High resolution phase-shifting holography

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Off-axis electron holography provides a means of determining both the amplitude and the phase of the electron wave after it has passed through a sample. Normally the specimen electron wave is interfered with a reference wave passing around the sample to form interference fringes (figure 1a), whose amplitude and phase are reconstructed using Fourier methods giving a reconstructed amplitude and phase (figure 1b) whose spatial resolution cannot be better than the spacing of the interference fringes. Reducing the noise in a hologram and thus in the reconstructed phase requires longer exposures once the optimum coherence has been found, with the limit to the resolution depending on the amount of drift of the specimen or biprism that can be tolerated.

In phase-shifting holography multiple holograms of the same area are obtained but with small phase shifts added between the two waves to move the fringes relative to the sample. The specimen wave can then be determined for each image pixel independently meaning that the spatial resolution is not limited by the hologram fringe spacing (Ru et al, 1994). However existing phase-shifting reconstruction methods still require the sample to be drift-free during the entire image series and the phase-resolution is limited by the presence of Fresnel fringes from the biprism and by the distortion caused by defects in the fibre-optics of the recording camera.

We show here an iterative method whereby a series of phase-shifting holograms can be reconstructed in the presence of both specimen and biprism drift to determine the specimen exit wave, using a method similar to that used by Boothroyd et al (1990) to determine the gain reference from energy-loss spectra. Paradoxically the method works best when a small amount of specimen and biprism drift is present. The hologram series is initially reconstructed using the method of Ru et al (1994). Using this initial estimate, the specimen exit wave can be subtracted from each hologram, the holograms aligned with respect to the camera and averaged to give the camera defects. Both of these estimates can be subtracted from the original holograms, the holograms aligned this time with respect to the hologram fringes so that their average gives the Fresnel fringes. Generally around 10 iterations is sufficient to separate the specimen intensity, amplitude and phase, Fresnel fringes and camera defects with resultant improvements in the quality of the specimen amplitude and phase (figure 1c).

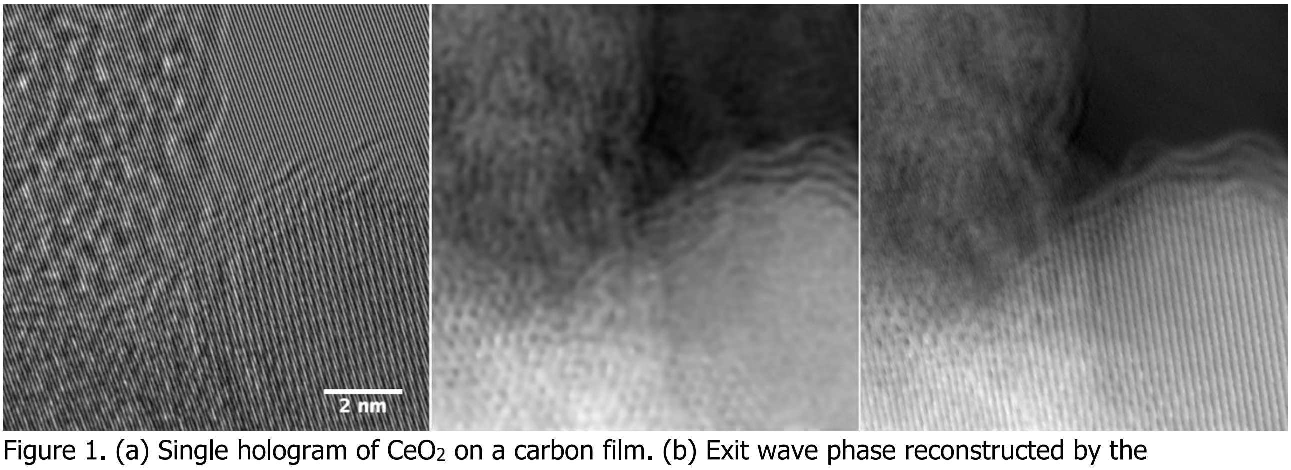

Figure 1. (a) Single hologram of CeO_2 on a carbon film. (b) Exit wave phase reconstructed by the conventional Fourier method. (c) Exit wave phase iteratively reconstructed from a series of 26 phase-shifting holograms.

Q Ru, G Lai, K Aoyama, J Endo, A Tonomura (1994)

Principle and application of phase-shifting electron holography

Ultramicroscopy 55, 209-220

CB Boothroyd, K Sato and K Yamada (1990)

The detection of 0.5at% boron in Ni_3Al using parallel energy loss spectroscopy

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