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Phase Shifting Reconstruction for High Resolution Electron Holography

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Electron holography was invented by Gabor [1] in 1948 to correct aberrations of electron microscopes. Since off-axis electron holography with an electron biprism was realized, aberration correction has been carried out by several researchers [2-4]. One of the serious problems of object wave reconstruction with the Fourier method is caused by the limitation of electron coherence. In order to obtain high spatial resolution on the reconstructed wave, fine interference fringes are essential. To be exact, the spacing of the fringes should be narrower than 1/3 of the spatial resolution that users demand on the reconstructed wave. In such conditions, however, the fringe contrast is drastically decreased because of the limited source coherence. Thus, it is difficult to improve the spatial resolution and the phase measurement precision at the same time.

Phase shifting electron holography was developed to obtain higher spatial resolution and more precise phase measurement [5]. The object wave is reconstructed from many holograms whose interference fringes are shifted one after another. The amplitude and phase are retrieved pixel by pixel from the intensity change of the holograms. Thus, the spatial resolution of the reconstructed wave is determined by the pixel size. This means that it is not necessary to make fine interference fringes, i.e. high contrast coarse fringes can be used for more precise reconstruction. Moreover, since many holograms are used for the reconstruction, the object wave can be reconstructed with higher S/N ratio. As the result, phase changes as small as $2\pi/300$ rad have so far been detected in some electromagnetic images [6].

Here we report the result when the phase shifting electron holography was applied to reconstruct the object wave of high resolution image. We used a Philips CM200 FE-TEM (200 kV, point resolution; 0.25 nm) with an electron biprism. Figure 1 (a) shows a high resolution image of HgCdTe single crystal oriented to the [110] direction recorded at a magnification of 900 KX. Figures 1 (b) and (c) are, respectively, one of the holograms and the corresponding reference hologram. The biprism voltage was adjusted to 24 V to form high contrast and uniform interference fringes. The contrast of the fringes in Fig. 1 (c) was 65 %. The fringe spacing is almost the same as the lattice spacing of the sample. Thus, it would be impossible to reconstruct the object wave using the conventional Fourier method because the sidebands are not separated from the centerband. For the reconstruction using the phase shifting method, 24 pairs of holograms and reference holograms were recorded. The reconstructed amplitude and phase images are shown in Fig. 1 (d) and (e) respectively. Atomic scale details are visible in both images. The amplitude and phase values corresponding to 0.021 nm were retrieved in each pixel. Phase differences as small as $2\pi/130$ rad were detected between some lattice positions.

In summary, we have applied the phase shifting method to reconstruct the object wave of high resolution image.

Although the high resolution image was completely buried in coarse interference fringes of holograms, the object wave was reconstructed with high spatial resolution and high phase precision.

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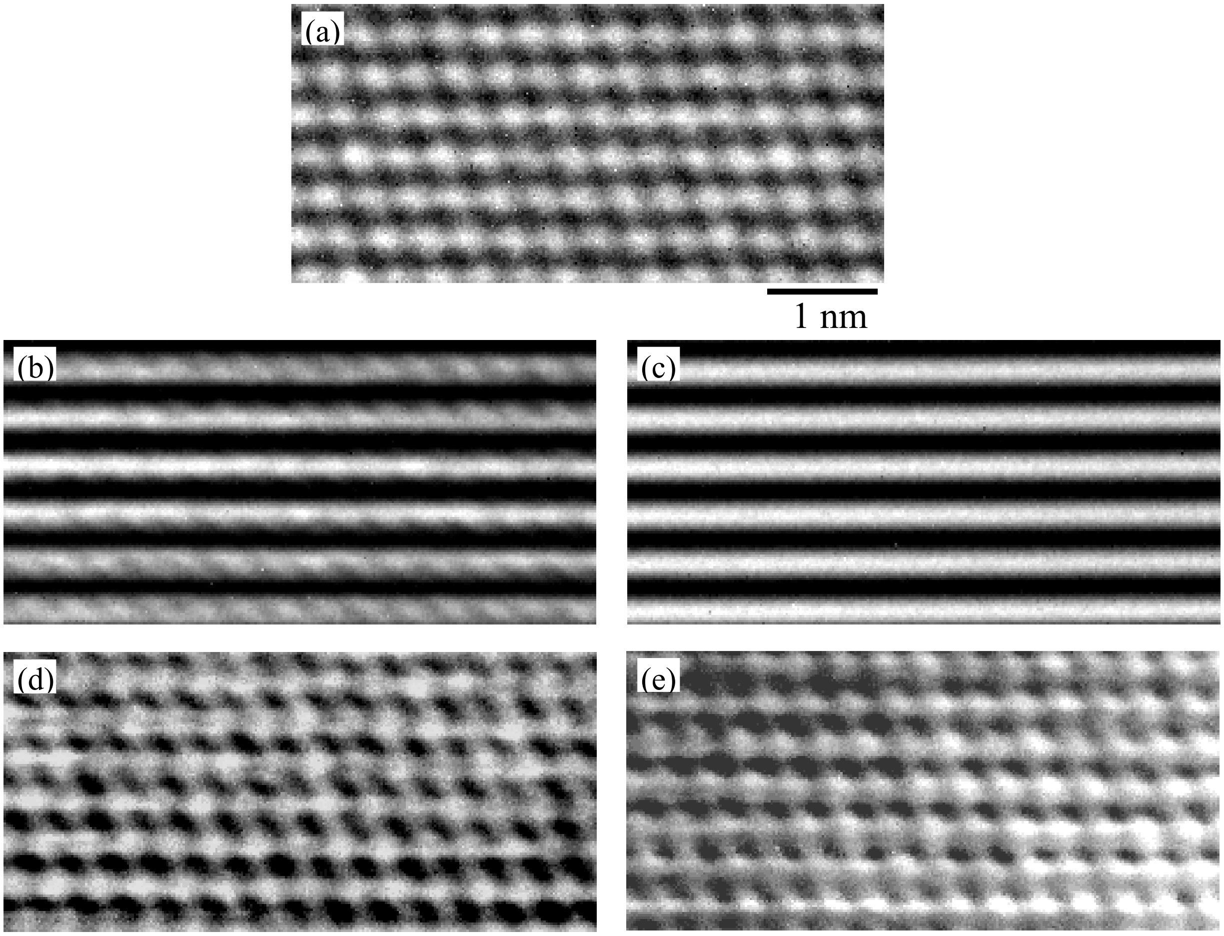

Fig. 1. Reconstruction of object wave by phase shifting electron holography: (a) HRTEM image of HgCdTe recorded at 900 KX; (b) typical hologram recorded during series; (c) corresponding reference hologram recorded in absence of object; (d) reconstructed amplitude image; and (e) reconstructed phase image.

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