Application of a Zach Phase Plate in High-Resolution Transmission Electron Microscopy

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Introduction

- Physical phase plates (PP) enhance the contrast of weak-phase objects (WPO) in transmission electron microscopy (TEM).
- Zach-PP\(^1\): An electrode, surrounded by insulating and metallic shielding layers, generates an electrostatic field close to the zero-order beam. Depending on the applied voltage, a relative phase shift between unscattered and scattered electrons is induced.
- Weak-phase objects and resolution:
  - Typical WPO: Biological samples or nanoparticles at low magnifications weakly change the mean phase of electrons over larger areas.
  - Single Atoms: Even for heavy atoms, the potential is smeared by the point spread function across an area. Introduced mean phase shift can be small.
- Crystalline specimens in HRTEM typically NOT weak-phase objects

Motivation

- Crystalline objects and phase-plates:
  - Contrast: Contrast in conjunction with high doses typically strong
  - Interpretation: Can be difficult due to thickness and delocalization effects
  - Non-periodic information: Contrast of point defects like oxygen vacancies can behave like weak phase objects.
- Image simulation of crystalline wave-function with point defects
- Vacancy of 50% Si-atoms in projection missing (Fig. 1)

Application of Zach Phase Plate

- InGaAs quantum dot images with different induced phase shifts (Fig. 2)

Analysis of HRTEM contrast

- Contrast change of reflections
  - Intensity of a reflection depends on structure factor, orientation, defocus, phase plate phase shift and spatial frequency
  - Varying phase shift changes intensity of reflections defocus remained constant (Fig. 3)

- Contrast change of lattice fringes
  - Fringe contrast changes with applied voltage similar to defocus changes
  - Line profiles perpendicular to fringes across the quantum dot demonstrate the phase shift dependence of contrast (Fig. 4)

Application of HRTEM techniques with phase plates

- Use of phase plates in HRTEM can add to existing methods:
  - Inline holography possible with phase plates [2]
  - CELFA [3] can be done with phase shift series
  - Phase shift series offer advantage of easy handling non-linear image contribution compared to defocus series
  - Non-linear intensity described by transmission cross coefficient remains constant during variation of phase shift

Challenges of HRTEM phase plates

- Positioning and characterisation of phase plate
- Positioning phase plate by beam tilt changes orientation of specimen, best practice using PP-holder requires very precise piezo holder
- Characterisation requires amorphous specimen, optimally near to area of interest
- Signal-to-noise ratio main problem of PP-HRTEM
- Charging of PP requires low dose
- Phase plate does not significantly decrease coherence
- Reduced charging expected for electrostatic phase-plates by Heating the plate-phase chip with a micro-heating.
- Use of bonded contacts for optimal grounding.

Summary

- HRTEM done with electrostatic phase plates
- Fringe contrast changes in dependence of induced phase plate phase shift
- Adoption of phase plates to HRTEM methods like wave-function reconstruction
- SNR main difficulty in conjunction with charging; coherence not an issue