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IT-9-P-2743 Illumination Wavefront Determination by Image and Diffraction Focal Series

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In a transmission electron microscope (TEM), the geometric optics of the illumination system typically are unknown to the user, outside of some basic principles such as condenser lens underfocus or overfocus. When the intensity of a nanoprobe is measured, the phase shift across the probe is lost. The phase shift contains fine oscillations that affect how the probe propagates through the specimen. We present here a method to measure the optical parameters of the illumination system. With an optical model of the illumination mode, an estimate of the probe phase can be found for any lens conditions. The resulting complex entry-wavefunction can then be used for simulation and optimization of the instrument for nanobeam diffraction or coherent diffractive imaging (CDI).

The illumination system is modeled as a single compound lens using the paraxial approximation, with a demagnification of the source and limiting condenser aperture above the lens as shown in Fig. 1. The method calculates the three degrees of freedom: (1) the electron probe diameter b, (2) the convergence angle of the illumination α (or equivalently numerical aperture) and (3) the focal length of the illumination system f (shown in Fig. 2). The dependent parameters, (4) the condenser aperture optical diameter a, and (5) the defocus from specimen to the cross-over *z*f , are calculated in-addition. The demagnification can be estimated ($1/M \sim 60$) for the given spot size from the nominal aperture diameter. By Fourier optics, the wavefront at the aperture can be numerically forward propagated by za to estimate the complex wavefunction at the specimen.

Our method relies on acquisition of focal series of the nanobeam probe in vacuum via the Python scripting interface. The objective lens excitation is fixed at the eucentric focus. The operating condenser lens, C3 in the case of a FEI Titan, is varied through a large range, forming a series of nanobeam probes at the specimen plane, as shown in Fig. 3. The range is from an image of the condenser aperture conjugate on the specimen plane (C3 = -0.25 in Fig. 3), to the illumination focused on the specimen plane (C3 = 0.02 in Fig. 3). The TEM is then placed in diffraction mode and a series of vacuum diffractograms over both diffraction lens (DL) excitations, and the same range of C3 excitations, is collected (not shown). The diffraction series allows the convergence angle α to be measured, and the combination of both series allows the focal length to be stated in nanometers rather than nominal units. The magnifications in image-mode and camera length in diffraction-mode at each C3 and DL were measured from a second series of images and diffractograms from a monocrystalline Silicon specimen.

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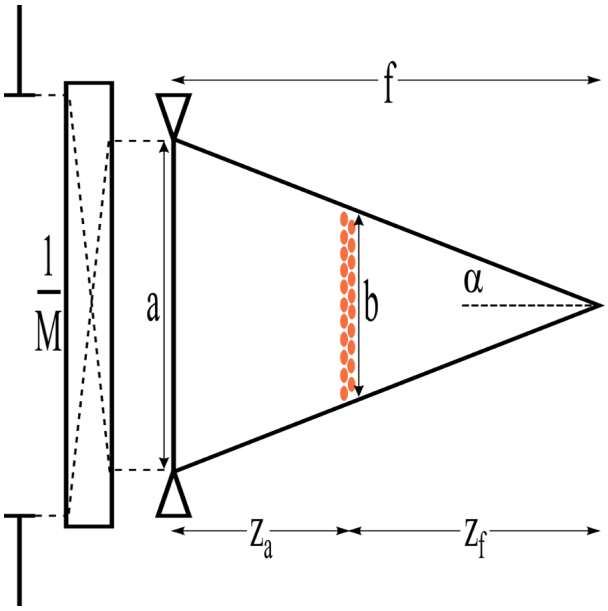

Fig. 1: The simplified TEM illumination model forms a probe on the specimen of diameter b and convergence angle α. The limiting aperture is demagnified by a factor 1/M. By varying the power of the lens for a series of focal lengths f, the unknowns of the model may be calculated and a conversion from nominal lens excitation to focal length made.

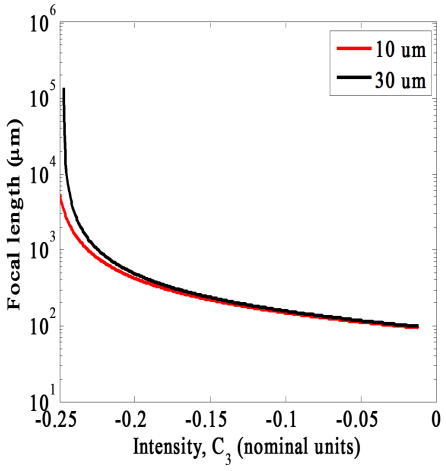

Fig. 2: Focal length of illumination f. The result for the two condenser apertures used, 10 µm and 30 µm, vary only slightly.

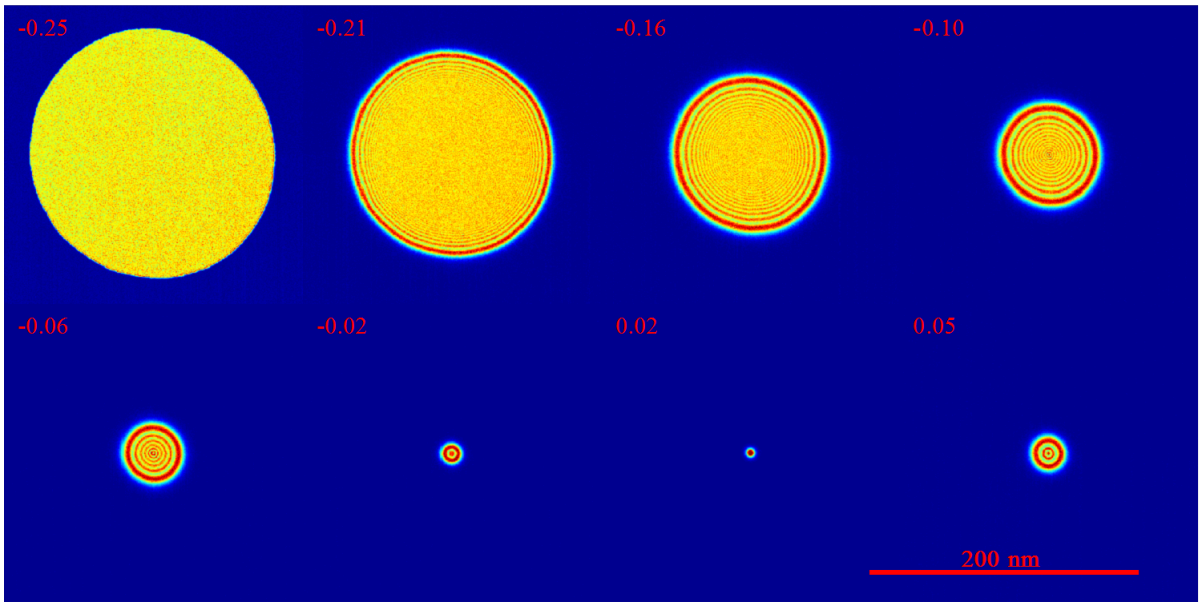

Fig. 3: A representative example set for the probe series in imaging mode for the condenser aperture in focus, at C3 = -0.25, to the focal point at C3 = 0.02, and just into overfocus, using the 10 □m aperture.