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Aberration-corrected Lorentz microscopy

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Spherical aberration correction has become a standard tool in a variety of TEM and STEM applications, in particular in high resolution observations. Lorentz microscopy, i.e., the study of magnetic features inside and surrounding a magnetic thin foil, has, since its inception, suffered from the presence of substantial spherical aberration, due to the fact that a lower quality, long focal length lens is typically used to obtain the images. Spherical aberration constants of several meters are not unusual, even on modern instruments; for instance, the C_s value for the Lorentz lens on a Titan 80-300 is around $8,400$ millimeters. Despite its large value, C_s is typically *not* the limiting factor for the spatial resolution in Lorentz mode. It is the fact that Lorentz images are usually taken out-of-focus, with, often, very large defocus values (tens to hundreds of microns) necessary to reveal the domain wall contrast. With the large defocus values comes a significant delocalization, especially on field emission instruments. A spherical aberration corrector used in Lorentz mode is therefore predominantly used to reduce delocalization effects, so that interpretable images can be obtained with smaller defocus values and a higher signal-to-noise ratio. In combination with an energy filter, high contrast Lorentz images with a spatial resolution in the neighborhood of 1 nm should be possible in principle.

In this contribution, we report on the successful correction of the spherical aberration of a Lorentz lens on a Titan 80-300 TEM, equipped with an image corrector and operated at 300 kV. The corrector's adapter lens (ADL) is used as the Lorentz lens, and the corrector settings are adjusted to bring down the spherical aberration well below 10 mm, i.e., a reduction by more than three orders of magnitude. Fig. 1(a) shows a screen shot from the aberration corrector control interface, in particular the Zemlin tableau acquired for a beam tilt of 1 mrad. It should be noted that Lorentz deflection angles are typically a few tens of μrad, so that a corrector alignment out to 1 mrad is more than sufficient for corrected Lorentz mode. The following are the values for the magnitudes of several important aberrations, as derived from the Zemlin tableau: $A_1 = 179.1$ pm, $A_2 = 26.5$ nm, $B_2 = 5.761$ nm, $C_3 = -3.429\,\mu$m, $A_3 = 26.37\,\mu$m, $S_3 = 14.04\,\mu$m, and $A_4 = 12.37$ mm. The spherical aberration of the ADL has therefore been corrected from a magnitude of about 8.4 meters down to just a few microns. This leads to a significant decrease of delocalization effects, as well as an improved signal-to-noise ratio. In other words, the point spread function is now a narrow single peak as opposed to a broader oscillating function, as shown in Fig. 1(b) and (c) (each at Scherzer defocus). Example under-focus and over-focus images for a multi-ferroic $Ni_{49.9}Mn_{28.3}Ga_{21.8}$ alloy are shown in Fig. 1(d) and (e), resp. In the central region of the image, the crystal orientation is such that a maze and bubble domain configuration occurs, whereas the regions on the left and right of the image prefer an in-plane magnetization with standard 180° domain walls. We will illustrate how the signal-to-noise ratio improves with aberration correction and zero-loss energy filtering, resulting in more reliable magnetic phase shift reconstructions. Implications for other ongoing LTEM-based projects, including vector field electron tomography, will also be discussed.

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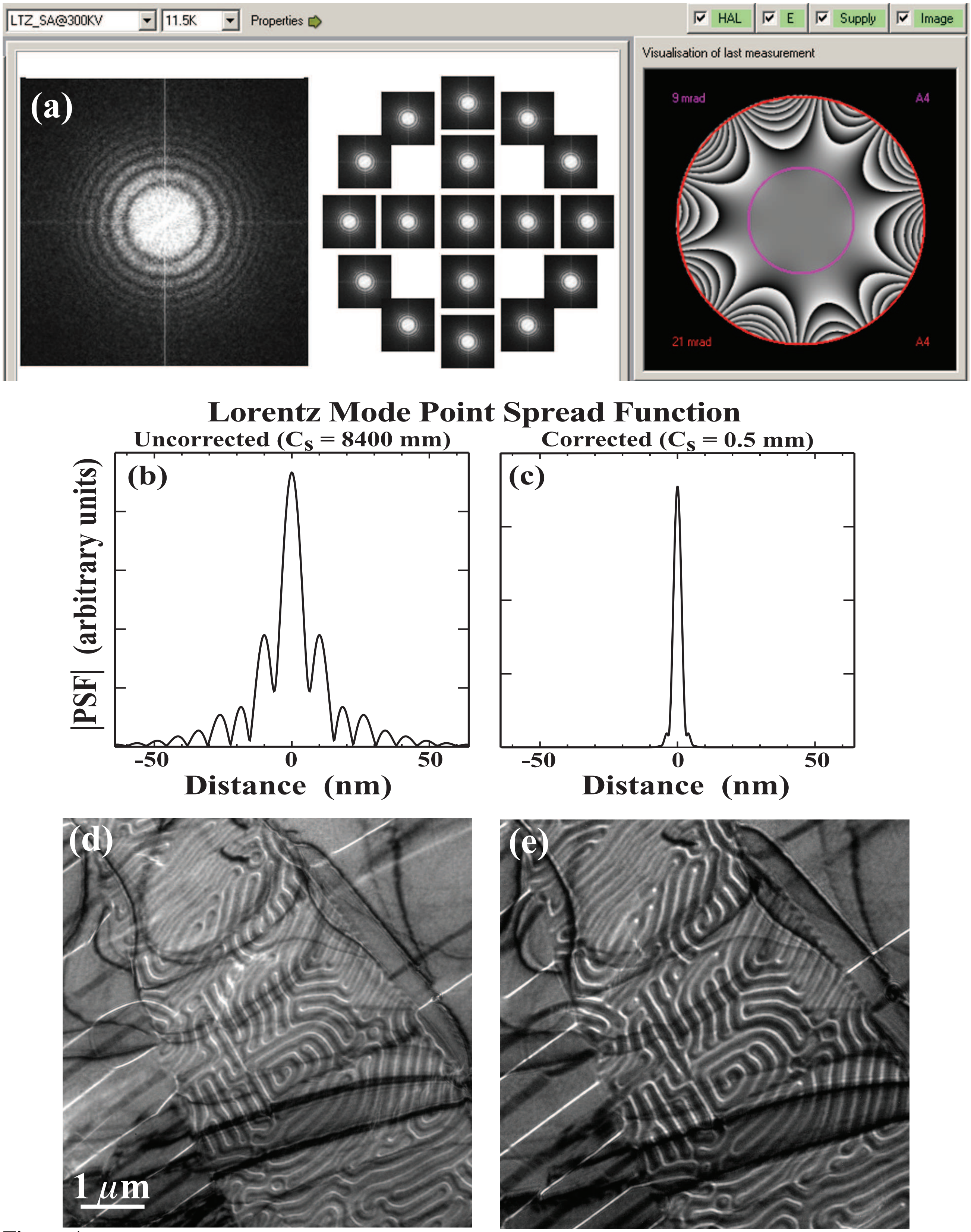

Figure 1: (a) Zemlin tableau at 1 mrad for corrected Lorentz mode; (b), (c) point spread functions for uncorrected and corrected Lorentz modes; (d) and (e) under- and over-focus images of a $Ni_{49.9}Mn_{28.3}Ga_{21.8}$ alloy.

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