# Simulating Hilbert phase contrast produced by an anamorphotic electrostatic phase plate

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In recent years a number of concepts have been proposed to improve the contrast of weak phase objects using phase plates for in-focus phase contrast: Carbon film Zernike or Hilbert-type phase plates have the disadvantage of contamination and charging of the film [1]. For a Boersch electrostatic phase plate construction elements of the device obstruct part of the electrons in the diffraction plane [2]. An obstruction free electrostatic phase plate using a highly anisotropic electric potential, which is applied to a highly anamorphotic image of the diffraction plane has been proposed [3], but not been tested experimentally.

Here we show that indeed the highly anisotropic and inhomogeneous electrostatic potential can be used to obtain a homogeneous phase shift applicable for Hilbert or Zernike phase contrast. We use finite element methods to calculate 3D potential distributions for different phase plate designs. These inhomogeneous 3D potentials are then projected along electron trajectories to produce planar phase shift distributions. These numerical phase plates are used to simulate images of a test object (Siemens star).

The sharp Delta-step-like phase shift of a carbon Hilbert phase plate can be approximated using a highly anamorphotic ratio of the electrostatic phase plate (Figure 1). Thereby the maximal gradient of phase shift at the potential step is achieved when the width of the phase plate slit is minimized. In our image simulations this leads to a maximal information transfer for low spatial frequencies without limiting effects of the transfer function or obstructing components (Figure 2).

By extending the length of the phase plate slit (i.e. its anamorphotic ratio), the mapping of the structure factors on the phase shifting potential can be optimized by enlarging the ratio of diffraction image extension to phase shift gradient area. Further more phase contrast image quality depends strongly on the position of the central beam with respect to the central potential step. This property will be usable for an optimal alignment of the phase plate in the back focal plane of the microscope. In the case of a misalignment a certain amount of structure factors will be transferred at lower contrast. The extent of contrast loss is strongly dependent on the design of the phase plate, and a high anamorphotic ratio of the physical phase plate proves to be desirable for practical use in the TEM.

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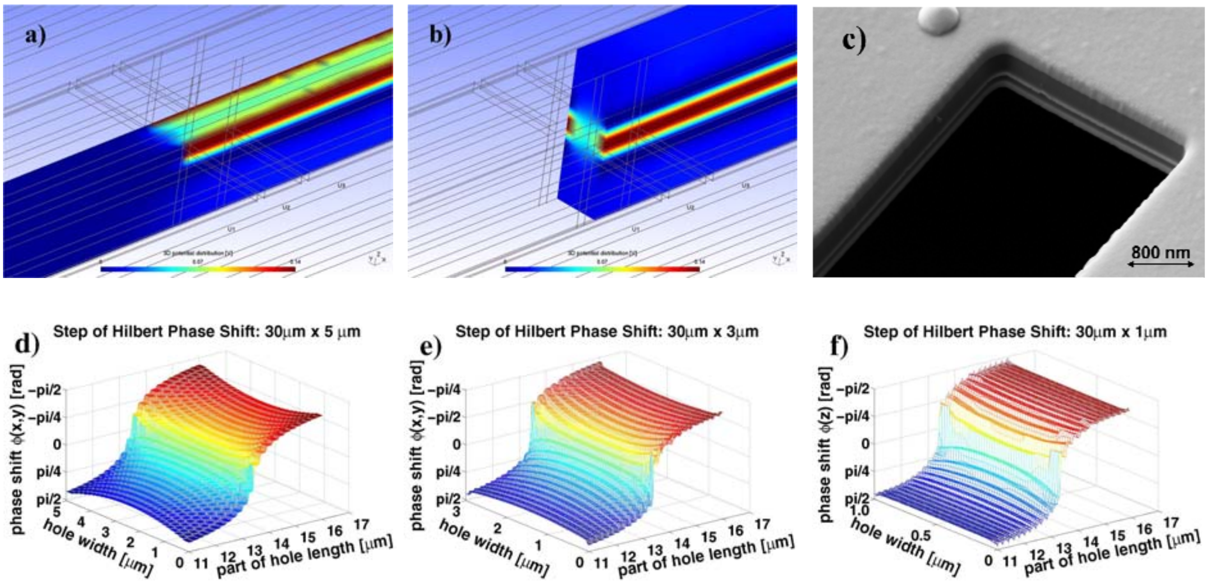


**Figure 1.** Cross sections through the 3D potential distribution inside the anamorphotic phase plate, picture of a microstructured anamorphotic phase plate [4] and resulting homogeneous phase shift at the potential step. The inhomogeneous potential distribution is shown in **Figure 1a)** and **1b)** for cross sections in xy- and xz-direction (30µm x 1µm). The strong gradient of the potential at the edges of the electrodes is shown by the color map. **Figure c)** shows an SEM picture of a phase plate prototype [4]. **Figure 1d)-1f)** show the calculated homogeneous phase shift in the potential step region for decreasing phase plate widths (30µm x 5µm, 30µm x 3µm, 30µm x 1µm). With decreasing width the gradient of the phase shift step approximates the ideal Delta-step of a Hilbert phase plate.

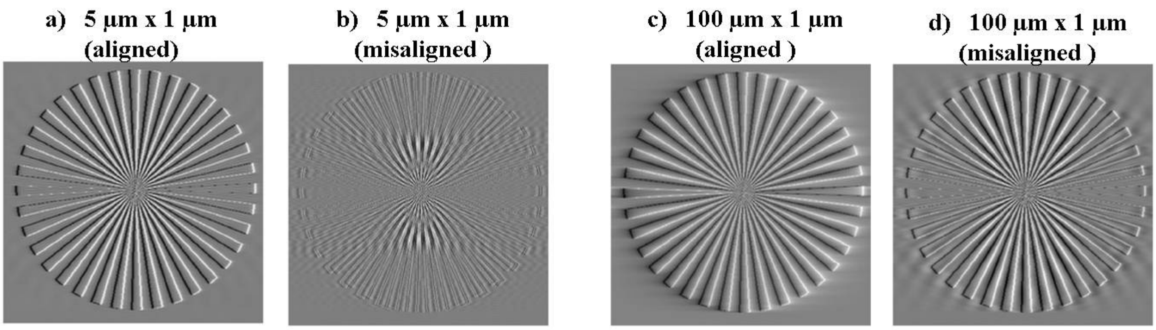


**Figure 2.** Effect of phase plate dimension and alignment on information transfer (electron energy 120keV, focal length 2.7nm). Shown are the simulated phase contrast images with aligned and misaligned anamorphotic Hilbert phase plates (potential field dimension: 5µm x 1µm and 100µm x 1µm). The shift of the central beam with respect to the central potential step is -1.33µm (**Figure 2b)**) and -6.00µm (**Figure 2d)**), showing the clear effect of information loss. This obvious effect of misalignment on object contrast will allow alignment of the phase plate in the TEM.

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