochromator. The selected focused probe is used for the acquisition of HRSTEM images and local EELS maps. Although today, atom size electron vortex beams can be readily generated and atomically resolved HRSTEM and EELS data can be acquired with OAM-selected EVBs, the application as a probe for local measurements of the electron energy loss chiral dichroism (EMCD) suffers from a poor S/N ratio and is thus still under development. One reason may be the incoherence of the vortex beam itself, which results in a strong reduction of the dichroic signal. Measurements on ferrimagnetic samples reveal magnetic signals, which are by far smaller than expected from simulations.

The monochromator provides for the flexibility to tune the degree of coherence on the vortex aperture by allowing to continuously vary the gun lens (GL) excitation. In this work we have therefore investigated the influence of the gun lens excitation on the coherence of the electron vortex beam and studied EMCD on various samples. As a measure of the coherence, the central intensity dip of the imaged probe is determined (see Fig. 1) [4]. Images of the vortex probe have been acquired utilizing two types of electron guns: (i) a standard Shottky FEG (SFEG) and (ii) a so-called high-brightness gun (XFEG). Normalized rotationally averaged profiles of the images are used to analyse the dependency of the EVB quality on the coherence (gun lens excitation). Both electron guns show an improvement of the spatial coherence with increasing gun lens excitation, measured by the central intensity dip in the $|L| = 1\ \hbar$ vortex beam (Fig. 2). For the XFEG operated at 200kV, a central intensity dip of $L_{Dip}/I_{max} = 0.3$ can be reached. Using the dip value and taking into account the size of the aperture and the convergence semi-angle of 22.5 mrad, we calculated the incoherence angle α_{incoh} to be between 45 nrad and 25 nrad for a gun lens excitation from 6 V to 200 V [3,4]. Following the van Cittert-Zernike theorem, a coherence length of 32 μm (for the 200 kV XFEG, GL = 200 V) can be calculated.

Hence, EVBs generated from fully coherent primary beams may by the missing piece to the puzzle as to how to substantially improve quantitative magnetic signals as obtained from individual atomic rows.

[1] J. Verbeeck et al., Nature **467** (2010), p. 301-304.

[2] D. Pohl et al., Sci. Rep. **7** (2017) 934.

[3] P. Schattschneider et al., Ultramicroscopy **111** (2011), p. 1461-1468.

[4] P. Schattschneider et al., Ultramicroscopy **115** (2012), p. 21-25.

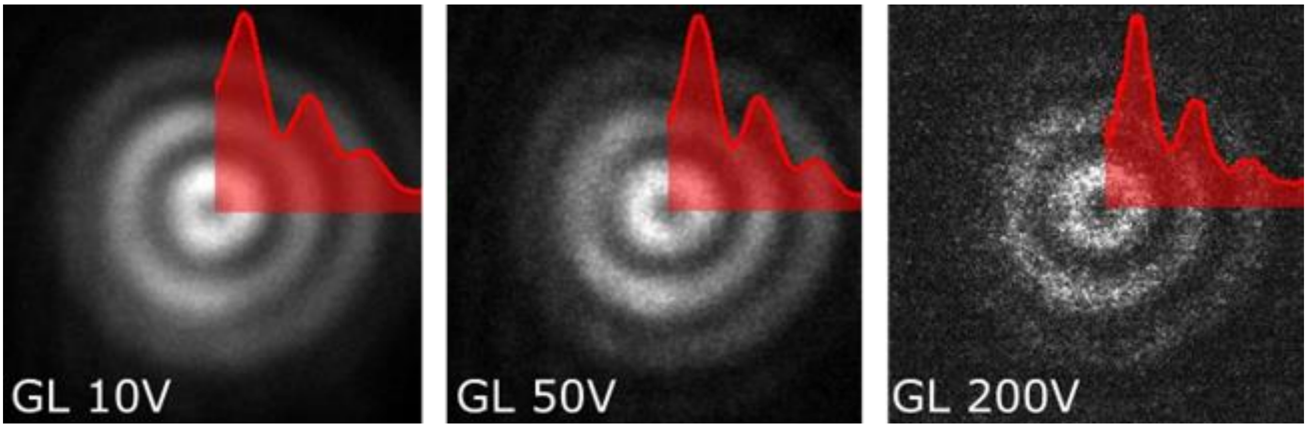

Figure 1: Images of the electron vortex beam for different gun lens excitations using a XFEG @ 200kV. An exposure time of 0.5 sec was used for all images. Insets show normalized and rotationally averaged intensity profiles.

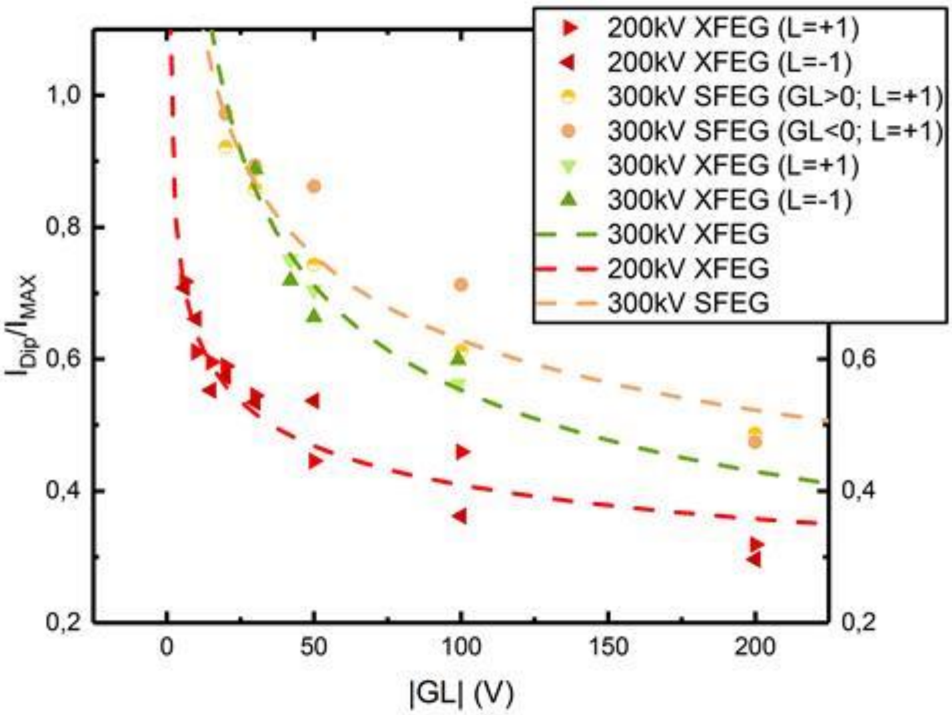

Figure 2. Relative intensity of the local minima at the center of the EVB as a function of the gun lens excitation for a SFEG and a XFEG system.