Opportunities and Challenges for Chromatic Aberration Corrected High-Resolution and Lorentz Transmission Electron Microscopy

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Chromatic aberration (C_C) correction promises to provide improved spatial resolution and interpretability when compared with the use of spherical aberration (C_S) correction in the transmission electron microscope (TEM) alone, primarily as a result of improvements to the temporal damping envelope of the objective lens, especially at lower accelerating voltages [1, 2]. The reduced dependence of image resolution on energy spread in a C_C corrected TEM offers benefits for conventional bright-field and dark-field imaging as a result of the decreased influence of inelastic scattering on spatial resolution. Less refocusing is also necessary when moving between regions of different specimen thickness, which promises to be advantageous for electron tomography of thick specimens. For energy-filtered TEM, C_C correction allows large energy windows and objective aperture sizes to be used without compromising spatial resolution. A further benefit of C_C correction results from the fact that combined C_S and C_C correction of the Lorentz lens allows images to be recorded in magnetic-field-free conditions with a spatial resolution of better than 0.5 nm with the conventional objective lens switched off.

Here, we present a selection of calibrations and results obtained in both high-resolution and Lorentz (magnetic-field-free) conditions from a recently installed Titan Ultimate TEM equipped with a high brightness electron gun, a monochromator, a C_S corrector on the condenser lens and a combined C_S and C_C corrector on the imaging lens. Figure 1 shows Fourier transforms of C_C and C_S corrected high-resolution TEM images of Au particles on C, demonstrating the ability to record 80 and 65 pm detail at 80 and 300 kV, respectively. Figure 2 shows a C_C and C_S corrected Lorentz TEM image of $Cs_{0.5}[Nb_{2.5}W_{2.5}O_{14}]$ [001] acquired at 300 kV with the objective lens switched off. The image contains 0.5 nm detail, offering the

prospect of imaging magnetic fields in selected materials with close to atomic spatial resolution. Such instrumental and methodological developments, based on combined C_S and C_C correction, promise to provide new and improved approaches for characterizing the positions, chemical identities and magnetic moments of individual atoms in the TEM.

References:

1. L. Reimer and P. Gentsch, Ultramicroscopy **1** (1975), 1-5.
2. B. Kabius, P. Hartel, M. Haider, H. Müller, S. Uhlemann, U. Loebau, J. Zach and H. Rose, J. Electron Microsc. **58** (2009), 147-155.

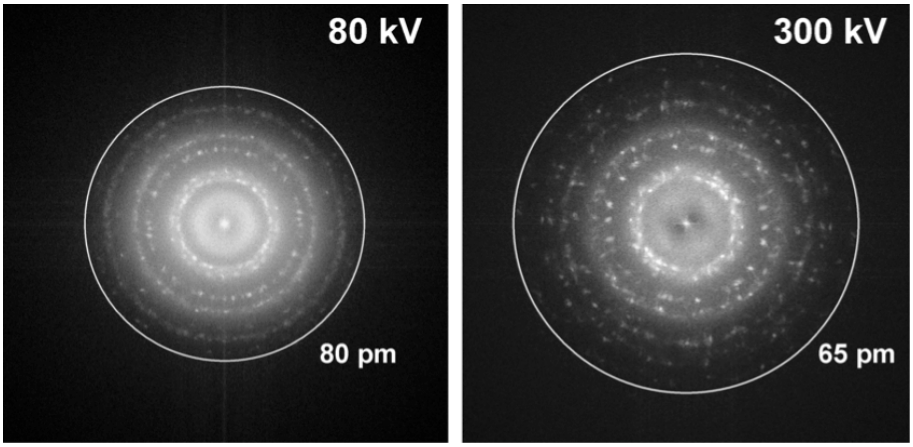

Figure 1. Fourier transforms of C_C and C_S corrected high-resolution TEM images of Au particles on C. The smallest spacing at 80 kV (left) is ~80 pm and at 300 kV (right) is ~65 pm.

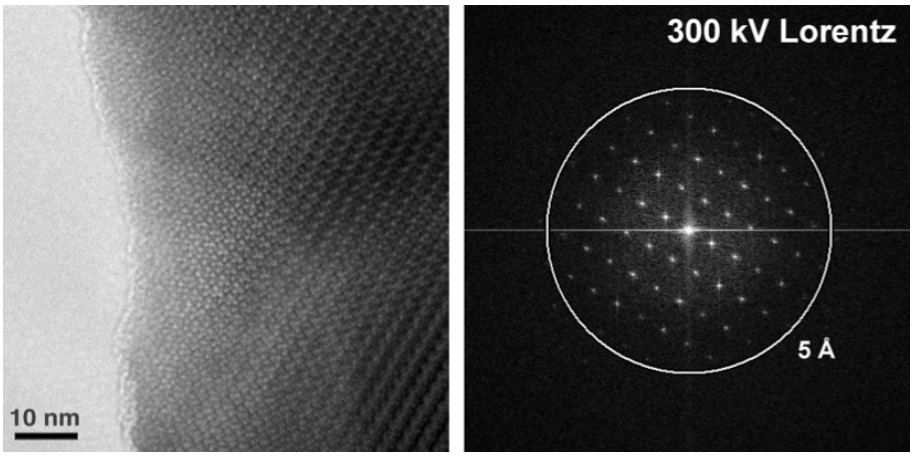

Figure 2. Left: C_C and C_S corrected image of $Cs_{0.5}[Nb_{2.5}W_{2.5}O_{14}]$ [001] acquired at 300 kV in Lorentz mode with the objective lens off. Right: Fourier transform revealing 5Å image detail.