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Secondary Electron Imaging with an Aberration Corrected Scanning Transmission Electron Microscope

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Secondary electrons (SE) are usually defined as inelastically scattered electrons with energies between 0 and 50 eV. The weak energies of the SE limit the escape depth to a few nanometers and therefore SE images are highly dependent on the surface topography. Since, SE images are generally reflective of the surface topography, interpretation is comparatively straightforward. Combined with high signal intensity and the ability to universally collected SE from most any sample, SE imaging is the most commonly used scanning electron microscope (SEM) technique and it has been estimated that SE images account for over 90% of the SEM images published [1].

In sharp contrast, SE imaging is probably the least commonly used scanning transmission electron microscope (STEM) technique with SE STEM images rarely published. To some extent, the lack of appeal for SE STEM imaging can be attributed to the geometry of some STEM specimens. Many STEM specimens such as thin foils, microtomed sections and focused ion beam thinned lamella are ideally flat and show little useful topographical features. Yet this does not account for the lack of SE STEM imaging of loose powder specimens particularly common to nano-materials. SE STEM images are also rarely collected because of the weak SE signal afforded in the STEM. The differential cross section of the SE is inversely proportional to the beam energy [2]. Because the acceleration voltage in the STEM is typically 1-2 orders of magnitude higher than the acceleration voltage in an SEM, the SE signal in the STEM is therefore significantly weaker.

More often than not STEM images are either collected using high angle annular dark field (HAADF) or bright field (BF) methods. The advantages of HAADF methods are that they are inherently higher resolution, have a high signal to back ground ratio and can provide compositional information through atomic number contrast [3]. The major drawback to both HAADF imaging and BF imaging techniques is that being a two dimensional projection they fail to provide any topographical information. To obtain topographical information from HAADF images require rather elaborate electron tomography experiments [4] or other computational image processing [5].

We have found that the recent advances in TEM instrumentation now allow SE STEM to be collected without compromising data quality. Aberration correctors have decreased beam probe size and increased beam current [6] resulting in better SE signal intensity and resolution. Moreover, multiple STEM images can be acquired simultaneously along with SE images. Comparing a HAADF image to the SE images greatly increases the confidence in image interpretation as is demonstrated in the STEM images shown in Figure 1 of a fractured composite silicon-carbon nanofiber. SE STEM images can also help deconvolute overlapping features and clearly show crystal faces as illustrated by the images of $LiMn_2O_4$ material shown in Figure 2.

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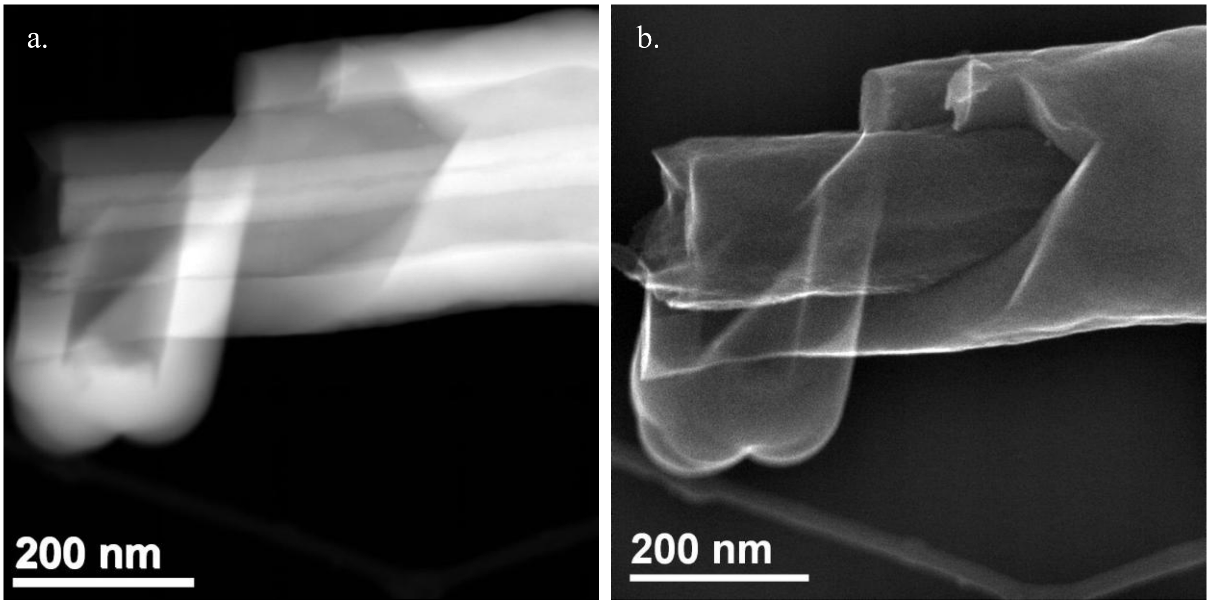

Figure 1. STEM images collected from a fractured silicon-carbon nanofiber (a. HAADF image and b. SE image).

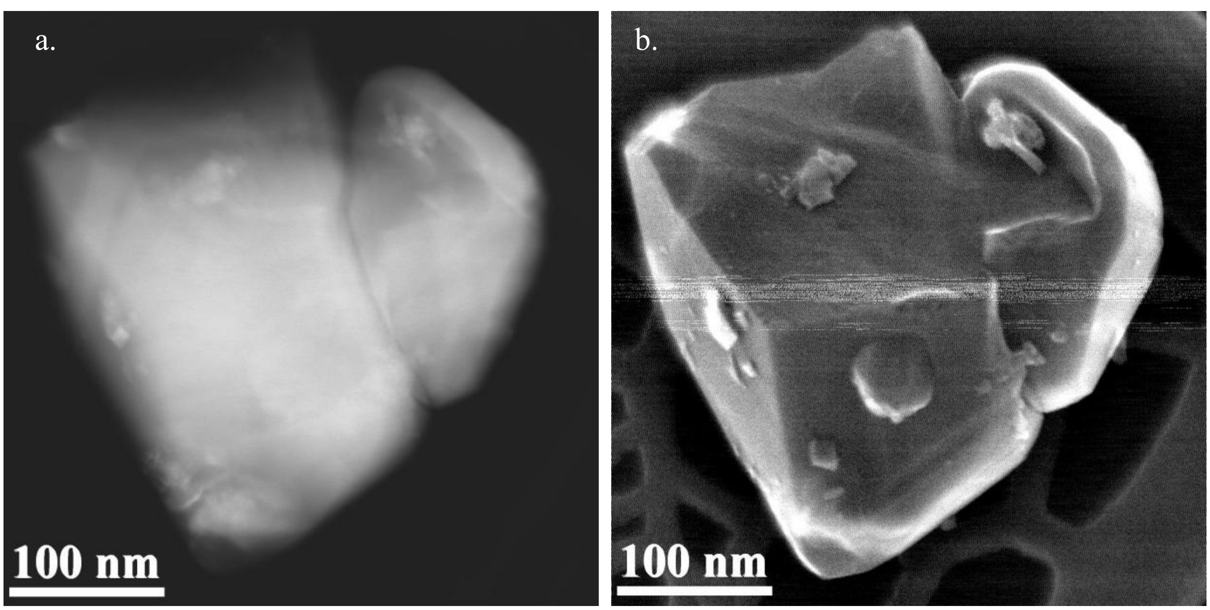

Figure 2. STEM images collected simultaneously from a $LiMn_2O_4$ spinel specimen (a. HAADF image and b. SE image).

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