Recent Progress in Chromatic Aberration Corrected High-Resolution and Lorentz Transmission Electron Microscopy

L. Houben[1], J. Barthel[1], A. Thust[1], M. Luysberg[1], C.B. Boothroyd[1], A. Kovács[1], J.R. Jinschek[2] and R.E. Dunin-Borkowski[1]

[1]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, Peter Grünberg Institute, Forschungszentrum Jülich, D-52425 Jülich, Germany
[2]FEI Company, Achtseweg Noord 5, 5651 GG Eindhoven, The Netherlands

Chromatic aberration (C_C) correction in high-resolution transmission electron microscopy (HRTEM) promises to provide improved spatial resolution and interpretability of images when compared with the use of spherical aberration (C_S) correction alone, primarily as a result of improvements to the temporal damping envelope of the objective lens, especially at lower accelerating voltages [1-3]. The reduced dependence of image resolution on energy spread in a C_C corrected microscope offers benefits for conventional bright-field and dark-field imaging as a result of the decreased influence of inelastic scattering on spatial resolution, even when using zero-loss energy filtering. Less refocusing is also necessary when moving between regions of different specimen thickness, which may be advantageous for electron tomography of thick specimens. For energy-filtered TEM, C_C correction allows large energy windows and large objective aperture sizes to be used without compromising the spatial resolution of energy-loss images, providing opportunities for recording background-subtracted chemical maps on the atomic scale and for using high (> 2 keV) energy losses. A further important benefit of C_C correction results from the fact that combined C_S and C_C correction of the Lorentz lens of a TEM allows ferromagnetic materials to be imaged in magnetic-field-free conditons with a spatial resolution of better than 0.5 nm with the conventional TEM objective lens switched off.

We have recently taken delivery of a Titan 60-300 field emission gun TEM equipped with a high brightness electron gun, a monochromator, a spherical aberration corrector on the condenser lens and a spherical and chromatic aberration corrector on the objective lens. Here, we present a selection of initial calibrations and test results from the microscope obtained under both high-resolution and Lorentz (magnetic-field-free) conditions. Figure 1 shows Fourier transforms of C_C and C_S corrected lattice images of Au particles on C that demonstrate the ability to record 80 and 65 pm detail at 80 and 300 kV, respectively. Figure 2 shows C_C and C_S corrected energy-loss images and a corresponding Ca elemental map that contains atomic resolution detail after background subtraction. Figure 3 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 turned off. The image contains 5Å detail, suggesting that it may be possible to image magnetic fields in selected materials with close to atomic spatial resolution.

References

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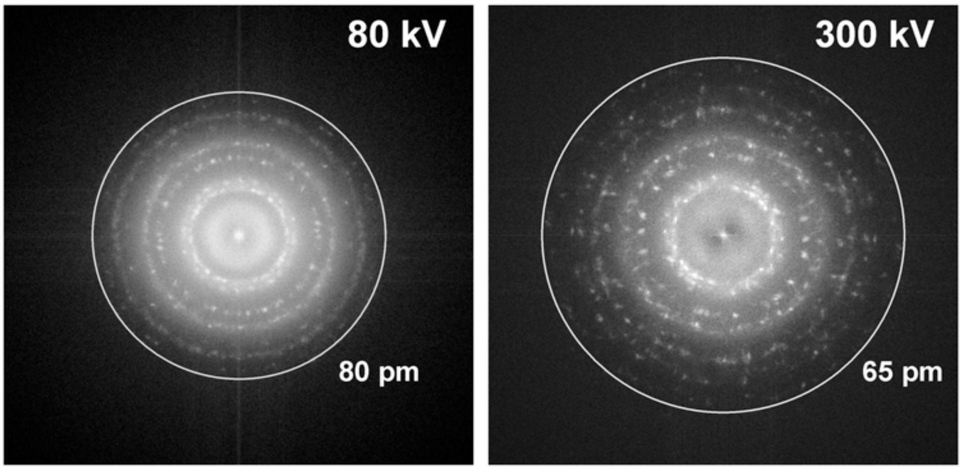

FIG. 1. Fourier transforms of C_C and C_S corrected HRTEM images of Au particles on a C support. The smallest detected image spacing at 80 kV (left) is ~80 pm and at 300 kV (right) is ~65 pm.

