Characterizing carbon nanotube mat supercapacitor electrode 3D-morphology with high resolution electron tomography

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Abstract:

The development of supercapacitor electrode materials is critical for future energy storage technologies and microscopy and microanalysis techniques are essential for accurate characterization. Nanomaterials used in the electrodes provide additional challenges for development as very high-resolution imaging techniques are required. These techniques, however, often provide only 2D representations of a material, which limits available information of the true bulk material morphology.

An intertwined carbon nanotube (CNT) mat was imaged with a FEI Technai F30 transmission electron microscope (TEM) at 300 kV to generate an electron micrograph tilt series for the generation of an electron tomogram. This technique provided a high resolution and 3D understanding of the electrode material's morphology, which enabled direct correlations with supercapacitor performance. The available electrode surface area and associated electrolyte mobility are important factors affecting supercapacitor performance. Similarly, characterizing the CNT entanglement and CNT bundle lengths is necessary to understand how the electrode material will perform structurally.

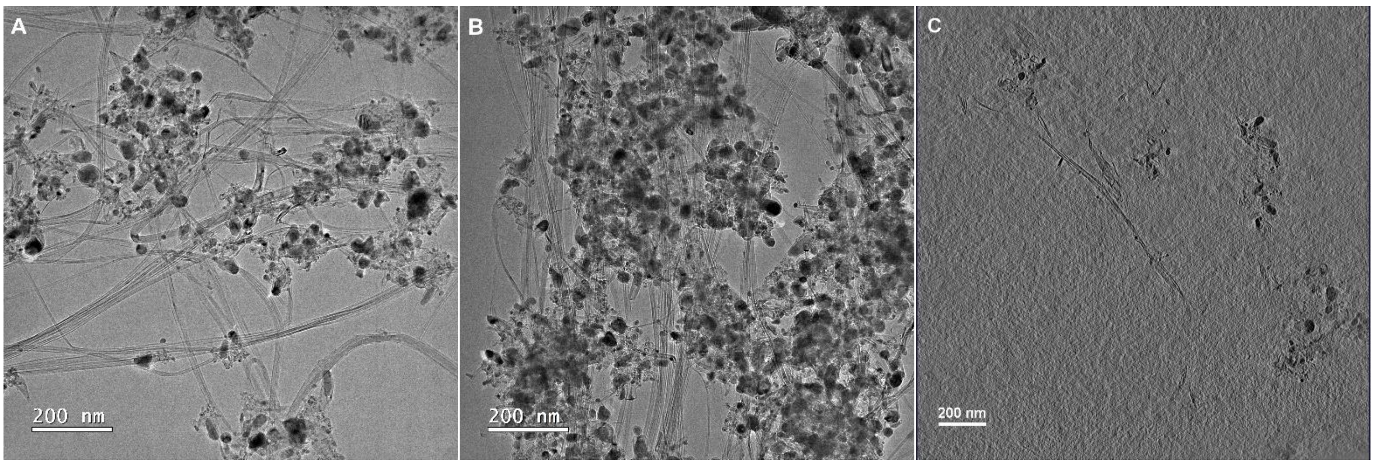

Figure 1: Transmission electron micrograph of CNT mat showing; ***A*** *intertangled CNTs,* ***B*** *large clusters of iron nanoparticles, and* ***C*** *single slice of electron tomogram showing large separation distances between neighboring particles.*

Figure 1A and B use conventional TEM to image the CNT mat, but fails to demonstrate the 3D nature of the material due to its large depth of field. In Figure 1A, CNTs appear to bundle and intersect on all angles and in Figure 1B the iron nanoparticle clusters appear to be microns in size, forming a super cluster. These 2D methods provide a deceptive impression of the 3D morphology and could be interpreted incorrectly. In contrast, the electron tomography in Figure 1C has revealed that this material is quite sparse in 3D, where CNTs only bundle inline and iron nanoparticle clusters are only comprised of tens of particles and not thousands. Movies of the tomogram and tilt series allow easy understanding of the bulk morphology of the CNT mat, which has been correlated directly with the electrochemical performance when used as a supercapacitor electrode.