Sculpting Electron Beam Profile and Phase with Nanofabricated Diffractive Optics

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We have developed nanofabricated electron diffractive optics for engineering both the amplitude profile and wavefronts of electron beams in conventional TEMs. This work is an expansion of our previous demonstration of electron vortex beams composed of free electrons carrying quantized orbital angular momentum[1]. We are optimizing the functional efficiency of these structures, and have also demonstrated their use for engineering the intensity profile of the beam as well as its phase.

Examples of nanoscale diffraction optics are shown in Figures 1 and 2. The holograms are fabricated using high resolution FIB to mill the desired pattern into a silicon nitride membrane. By optimizing the pattern design and membrane properties, we are now able to pattern larger holograms up to 80 microns in diameter, with line periodicity down to 60 nm. These larger area holograms are beneficial for high-resolution TEM imaging.

Use of electron vortex beams for experimental techniques in electron microscopy requires holograms with better diffraction efficiency. We designed the depth of the patterned features to modulate 300 keV TEM electron beam by π radians, such that the intensity of electrons diffracted into the first order is maximized. The pattern depth can also be varied over the area of the hologram. In the phase grating hologram shown in Figure 2, the depth of the slits varies radially from the center of the grating as a Gaussian function, such that slits near the edge of the patterned area diffract electron waves less efficiently. The resulting electron beam in the first diffraction order has a Gaussian intensity profile, save for a dark spot due to the engineered phase vortex.

[1] B. J. McMorran, A. Agrawal, I. M. Anderson, A. A. Herzing, H. J. Lezec, J. J. McClelland, and J. Unguris, Science **331**, 6014 (2011).

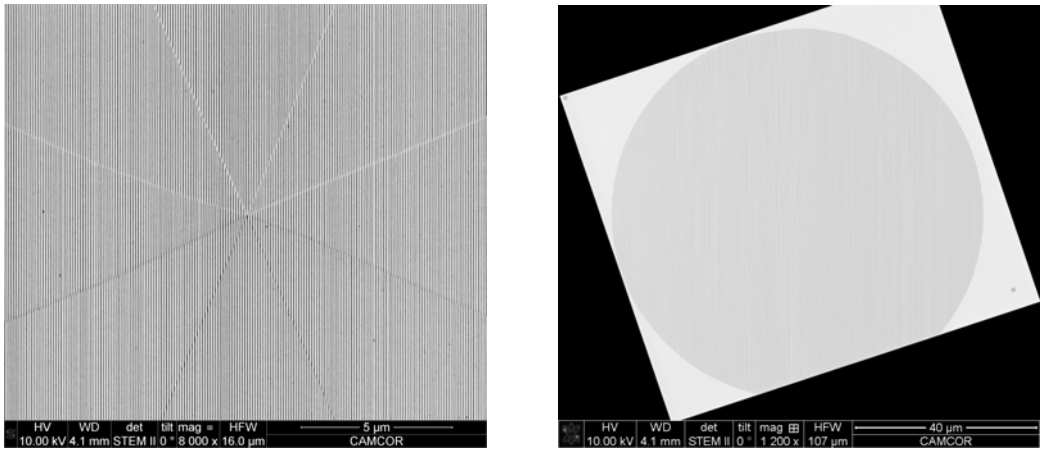

Figure 1: Phase gratings for TEMs: These STEM images show examples of large-area electron diffraction holograms milled into silicon nitride membranes. The holograms cover circular areas 80 μm across, with a line periodicity of 75 nm. The circular hologram on the right spans the square aperture holding the silicon nitride membrane.

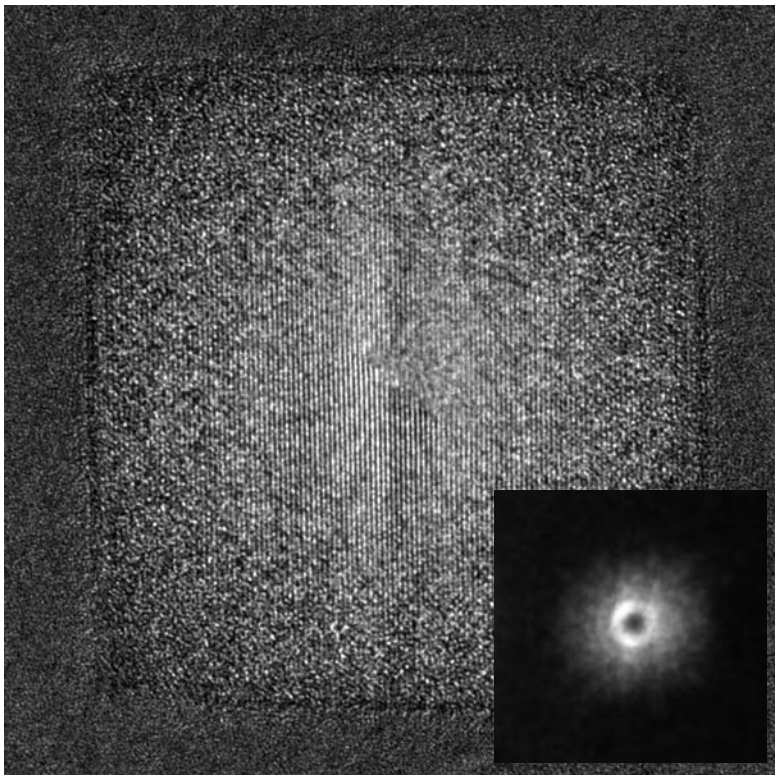

Figure 2: Electron Gaussian beam with phase vortex: Like the gratings shown in Figure 1, the forked diffraction grating shown in the TEM image on the left is composed of trenches milled into a silicon nitride grating, except here they are milled with varying depth. The resulting electron beam in the first diffraction order (shown in the inset TEM diffraction image) closely approximates a Gaussian beam with a phase vortex – a Laguerre-Gaussian electron beam.