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Characterization of a Double-tip Field Emission Source Using Inline Axial Holography

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In conventional high resolution transmission electron microscopy (HRTEM), the data recording process samples only the intensity of the electron wave after interaction with the sample, losing the phase component of the signal that records the majority of information about the beam-sample interaction. By recording a series of images with varying defocus, tilt, or other phase-modulating function, the phase information that is encoded within the intensities can be recovered though the use of the Gershberg-Saxton [1] or other well-documented algorithms. The additional information provided by the phase component of the full complex electron wave may be used not only to better characterize the sample itself, but may also provide useful information about the electron source.

Using the TEAM 0.5 (FEI Titan-class) aberration-corrected high resolution scanning transmission electron microscope at NCEM, we have recently discovered a focus-dependent imaging artifact that is only fully revealed through the reconstruction of a complex electron exit wave. Single images at arbitrary defocus showed no indications of an alignment problem with the microscope, and the CEOS aberration-corrector was well-behaved and easily tuned to typical residual aberration values. However, the summation of a spatially aligned focal series without reconstruction yielded an FFT with parallel streaks extending past the information limit of the microscope. Furthermore, upon reconstruction of a 41 image focal series (-1.72nm defocus step), the Fourier Transform of the complex electron wave revealed a second set of eccentric rings with an second origin offset from the center of reciprocal space (Figure 1). Both of these artifacts are consistent with the presence of a second, tilted beam in the column.

The imaging artifact ascribed to a second, tilted beam in the column was present at both 80kV and 300kV accelerating voltages, on all cameras, with and without the application of the Wien-type monochromator. The presence of a second beam in the electron column under all operating modes indicates a problem with the electron source. The presence of an additional terrace on the FEG emitter tip may yield a second emission source that is non-paraxial with the primary terrace, leading to a tilted second beam. However, it should be noted that the non-monochromated energy spread was 0.76eV, and monochromated energy spread was 0.12eV while the double-ring artifact was observed (both typical values for an X-FEG source on a monochromated FEI Titan microscope). Furthermore, aberration-corrected STEM images exhibited typical resolution, indicating that a possible second beam must be very weak in comparison to the primary beam (less than 1%).

The amelioration of this double-beam imaging artifact was achieved by raising the extraction voltage of the FEG source to 4500V (peak screen current of 32nA) over a period of four days. During that time, the FEG tip appeared to re-form with a single terrace, and the double-tip artifact vanished. Because this imaging artifact may only be observed in a reconstructed complex electron exit wave (not a widely used technique), it is unknown how common such a double-terraced tip may be in other microscope facilities or whether this unusual tip condition is limited to the specific FEI X-FEG design [2].

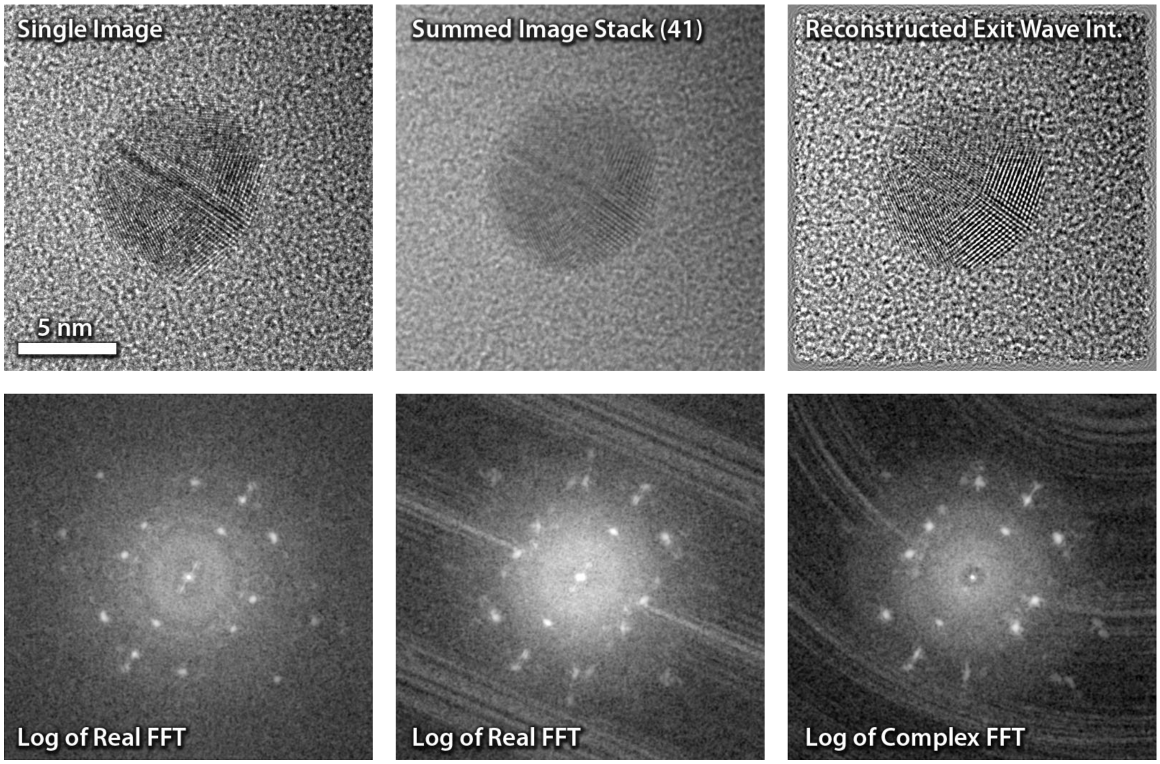

Figure 1. (left) Single HRTEM micrograph of a gold nanoparticle on amorphous carbon support. (center) Summed stack of 41 images with defocus values varying linearly from -35 to +35 nm. (right) Intensity of reconstructed exit wave. FFTs shown for each image. Note the artifacts visible as lines in the summed image stack FFT and as circles in the reconstructed exit wave FFT do not appear at all in single images.

References:

[1] R W Gerschberg and W O Saxton, Optic **35** (1972) p. 237
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