Recent progress in chromatic aberration corrected transmission electron microscopy

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Chromatic aberration correction in the transmission electron microscope (TEM) promises to provide improved spatial resolution and interpretability when compared with the use of spherical aberration correction alone, primarily as a result of improvements to the temporal damping envelope of the objective lens of the microscope, especially at lower accelerating voltages [1, 2]. The reduced dependence of image resolution on energy spread in a chromatic aberration 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, even when using zero-loss energy filtering. The fact that less refocusing is necessary when moving between regions of different specimen thickness is also potentially advantageous for electron tomography of thick specimens. For energy-filtered transmission electron microscopy (EFTEM), chromatic aberration correction allows large energy windows and large objective aperture sizes to be used without compromising the spatial resolution of energy-loss images. A further benefit of chromatic aberration correction is associated with the fact that combined chromatic and spherical aberration correction of the Lorentz lens of a transmission electron microscope allows images to be recorded in magnetic-field-free conditions with a spatial resolution of better than 0.5 nm with the conventional microscope objective lens switched off.

Recent results obtained using an FEI Titan Ultimate TEM equipped with an achroplanatic CEOS CCOR C_C/C_S corrector will be presented. The low accelerating voltage provided by this microscope, currently down to 50 kV, is beneficial for studies of materials that contain organic ligands, ligand-stabilised materials and materials that are functionalized with organo-metallic compounds. Examples will be taken from studies of materials that include graphene, carbon nanotubes, layered oxides and nanoparticles. Figure 1 shows an example of an atomic-resolution elemental map of Ca obtained from a thin TEM foil of a CaTiO_3/SrTiO_3 multilayer. The quantification of such elemental maps to provide atomic-resolution information about the local chemical composition of a specimen is complicated by the preservation of elastic contrast, which gives rise to thickness- and defocus- dependent image detail at all energy losses. The optical stability of the microscope over minutes of collection time, accurate image alignment and careful background subtraction are also required to obtain meaningful and reliable atomic-scale EFTEM elemental maps.
When combined with electron tomography, advances in specimen preparation, off-axis electron holography and automated image acquisition, such instrumental and methodological developments promise to lead to new and improved approaches for characterizing the positions, chemical identities, electronic structures, magnetic moments and electrostatic potentials of individual atoms, ultimately in three dimensions [3].

Figure 1: (a, b) Chromatic and spherical aberration corrected high-resolution energy-loss images of a CaTiO$_3$/SrTiO$_3$ [001] multilayer recorded at 300 kV. (a) is a Ca L$_{23}$ pre-edge image, while (b) is a Ca L$_{23}$ post-edge image. (c) shows the resulting background-subtracted EFTEM elemental map. (d, e, f) show noise-reduced images obtained by averaging images (a), (b) and (c) over 5 x 5 periods of the CaTiO$_3$ layer. The intensity in the elemental map is consistent with the presence of Ca on the A sites of the pseudo-cubic perovskite lattice.

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