Artefacts in electron holography

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Off-axis electron holography has shown to improve the point resolution of our CM30FEG-Special Tübingen electron microscope from 0.2nm to 0.13nm [1]. However, in off-axis electron holography artefacts may arise specific to the method. In particular at high resolution they must be avoided or taken into account to obtain reliable results after correction of aberrations. In the following we describe some artefacts found so far to be essential. Details are being published [2].

Vignetting effects

Vignetting shows up in a hologram in that the biprism inserted between back focal plane and image plane acts as a spatial frequency filter with transmission varying with the position in the image plane: image stripes close to the biprism shadow only contain single-sideband information (fig.1). This is not tolerable in the case of an object made up by both amplitude and phase components because double sideband information is needed to reconstruct both amplitude and phase of the object wave. Related to the object, the width of the part of the hologram free from vignetting turns out to be

$$w_{obj} - n_b = w_{obj}\left(1 - \frac{R_{\max}}{R_c}\right) - 2r\frac{f}{a}\frac{R_{\max}}{R_c}$$

(R_{max}: maximum spatial frequency of object, R_c :carrier frequency of hologram fringes, r: radius of biprism filament, a: distance back focal plane-intermediate image, f: focal length, w_{obj}: width of hologram, v_b: vignetted area). Evidently, less than 2/3 of the hologram at the far side of the biprism filament is free from vignetting.

Fresnel diffraction at the biprism filament

The biprism is located at some distance above the image plane. Therefore, in the image plane one finds both amplitude and phase of the image wave and the reference wave modulated by Fresnel diffraction at the biprism filament (fig.2). At first glance, the modulation seems to be negligibly small, however, it must be compared to the modulation by the object which, e.g. in the case of single atoms, may be much smaller than Fresnel modulation. In general, Fresnel modulation cannot be corrected by means of a reference hologram since Fresnel modulation in the object wave depends on the object structure.

Windowing

The hologram represents only a small window of the image wave transmitted to the final image plane of the electron microscope. Therefore, the Fourier spectrum available in the computer under reconstruction is convoluted with the Fourier transform of the window. Consequently, the numerical phase plate for correction of aberrations acts on spread-out reflections whereas the wave aberration in the electron microscope acted on δ-peak like reflections. Therefore, due to the gradient of the wave aberration over the spread-out reflections, the corresponding elementary waves superimposing in the image plane are mutually shifted aside such that the correct object wave results only in a center area of the field of view. The results show that the useful field of view is smaller by the point spread function of the electron microscope than the width of the hologram.

Geometric distortions

In an electron microscope, geometric distortions occur as a consequence of the aberrations of the magnifying lenses or due to local parasitic charges along the electron path. They produce deformations of the geometric arrangement of image details like atom positions which may be well annoying but usually they do not affect resolution. In electron holography, however, they do affect resolution. The reason is that distortion of the hologram fringes results in an artificial phase distribution of the reconstructed wave, which in turn produces a displacement of the reflections in Fourier space depending on real space position. Therefore isoplanacy is reduced and correction of aberration - assuming isoplanacy over the whole field of view - is only effective in the resulting isoplanatic patch. To reach 0.1nm resolution with our microscope, distortions must be less than 0.1%. This can only be reached by careful distortion correction with the help of an empty reference hologram prior to correction of coherent aberrations.

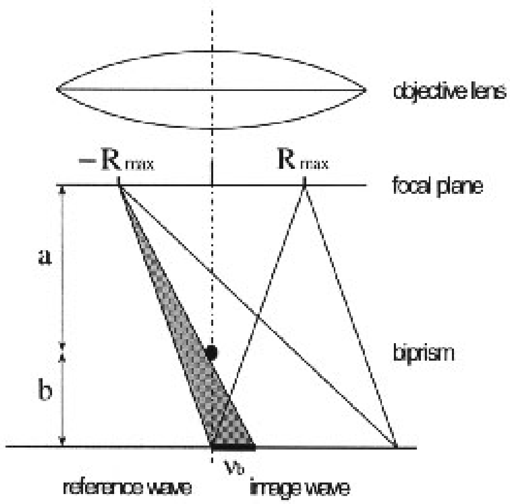

Fig.1 Vignetting by biprism filament. Applying a positive voltage to the biprism, the spatial frequency -Rmax does no more contribute to the image wave in a stripe of width v_b parallel to the filament. Single side band imaging results.

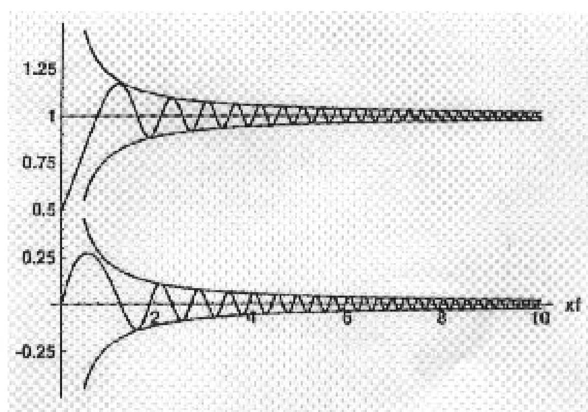

Fig.2 Fresnel modulation at the left side of the reconstructed field of view. Amplitude (top) and phase as function of coordinate $x_f = x\sqrt{\frac{2ka}{b(a+b)}}$ perpendicular to the biprism filament

References:

[1] A. Orchowski, W.D. Rau and H. Lichte, Electron holography surmounts resolution limit of electron microscopy, Phys.Rev.Letters 74(1995), 399-402

[2] H. Lichte, D. Geiger, A. Harscher, E. Heindl, M. Lehmann, D. Malamidis, A. Orchowski and W.D. Rau, Artefacts in electron holography, Ultramicroscopy, in press

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