Materials Applications of Aberration-Corrected STEM

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The 300 kV VG Microscopes' HB603U STEM at Oak Ridge National Laboratory with Nion aberration corrector recently achieved the first direct image of a crystal at sub-Angstrom resolution, as shown in Fig. 1. [1] The 0.78 Angstrom spacing of the dumbbell seen in Si⟨112⟩ is clearly resolved in the image and the Fourier transform indicates a probe size of 0.6 Ångstrom. This small probe allows the imaging of light atom columns next to heavy columns. Oxygen columns can now be imaged in the ⟨100⟩ projection in perovskites and related materials such as the manganites and high temperature superconductors. Figure 2 shows oxygen columns in $SrTiO_3$ with relative contrast close to that predicted from simulations using the experimentally determined aberration parameters.

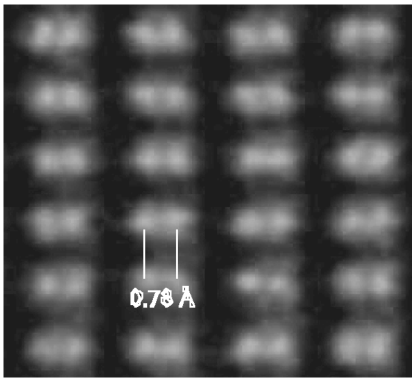

Fig.1: Z-contrast image of Si⟨112⟩ resolving the 0.78 Å dumbbell.

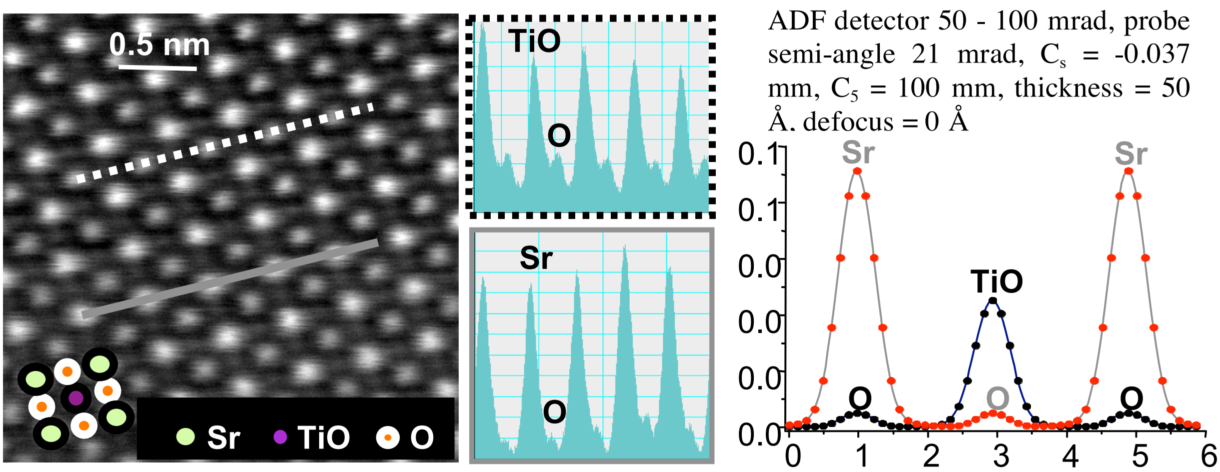

Fig 2: $SrTiO_3$ ⟨100⟩ imaged with a 0.6 Å probe showing O columns, compared to simulated line traces Sr-O-Sr and O-TiO-O. Simulations without O columns show no peaks at the oxygen locations.

It has long been appreciated that the STEM can provide a phase contrast bright field image through the use of a small axial collector aperture (equivalent through reciprocity to the condenser aperture of a TEM). The drawback has been that with spherical aberration very small apertures were required to avoid damping the transfer function unacceptably at high spatial frequencies, meaning phase contrast imaging in STEM could use only a very small fraction of the incident probe. After aberration correction, the transfer function shows far fewer oscillations (see Fig. 3), so a much larger aperture can be used and the transfer function becomes limited only by energy spread. Figure 4 compares aberration-corrected phase and Z-contrast imaging of $SrTiO_3$ ⟨110⟩, obtained at their respective optimum defocus settings from a through focal series. The oxygen columns are very visible in the phase contrast image. The STEM now becomes a viable means of acquiring aberration-corrected phase contrast images, with the advantage of simultaneous Z-contrast imaging and EELS.

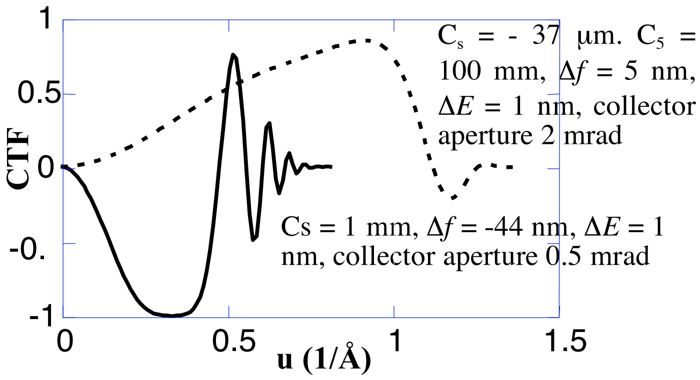

Fig. 3: Phase contrast transfer function of the HB603U before aberration correction (solid) and after (dashed).

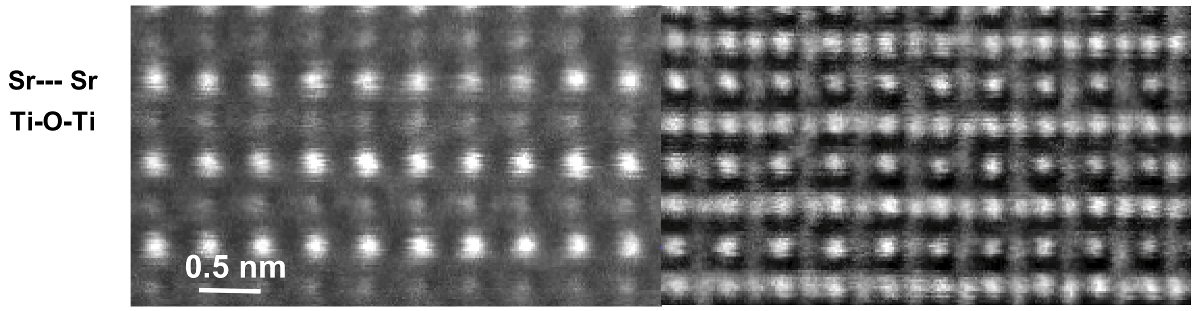

Fig. 4: Aberration-corrected Z-contrast and phase contrast images of $SrTiO_3$ ⟨110⟩ taken at a defocus of +2 and +6 nm respectively (raw data).

The small probe provides significantly enhanced sensitivity to single atoms, both imaging [2,3], and EELS [4]. Furthermore, the reduced depth of focus provides the possibility of 3D reconstruction through depth sectioning, with depth resolution at the nanometer level today but approaching the atomic level in future generations of aberration-corrected STEM [5].

References:
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