Aberration Corrected and Monochromated STEM/TEM for Materials Science


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The development of aberration correctors has improved the spatial resolution and sensitivity of both phase contrast imaging in high-resolution transmission electron microscopy and Z-contrast imaging in scanning transmission electron microscopy (STEM) [1,2]. In both cases, the ability to now correlate atomic scale changes in composition with the structure of interfaces and defects has opened a new realm in our ability to understand materials properties. An example of the type of images that can be obtained using the STEM approach to aberration correction is shown in Figure 1. Here the structures of mixed dislocations in GaN have been identified using the increased spatial resolution and signal to noise facilitated by the Nion corrected VG HB501 at the SuperSTEM in Daresbury, UK [3].

Similar to the advances afforded by aberration correction, the incorporation of monochromators into Schottky field emission TEM/STEM instruments has led to enhancements in spatial resolution for TEM imaging and dramatically improved the energy resolution achievable for electron energy loss spectroscopy (EELS) [4]. For instruments without aberration correction, the current combined limits of spatial and energy resolution for monochromated EELS have been particularly useful for the analysis of the low-loss region of the spectrum (where delocalization reduces the spatial resolution), permitting quantum confinement effects and optical responses of individual nanostructures to be measured directly. Figure 2 shows a series of low-loss spectra obtained from a sample containing a size distribution of CdSe quantum dots, where the bandgap change with size is readily observed and compared to optical [6] and theoretical studies [7] (These results were obtained from the FEI Tecnai in the National Center for Electron Microscopy at Lawrence Berkeley National Laboratory).

While the technology for aberration correction and monochromation has generally been incorporated into separate instruments, recent developments have permitted TEM correctors, STEM correctors and monochromators to be installed on a single microscope. One such instrument is the double corrected and monochromated FEI 80-300kV Titan that has been installed at Lawrence Livermore National Laboratory (LLNL). In this presentation, results from this system will be described that integrate TEM, STEM, and EELS to study nanowires, quantum dots, grain boundaries, semiconductor alloys and hydrogen storage materials [7].
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Figure 1: (a) Aberration-corrected Z-contrast image of a full-core mixed dislocation, and (b) aberration-corrected Z-contrast image of a dissociated mixed (partial dislocation), showing a stacking fault in between the (edge and screw) dislocation cores of approximately 3nm length.

Figure 2: (a) EEL spectra from 4 particles of different diameters; 2.0(±0.5) nm, 4.0(±0.5) nm 5.0(±0.5) nm and 7.0(±0.5) nm (b) Comparison of measured band gaps with optical [5] and theoretical studies [6].