doi:10.1017/S1431927613004960
Microsc. Microanal. 19 (Suppl 2), 2013

# Contribution of $C_c$-Correction to High-Resolution TEM at All Electron Energy Loss Regimes

J.G. Wen, D.J. Miller, N.J. Zaluzec, J.M. Hiller, R.E. Cook

Electron Microscopy Center, Argonne National Laboratory, IL 60439

High-resolution transmission electron microscopy (HRTEM) is a widely used technique to study materials at atomic resolution. With the development of spherical aberration correctors, direct structural mapping for thin TEM specimen has been achieved at negative $C_s$ imaging conditions (NCSI) by Jia *et al* [1]. The direct structural mapping has been demonstrated to be useful in many complex oxides such as superconductors, ferroelectric oxides, etc. Recently, an image corrector with the combination of spherical and chromatic aberration correction has been developed [2,3], and thus offers us an opportunity to study the contribution of $C_s$- and $C_c$-correction to HRTEM imaging. Here, we report the contribution of $C_s$- and $C_c$-correction to HRTEM imaging at different energy-loss regimes.

For conventional HRTEM image at zero-loss, we found $C_c$-correction improves both resolution and especially contrast as shown in Fig.1. The contribution of $C_c$-correction reduces the limit of damping envelope to contrast-transfer function as well as image delocalization. $C_c$-correction significantly reduces the focus range in images formed from electrons with an energy spread, as shown in the formula $\Delta f = C_c \cdot \Delta E/E$. Since correction of $C_c$ can reduce $C_c$ by as much as three orders of magnitude, not only is the focus range in images is reduced significantly for electrons with a given $\Delta E$, but a much larger $\Delta E$ can be used without significantly compromising resolution. When $C_c$ is corrected (for example $C_c = 1$ μm), electrons though a large slit window like 50 eV are focused in a narrow range of 0.375 nm, and thus widening slit width increases counts to energy-filtered TEM (EFTEM) TEM image to improve both resolution and S/N. Fig. 2 shows the jump-ratio EF-HRTEM images of pre- and post-edge of Ca $L_{2,3}$ to map the Ca containing layers taken at energy loss of 320 eV and 360 eV with a slit window of 50 eV. These two EF-HRTEM images show similar, but different "Z"-contrast" with HAADF image, due to the fact that the contrast in EF-HRTEM images is from inelastic scattering. Although the electrons that contribute an EFTEM image come from any inelastic scattering events, we found that EF-HRTEM images change contrast with defocus similar to conventional HRTEM images, indicating these in-elastically scattered electrons are coherent [5].

## References:

[1] Jia C.L. and Urban K, "Atomic-resolution measurement of oxygen concentrations in oxide materials". Science 303, 2001-2004 (2004).

[2] Kabius, B. *et al*, "First application of $C_c$-corrected imaging for high-resolution and energy-filtered TEM", J. Electron Microscopy, **15**, 1456-1457 (2009)

[3] Miller, D.J. *et al*, "New Opportunities for *in situ* Science Based on the TEAM Platform", Microscopy & Microanalysis, **17 (52)**, 450-451 (2011)

[4] Haider, M. *et al*, "Current and future aberration correctors for the improvement of resolution in electron microscopy", Phil. Trans. R. Soc. A **367**, 3665-3682 (2009)

[5] Research at the Electron Microscopy Center (EMC) at Argonne National Laboratory is supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.

