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Model-based Low Voltage Imaging of Core-shell Hybrid Nanoparticles
Lawrence F. Drummy, Kimberly Kern, Hilmar Koerner, Richard A. Vaia
AFRL/RXAS, Air Force Research Labs, WPAFB, OH, USA

Hybrid materials have been the focus of significant recent attention due to their potential for exhibiting novel material properties by synergistically combining constituents. Because of their high interfacial area to volume ratio, core-shell hybrid nanoparticles have shown property enhancements in several applications including energy storage and sensing. A limiting factor for the performance of core-shell nanoparticles in these applications is synthetic reproducibility, and direct methods for characterization are needed in aiding reaction optimization and purification. Low Voltage Transmission Electron Microscopy (LVTEM) has traditionally provided high imaging contrast for materials composed of light elements such polymers, biomolecules and oxides. However, the density differences in core-shell materials are often small, and the internal interface between the core and the shell often occurs on top of a sloping background (such as the projected thickness of a sphere), making the boundary extremely difficult to visualize. In this work LVTEM imaging is combined with a geometrical model to calculate the expected intensity profiles of core-shell nanoparticles based on their known material scattering cross sections. Shell thickness in assemblies of polystyrene functionalized silica nanoparticles was varied by controlling the molecular weight and grafting density of the polymer on the nanoparticle surface. Core-shell calculated intensity profiles were fit to 2D projection TEM images of the nanoparticles, thus producing an effective 3D model for the structure. Segmentations were produced via hybrid median noise filtering and quantitative measurements of particle core size and shell thickness distributions were made. For model validation, the mass-thickness parameter of the microscope was calibrated using layered nanocrystals of known composition and thickness. As a cross-calibration with an independent characterization technique, small angle X-ray scattering provided global material structural parameters such as average interparticle spacing in 3D assemblies. This work is expected to provide a basis for quantitative microscopy experiments where the measured intensity distribution is directly related to a structural and chemical model.