Atomic Resolution Electron Holography Performance of a Titan TEM with High-Brightness Electron Gun

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Electron holography is an extremely powerful method utilizing the phase of the electron wave. At atomic resolution, electron holography exhibits its strengths in allowing sophisticated wave optical analysis: Particularly for a Cs-corrected TEM, the a-posteriori correction of residual coherent aberrations is definitely mandatory aiming for lateral resolutions of 0.1 nm or better. Furthermore, imaging in the light of single reflections and diffraction from areas as small as a few unit cells are essential numerical methods for analysis of crystalline specimen (see e.g. in [1]).

The performance of electron holography also at atomic dimensions is mainly determined by two aspects: First, the lateral resolution is given by the information limit of the TEM. Second, the signal resolution is described by the phase detection limit, which is a figure of merit for the smallest phase difference significantly detectable between adjacent reconstructed data points (pixels). Both aspects are combined in a figure of merit called information content [2], which at the end depends on the brightness of the electron gun, the stability of the TEM, and the performance of the CCD-camera.

A significant improvement in brightness is realized by the new FEI's high-brightness electron gun, the so-called X-FEG, having an approximately five time higher brightness than a conventional Schottky field-emission gun. Consequently, a Titan X-FEG TEM, 300 kV acceleration voltage, and image Cs-corrector is an amazing instrument for atomic resolution electron holography. Figure 1 shows a hologram of a large angle grain boundary in Au [110]. In order to overcome the limited MTF/DQE of current CCD-cameras at least to some extent, the hologram was oversampled using the bottom-mounted 2k GIF CCD-camera yielding a total electron optical magnification of 3.15 Mx. In the Fourier spectrum of the hologram, the sidebands exhibit linearly imaged reflections up to {313} corresponding to a lattice plane spacing of 0.094 nm, which proofs the holographic sub-Ångström performance of the Titan X-FEG TEM. After MTF-correction and reconstruction, both amplitude and phase show atomically resolved details, however, slightly blurred. Subsequent correction of residual coherent aberrations yields the object exit-wave finally resolving the true atom positions at an improved contrast well above noise level (figure 2). This is the prerequisite for atomic columns analysis like e.g. determination of their displacement in the vicinity of the grain boundary or the measurement of their atomic weight. Further instrumental improvements would be a higher stability of the biprism and CCD-cameras with better MTF/DQE.

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2. H. Lichte, Ultramicroscopy 108 (2008) 256.

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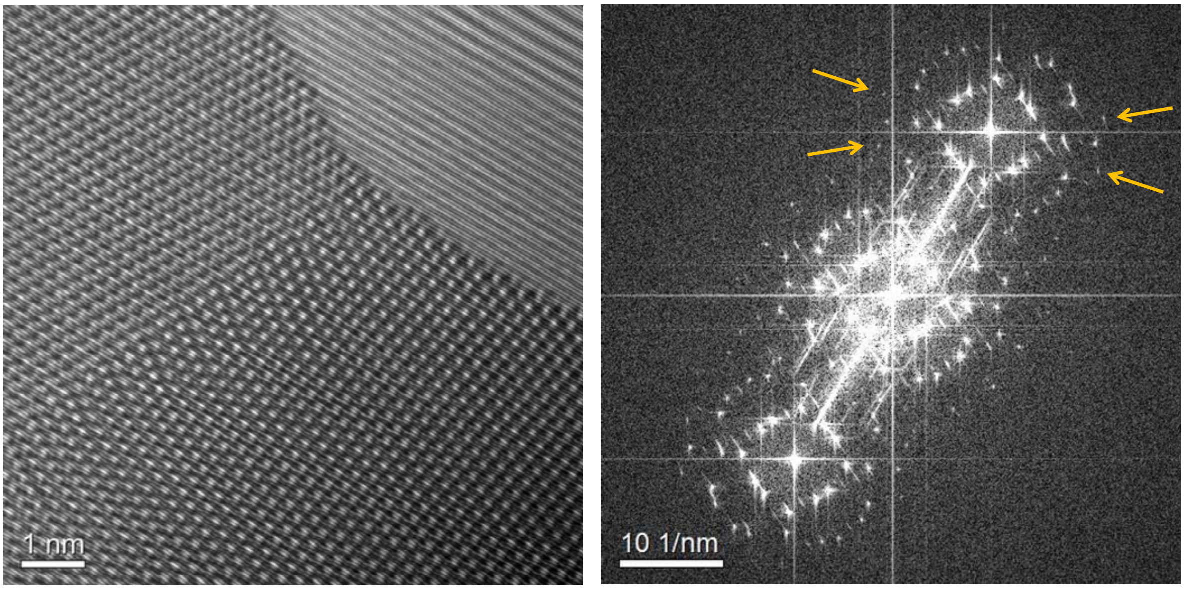

