Materials Advances through Aberration-Corrected Scanning Transmission Electron Microscopy

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In just a few years, the successful correction of electron microscope aberrations has more than doubled the achievable resolution. Our VG Microscopes 300 kV scanning transmission electron microscope (STEM) equipped with a Nion aberration corrector recently achieved the first direct sub-Angstrom imaging of a crystal lattice, with a resolution of 0.06 nm. Besides improved resolution, the small beam size gives increased sensitivity; low-Z columns such as oxygen can be imaged adjacent to high-Z columns, and *individual* high-Z atoms can be imaged on or within specific columns of a crystal. Simultaneous electron energy loss spectroscopy is available, and single *atom* spectroscopy has recently been achieved.

Aberration-corrected images have revealed the form of catalytically active gold nanoclusters on titania, the sites of rare earth dopants in ceramic grain boundaries, the sites of La dopants on thermally stabilized alumina surfaces, and dislocation core structures more complex than previously imagined. First-principles theory transforms images into energetics leading to new understanding of structure-property relations and functionality.

A previously unanticipated advantage of aberration correction is the reduced depth of focus, which allows 3D imaging by optical sectioning in a manner analogous to confocal optical microscopy. Examples will be presented of the 3D imaging catalysts, and of single Hf atoms within a $Si/SiO_2/HfO_2$ gate dielectric structure. Presently the depth resolution is on the nm scale, but future generations of aberration-corrected STEM should approach atomic resolution in depth as well as laterally.