Towards electron holography of 3D magnetization distributions in nanoscale materials using a model-based iterative reconstruction technique


Tu.11 Towards electron holography of 3D magnetization distributions in nanoscale materials using a model-based iterative reconstruction technique

Simulation of phase maps (forward model)

The magnetic phase shift originating from a magnetic specimen examined in the TEM can be described in terms of the Aharonov-Bohm effect:

\[ \phi(x, y) = -\frac{\pi}{\hbar} \int_{\Omega} A(r) \cdot \frac{\partial}{\partial r} [M(r) \cdot \frac{\partial}{\partial r} M'(r)] \, dr' \, dz \]

Forward Model as a (linear) matrix operation:

\[ y = F(x) = M \cdot x = Q \cdot P \cdot x \]

Result:

Reconstructed distributions show distinct projected magnetization structures (homogeneous and vortex states). Phase maps from reconstruction are compared to input in the figures to the right. RMS deviation:

- 2 particles: 0.042 rad
- 4 particles: 0.054 rad

Outlook to the retrieval of 3-dimensional magnetization distributions

Model-based iterative reconstruction technique

Inverse Problem: Retrieve the magnetization distribution from a given set of phase maps via a model-based reconstruction algorithm.

ill posed problem \rightarrow non-uniqueness \rightarrow regularization

Minimize the cost function:

\[ J(x) = \frac{1}{2} \| F(x) - y \|^2_{S_f^{-1}} + \frac{1}{2} \| x \|^2_{S_h^{-1}} \]

\[ S_f: \text{covariance matrix of the measurement errors} \]

\[ S_h: \text{a priori covariance of the magnetization distribution} \]

Regularization selects the most physical solution from the pool of possible solutions by including physical constraints.

Minimize magnetic exchange energy: \( E_{xx} = (\nabla M_1^2 + \nabla M_2^2 + \nabla M_3^2) \, dx \)

(\text{Corresponds to first-order Tikhonov regularization; favors slow variations in } M).