Figure 1. Left: Hologram of a large angle grain boundary in Au [110]. The interference fringe spacing is 0.054 nm, the biprism voltage 900 V, and the fringe contrast in the upper right part 13.2%. Right: The corresponding Fourier spectrum shows the centerband and the two sidebands. The arrows mark {313}-reflections, which are related to a lattice plane spacing of 0.094 nm.

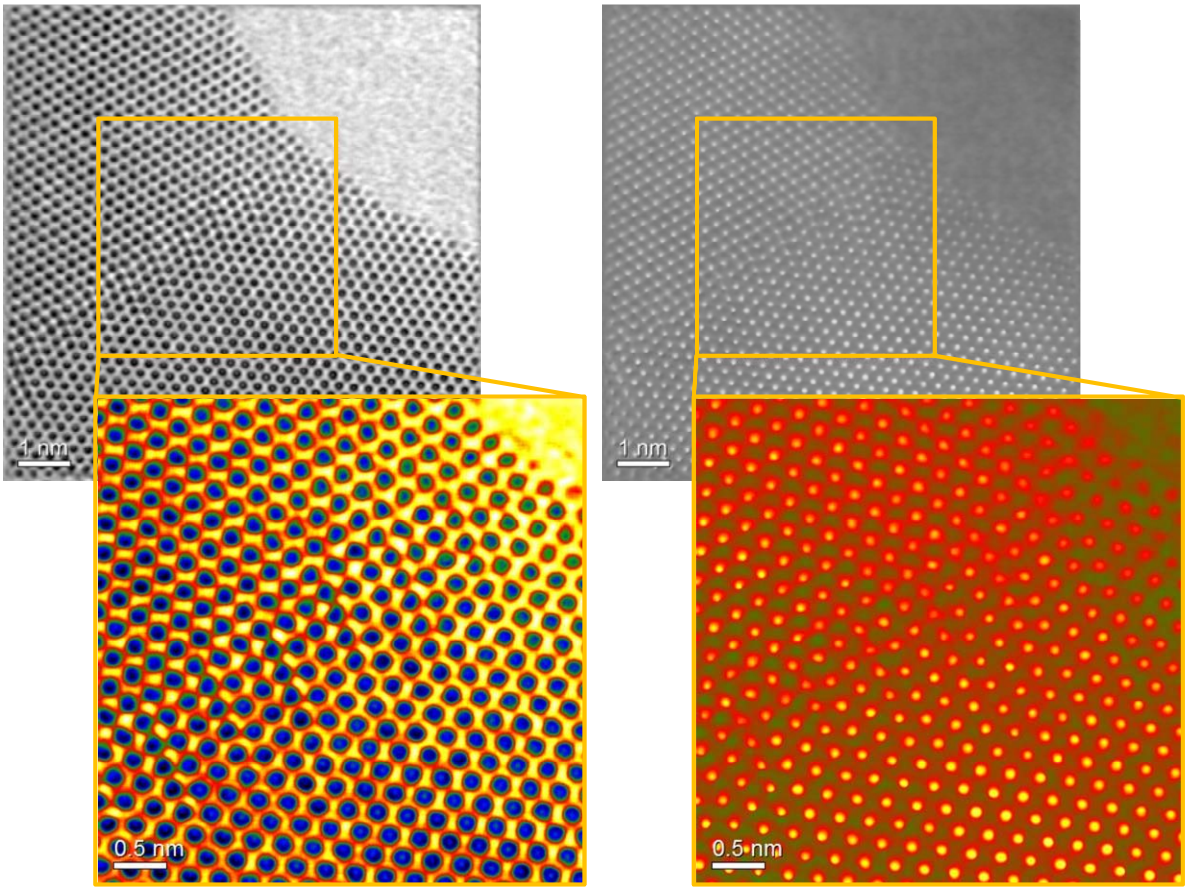

Figure 2. Reconstructed and corrected object exit-wave in amplitude (left, display range 0..1.4) and phase (right, display range 0..2π) showing quantitative information on both the position and weight of atomic columns.

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