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# Superposition of Fraunhofer Diffractions from Fork-Shaped Gratings and their Openings with Electron Vortex Beam

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Electron vortex beams carrying intrinsic orbital angular momentum are potentially usable as probes for next generation electron beam machines, especially transmission electron microscopes (TEM). The beams is expected provide a novel observation means for polymer compound materials and electromagnetic materials.

We fabricated a fork-shaped grating [1] made from a SiN-membrane with a 200-nm-thickness by using a focused ion beam machine (FB-2100, Hitachi High-Technologies Corp.). The maximum grating size in one direction was 10 μm. Electron diffractions from the gratings were observed with a 300-kV field emission electron microscope (H-9000) [2]. The optical system was constructed for small angle diffraction with a camera length of 150 m and was similar to a twin-Foucault imaging system [3].

During the experiment, we noticed the shape and size of the grating openings were superimposed on the shape of the diffraction spots of the vortex beam. This phenomenon is considered to be due to a combination of Fraunhofer diffractions from the grating and the opening. Figure 1 shows electron micrographs of circular-fork-shaped gratings (left panels) and their electron diffractions (right panels). As the size of the grating opening was made smaller, the diameter of the ring of diffraction spot, a typical shape of the vortex beam, increased.

The left panels of Figure 2 show TEM images of fork-shaped gratings with circular, triangular, square, and pentagonal openings. The right panels show electron diffractions whose spot-shapes are reflected by those of the openings.

The combination of the fork-shaped grating and its opening allowed us to observe the rotational phenomena of the diffraction rings in through focus condition. Figure 3 shows diffraction patterns from a fork-grating with diamond-shaped opening for three different focuses. The diffraction spots on the right are rotated in the opposite azimuth direction to those on the left. Figure 4 plots the rotation angles of the first, second and third diffraction rings (spots) versus the defocusing distance. The first diffraction rings rotated more than second and third rings. The phenomenological picture of this rotation is consistent with the phase distribution of the vortex beam. The rotation itself can be explained by the Gouy phase [4, 5].

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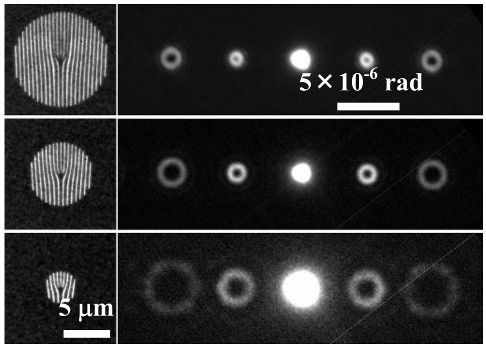


**Figure 1.**

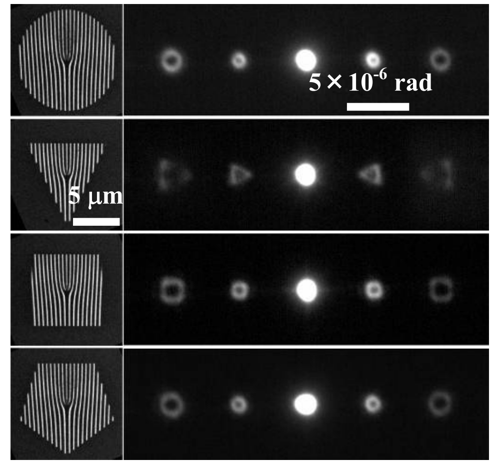


**Figure 2.**

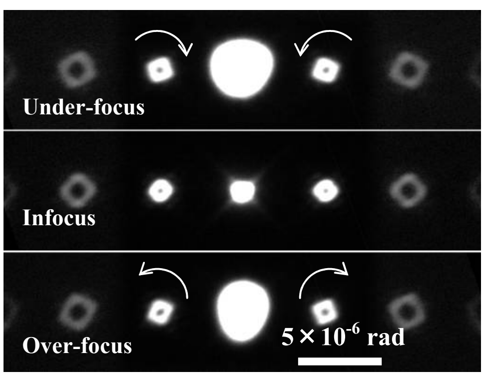


**Figure 3.**

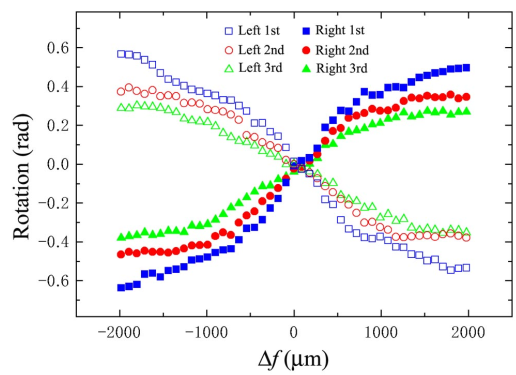


**Figure 4.**

**Figure 1.** Manufactured fork-shaped grating (left) and electron diffractions (right). Ring diameter of diffraction is related to the opening size.

**Figure 2.** Manufactured fork-shaped grating (left) and electron diffractions (right). The shape of each diffraction ring is reflected with the shape of the opening.

**Figure 3.** Electron diffractions from grating with diamond-shaped opening for three different defocusing conditions.

**Figure 4.** Rotation angles of the first, second and third diffraction rringson both sides versus the defocusing distance.

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