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IT-11-P-3191 Hybridization of Off-Axis and Inline High-Resolution Electron Holography

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In conventional TEM experiments, only the intensity (i.e., the square of the amplitude) of the wave function can be measured. The phase information gets lost when the electron is detected by the CCD camera. Denis Gabor introduced an approach that could be used to solve this problem 66 years ago [1]. In Gabor's original setup, which is the pioneering scheme for inline holography, the wave that has been scattered by the specimen (the object wave) interferes with a reference wave propagated along the same axis. Using laser light, Leith and Upatnieks [2] showed that separation of the axes of propagation of the reference and object waves could be used to solve the twin-image problem. Möllenstedt later translated this idea back to electron microscopy, creating the field of off-axis electron holography [3,4]. Inline electron holography, or focal series reconstruction, is now a common method in high-resolution TEM. Although it is very efficient for recovering high spatial frequency variations in phase, it is inefficient for recovering phase information at low spatial frequencies. In contrast, high-resolution studies are very challenging for off-axis holography, because the interference fringes must be at least twice as fine as the finest feature of interest in the object to be resolved.

In this study, we present a new approach that combines off-axis and inline holography and allows reliable phase information to be recovered for all spatial frequencies. For a desired signal-to-noise ratio, the required total exposure time is lower than that for traditional high-resolution off-axis electron holography.

All holographic data were acquired using round illumination with a FEI Titan TEM operated at 300 kV and using a bi-prism voltage of 97.4 V for off-axis electron holography. Figure 1 shows phase and amplitude images of a gold particle obtained using inline and off-axis electron holography and the hybrid method, respectively, for a total exposure time of 7s. Although the noise level in the vacuum region is slightly higher than for inline electron holography (0.055π vs. 0.046π), the recovery of low spatial frequencies is far better than for inline holography alone. Such noise levels are difficult to achieve using off-axis holography for the exposure time utilized here.

[1] D. Gabor, Nature vol. 161 (1948), p. 777–778.
[2] E.N. Leith, J. Upatnieks, J. Opt. Soc. Am. vol 52 (1962), p. 1123–1130.
[3] G. Möllenstedt and H. Düker, Naturwissenschaften vol. 42 (1955), p. 41–41
[4] G. Möllenstedt and H. Wahl, Naturwissenschaften vol. 55 (1968), p. 340–341

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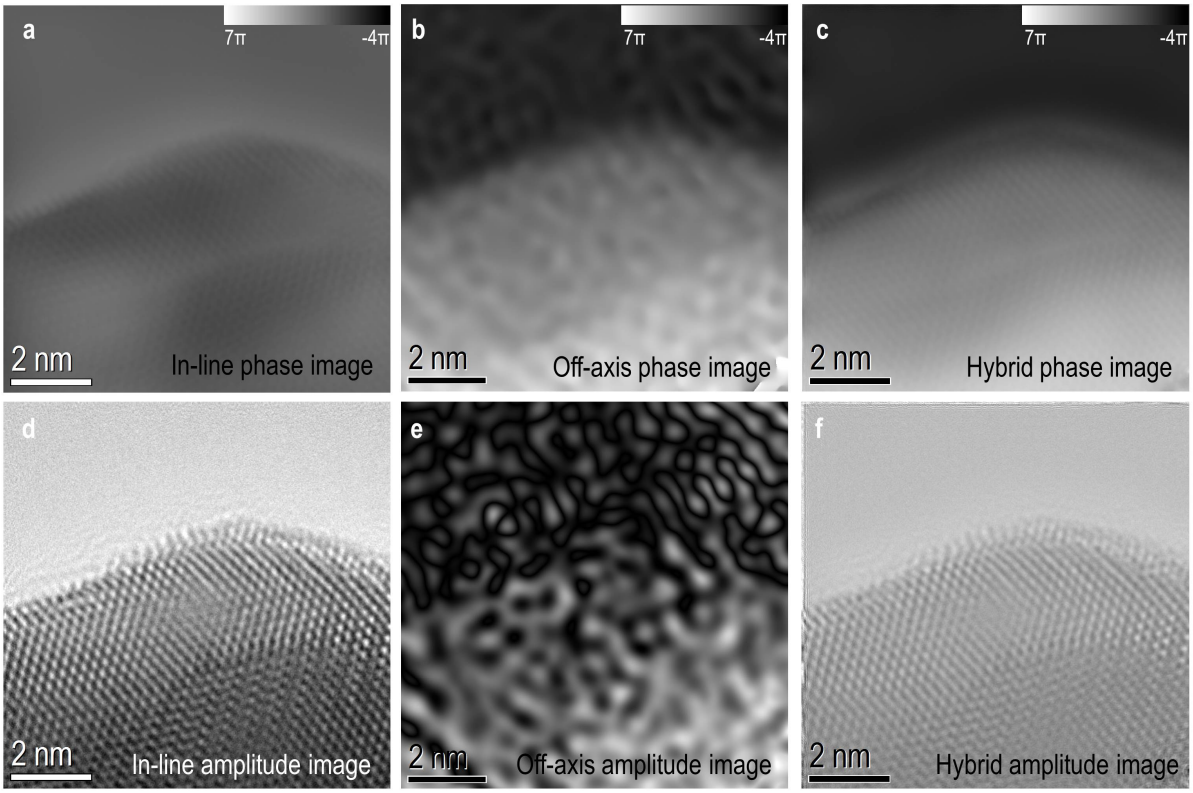

Fig. 1: a)-c) Reconstructed phase, d-f) reconstructed amplitude images from inline, off-axis and hybrid methods, respectively.