Optimized Fabrication and Application of Electrostatic Phase Plates for Transmission Electron Microscopy

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Introduction

Electrostatic physical phase plates (PP) enhance the contrast of weak-phase objects in transmission electron microscopy (TEM)

- An electrode, surrounded by insulating and metallic shielding layers, generates an electrostatic field close to the zero-order beam. (Fig. 1)
- Depending on the applied voltage, a relative phase shift between scattered and unscattered electrons is induced.

Boersch-PP

- Three supporting rods and an inner ring lens guarantee a homogeneous electrostatic field but obstruct information at low spatial frequencies (Fig. 2a). Cut-on frequency is determined by outer ring diameter.

Zach-PP

- With only one supporting rod, obstruction of spatial frequencies is significantly reduced (Fig. 2b). Cut-off frequency is determined by the shape of the electrostatic field.

Schematic illustration of Zach-PP located in the back-focal plane (BFP) of the objective lens.

Motivation

- Electrostatic charging limits application of PPs
- Low spatial frequencies cannot be resolved with present PP design
  - Ratio between size of diffraction pattern and PP dimension has to be enlarged by increasing the focal length and scaling down the PP sizes
  - Need for small tip, large aperture radius and thin layers

Fabrication of Zach-PP

Seven production steps to produce a Zach-PP (Fig. 3) including electron-beam evaporation (EBE), electron-beam lithography (EBL), focused ion beam (FIB) and reactive ion etching (RIE).

Fig. 3: Production scheme of Zach-PP: a) Si with 100nm SiO2, membrane b) Gold electrode c) etched aperture hole d) insulating HfO2 layer e) shielding Au layers f) FIB cutting of tip.

RIE simplifies process and allows production of PPs with larger aperture radius and narrower tips due to high precision of EBL (Fig. 4).

- The high C of HfO2 guarantees good isolation in spite of thinner layers.

Field simulations

Simulations of electrostatic potential of Zach-PP provide better knowledge of phase-shifting characteristics (Fig. 6).

Summary

- Optimized fabrication with narrower PP design and enlarged aperture radius
- PP heating and thinner insulating layers significantly reduce electrostatic charging
- Potential simulations provide better knowledge of phase shift

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References