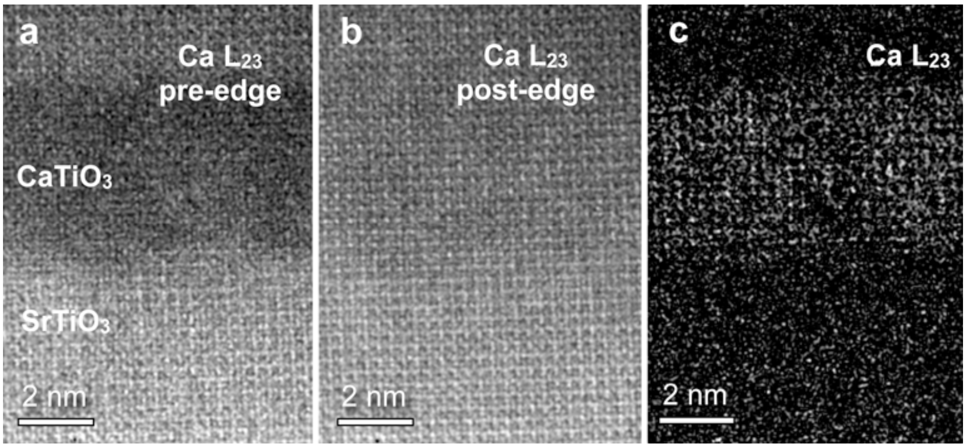

FIG. 2. Atomic resolution C_C and C_S corrected (a) Ca L_{23} pre-edge and (b) Ca L_{23} post-edge energy-loss images of a $CaTiO_3/SrTiO_3$ [001] multilayer acquired at 300 kV using 10 eV energy-selecting windows and no objective aperture. (c) Background subtracted Ca map showing Ca on the A sites of the pseudo-cubic perovskite lattice.

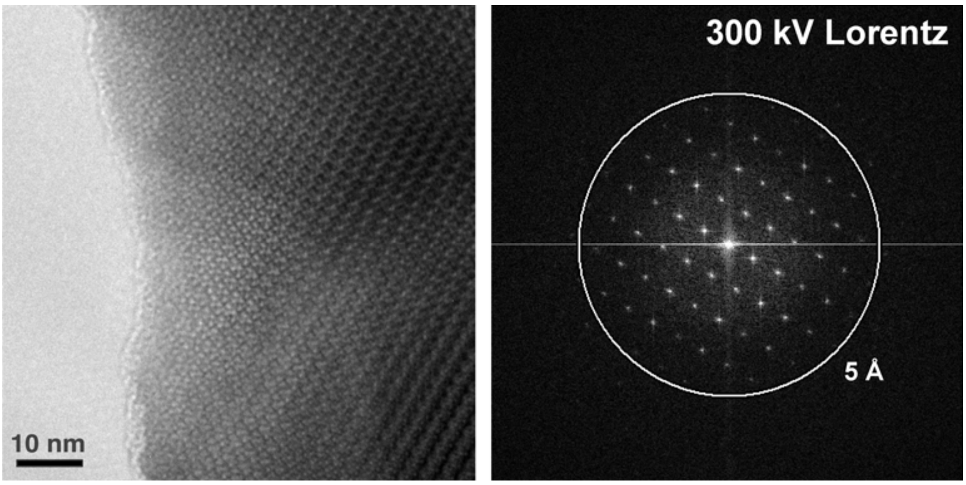

FIG. 3. Left: C_C and C_S corrected image of $Cs_{0.5}[Nb_{2.5}W_{2.5}O_{14}]$ [001] acquired at 300 kV in Lorentz mode with the objective lens turned off. Right: Fourier transform revealing 5Å image detail.