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A new perspective for a tunable phase plate based on Ampere's law

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In-focus phase contrast devices that are analogues of the optical phase plate (PP) introduced by Zernike [1] have been investigated for decades and have emerged from a wide range of possible phase-sensitive imaging techniques as promising and viable methods for enhancing the contrast of biological specimens in the transmission electron microscope (TEM). However, most PPs for electrons that have been proposed so far suffer from deficiencies that include insufficient contrast enhancement, additional aberrations, short lifetime, difficult alignment and/ or electrostatic charging by the electron beam (even when self-charging is responsible for producing phase contrast) [2, 3]. Charging, in particular, is very difficult to measure and control, deteriorates device performance and limits widespread applications.
Here, we introduce a new substrate-free PP concept for TEM that is based on Amperes law and addresses all of these problems. We refer to the device as a "tunable Ampere phase plate" (TAPP). It is designed to provide almost-ideal phase contrast, while providing a spatial resolution of up to 1-4 Å, as well as both tunability and ease of application.
The operating principle of the TAPP is based on a magnetic field circulating around a vertical segment of current-carrying wire, which introduces a position-dependent phase shift to a passing electron wave. When the TAPP is positioned in the back focal plane of the imaging lens, it acts as an additional transfer function that enhances phase contrast arising from an object.
We have used focused ion beam (FIB) milling to fabricate a prototype TAPP from etched Au wires in the form of three orthogonal segments, thereby making a hook-shaped device, as shown in Fig. 1. The middle segment of the hook could then be positioned parallel and the other two segments perpendicular to the incident electron beam direction.
We have established the validity of the concept using both experimental electron holographic measurements of phase shifts around the device (Fig. 2) and a theoretical model based on Amperes law. We have also used computer simulations to predict the contrast enhancement expected for studies of biological cells and macromolecules.
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References:
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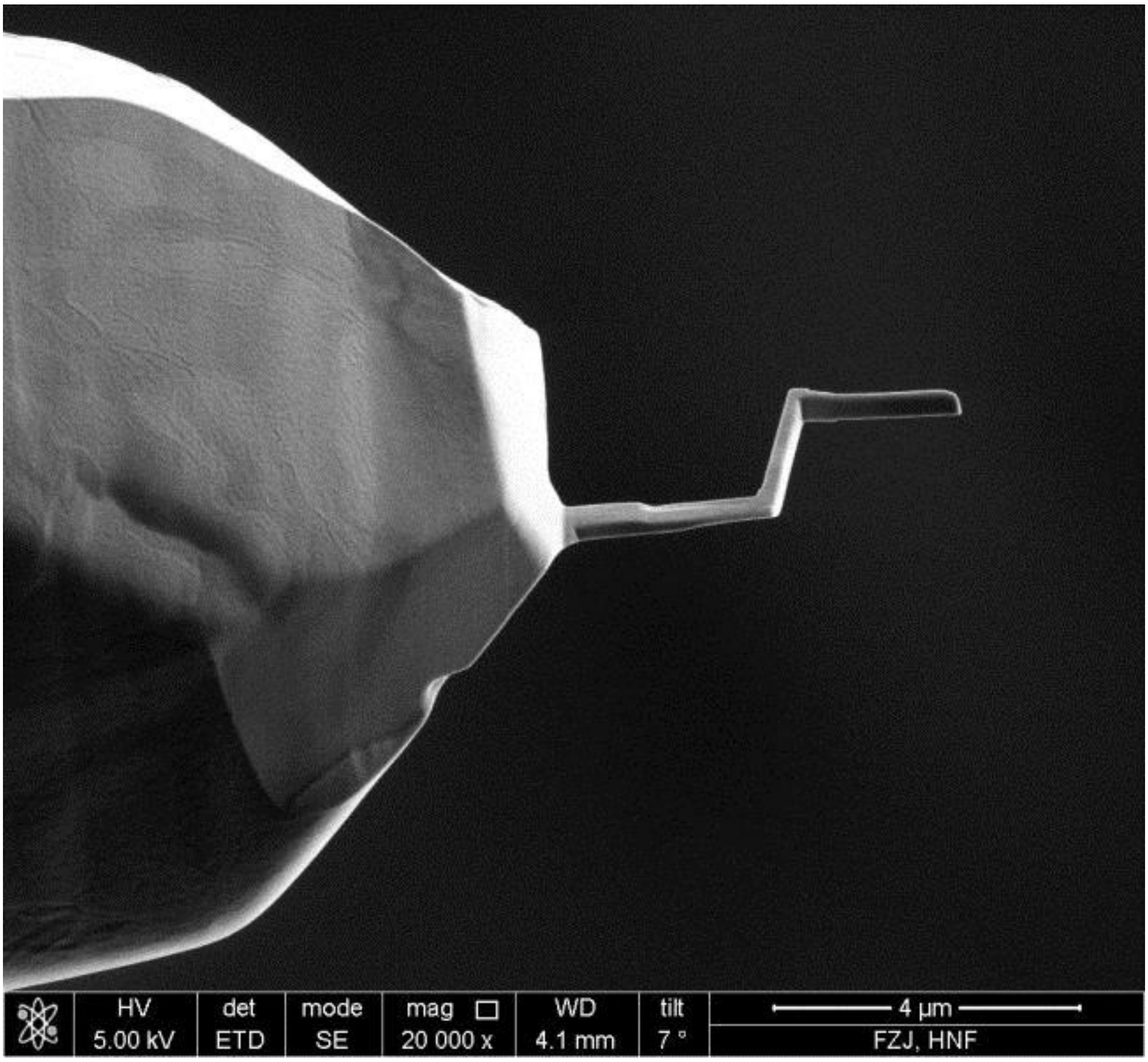

Figure 1. Secondary electron image of one side of the TAPP.

Figure 2. 8x amplified phase images of the vacuum region around the contacted TAPP recorded using off-axis electron holography for currents of 0 (left), 2 mA (middle) and 4 mA (right).