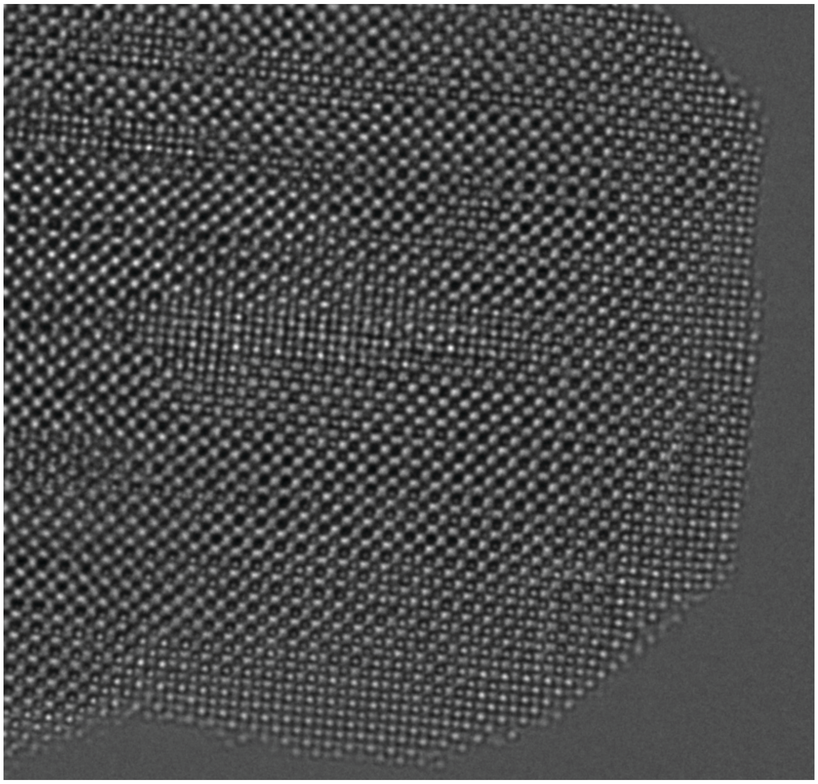

**Fig. 1**. HRTEM images of along [100] zone axis of a $(SrTiO_3)_2/(LaMnO_3)_2$ superlatice film on a $SrTiO_3$ substrate. The $C_s$- and $C_c$-correction improves both resolution and contrast as shown in HRTEM image.

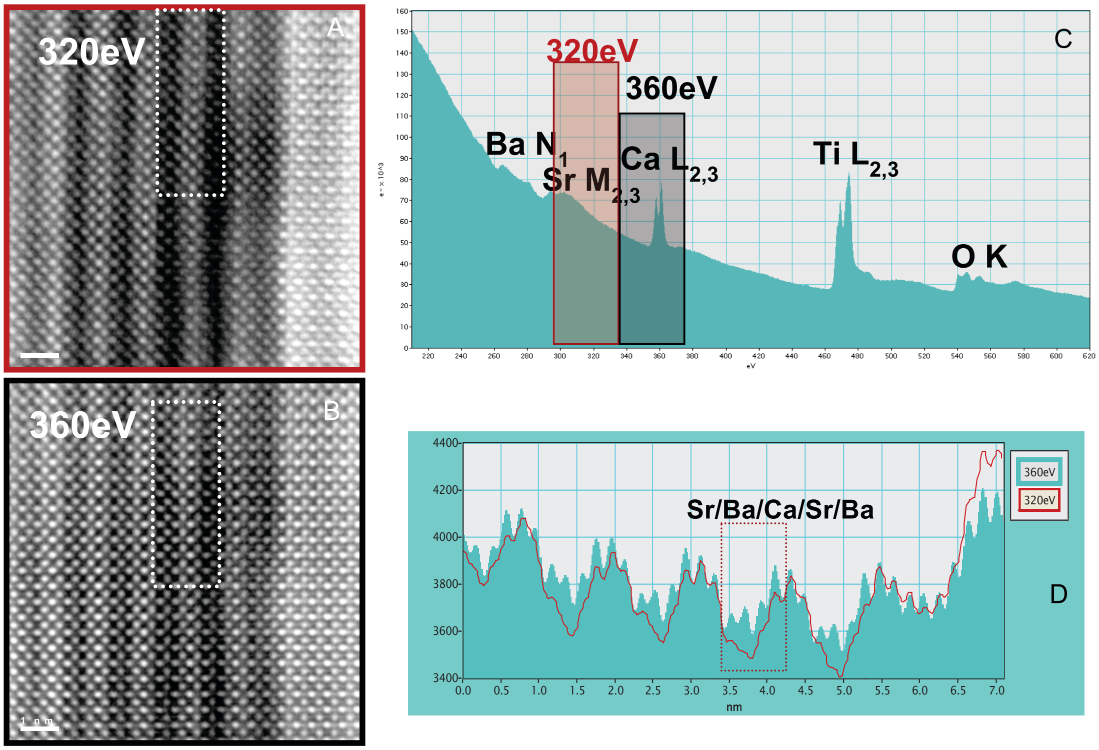

**Fig. 2**. EF-HRTEM images of A) pre- and B) post-edge of Ca $L_{2,3}$ for a $CaTiO_3/SrTiO_3/BaTiO_3$ superlattice on a $SrTiO_3$ substrate along [100] zone axis. These two images are taken with slit width of 50 eV. C) shows the location of the slit window in the EELS spectrum. D) Intensity profile shows the enhanced intensity in the $CaTiO_3$ layer.