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Electron-Beam Shaping

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In recent years, advances in nano-machining are thriving, allowing micro- and nano-scaled elements to be fabricated. Specifically, the authors have fabricated computer-generated holograms using nano-scale phase-masks [1], and demonstrated their operation in a standard TEM. Here, we continue to investigate applications for such phase-masks by imprinting the electron beam with familiar aberrations such as tilt, astigmatism, trefoil, and a spherical phase.

One of the greatest struggles of electron microscopes, since their debut nearly a hundred years ago, was the reduction or amelioration of the effects of aberrations. Technological advances in fabrication methods allowed the microscopy community to take incremental steps towards the perfection of the electron microscope, and magnetic lens design in particular. A landmark in this direction of research was made by Scherzer (1936) [2] who showed that the existing, rotationally-symmetric, static and charge-free lenses cannot correct for spherical aberration - the dominant aberration at the time. Much later, this led to the successful demonstration of aberration correction using two electromagnetic hexapoles by Haider (1998) [3].

While somewhat more common today, spherical aberration-corrected microscopes are still very expensive. In lower magnifications, such as those used in Lorentz mode, it may be sensible to use a passive element which does not induce a magnetic field and does not require fundamental changes in the microscope's architecture. Such elements, in their early manifestations, have been previously introduced [4] but were not pursued. The rely on the mean inner potential of the material, in this case silicon nitride, to act as a refractive index for electrons through the expression,

$$\varphi = \frac{2\pi}{\lambda}(n-1)t = \frac{2\pi}{\lambda}\frac{eU_i}{E}\frac{E_0+E}{2E_0+E}t$$

where φ is the phase change imprinted on the beam by traversing thickness t in the material, λ is the de-Broglie wavelength associated with the electron's energy E_0 and acceleration energy E. U_i is the mean inner potential, and the familiar form on the left, from light optics, associates the refractive index n to the phase change. Thus, by selectively changing the thickness at pre-designed positions, a desired spatial phase-change is induced to the complete beam.

We have fabricated a set of different phase plate for electrons that can potentially compensate different aberrations of the electron-optics system, as shown in Fig. 1. Two examples of generated electron beams that can compensate for astigmatism and trefoil are shown in Fig.2 below.

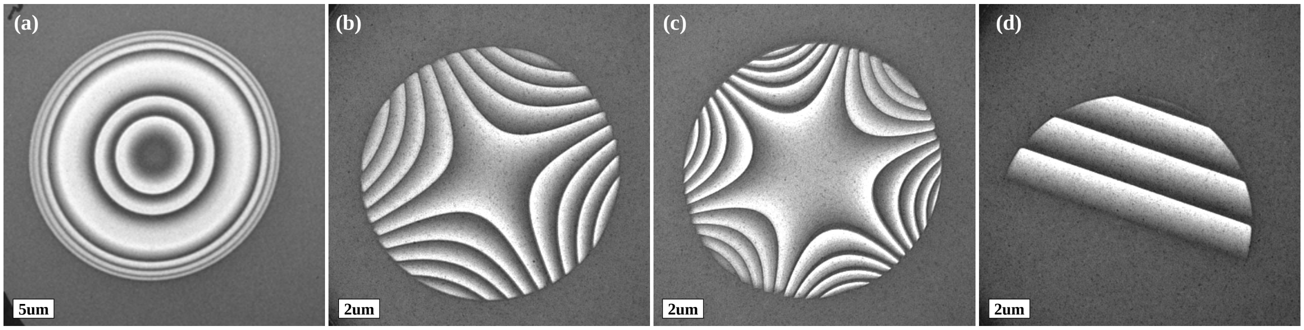

Figure 1. TEM images of phase-masks imparting (a) spherical, (b) astigmatic, (c) trefoil, and (c) half-beam tilt phase to the electron-beam. Contrast and brightness have been changed for visibility.

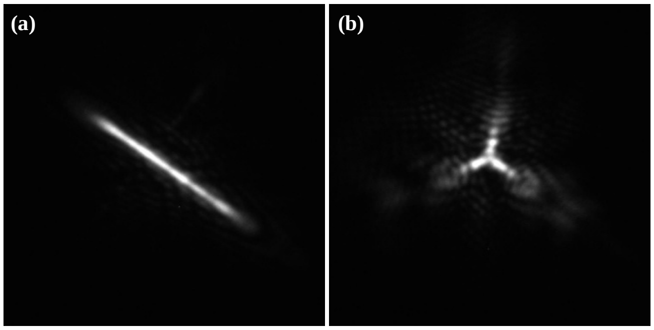

Figure 2. Defocused TEM measurements of the beam, after traversing in some of the phase-masks in Fig.1, namely (a) astigmatism, and (b) trefoil.

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[2] O. Scherzer, Zeitschrift für Physik **101** (1936), 593.
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