Electron Diffractive imaging using Fork-Shaped Grating Masks

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An electron vortex beam is propagating electron which carries an orbital angular momentum (OAM) [1]. Because an electron has an electric charge and a mass, electron vortex beam is considered to have a magnetic moment and a moment of force, with which imaging of magnetic materials and manipulation of nano-sized objects are expected [2,3].

Electron vortex beams are generated using amplitude holograms such as binary masks of forked gratings [2] and spiral zone plates [4], and using phase holograms of forked gratings as their diffracted waves when the holograms are illuminated by a plane wave [2]. Recently, spiral phase plates with a smooth and continuous variation of the thickness of Si₃N₄ membranes were successfully prepared by nano-fabrication techniques, which were not realized in the first report by Uchida and Tonomura [1].

In the present study, the forked grating masks are used as a selected area aperture for electron diffractive imaging, which imposes a real space constraint. Diffractive imaging is lens less imaging for reconstructing the wave field from a diffraction pattern. Diffractive imaging requires a constraint in real space, or “support region”, which corresponds to a beam illuminated area of the specimen. The support region has so far been restricted by a narrow beam itself or a single circular hole inserted at the first image plane of microscopes. In the present study, the support region is restricted by a forked grating. Forked gratings provide not only a transmitted peak but also discrete Bragg peaks which contain rich information of the object located in the support region, and thus one can expect more reliable phase retrieval than the case using a hole mask.

The patterns of the forked gratings with a 5 µm diameter were designed by computer hologram whose Burgers vector of \( b = 1 \). The forked gratings were fabricated from 1µm thick PtPd films deposited on 50nm thick Si₃N₄ membranes by using a focused ion beam (FIB) instrument. The forked gratings were introduced into a position of selected-area aperture of a transmission electron microscope. Diffraction patterns were taken by a Gatan imaging fileter with a 16 bit 2k x 2k CCD camera.

Figures 1(a) and 1(b) show a TEM image of the forked grating and its diffraction pattern, respectively. Figures 1(c), 1(d), 1(e) and 1(f) show retrieved amplitudes of image and diffraction pattern, and retrieved phases of image and diffraction patterns, respectively. The retrieved diffraction amplitude (Fig. 1(d)) shows a good agreement with the experimental amplitude (Fig.1(b)). A flat phase in the retrieved phase of the image (Fig.1(e)), which is consistent to the plane wave incidence, is well reproduced. A deformation of the wavefront of incident electron beam by a quadruple magnetic field produced by a stigmator of the intermediate lens of the microscope is also successfully visualized by the present method.

A wavefront deformed by a specimen is also reconstructed. We used Au
nano-plates as test specimens. Figures 2(a) and 2(b) show an experimental TEM image and diffraction pattern of a Au nano-plate. Figures 2(c), 2(d), 2(e) and 2(f) show retrieved amplitudes of the image and diffraction pattern, and retrieved phase of the image and diffraction pattern, respectively. The retrieved diffraction amplitude (Fig. 2(d)) shows a good agreement with the experimental amplitude (Fig. 2(b)). The thickness of the Au nano-plate is obtained from the phase map (Fig. 2(e)), which is consistent to the thickness determined by electron holography. We discuss how the phase retrieval using a forked grating mask is effective by comparing with the cases using a regular grating and a single circular hole.

References

FIG. 1. Experimental image (a) and diffraction pattern (b), and retrieved amplitudes of image (c), diffraction pattern (d), retrieved phases of image (e) and diffraction pattern (f) in the case of the plane wave incidence.

FIG. 2. Phase retrieval of a Au nano-triangle. Experimental image (a) and diffraction pattern (b), and retrieved amplitudes of image (c), diffraction pattern (d), retrieved phases of image (e) and diffraction pattern (f) in the case of the plane wave incidence.