Reconstruction methods for combined HAADF-STEM and EDS tomography

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Issue Date: 2018-12-10

6 Conclusion

In this PhD thesis, we propose several approaches to pave the way for HAADF-STEM + EDS tomography: (1) the HAADF-EDS bimodal tomographic reconstruction technique, which is based on jointly modeling the consistence of the two imaging modalities; (2) TNV-regularized joined reconstruction which allows to incorporate the prior knowledge that common edges exist in the reconstructions from HAADF and EDS data respectively; (3) a set of algorithmic recipes to tailor various reconstruction algorithms for given experimental conditions and sample properties; (4) an algorithm for automatically correcting the nonlinear damping effects in HAADF-STEM tomographic data.

Experimental results of the HEBT algorithm in Chapter 2 show that HEBT enables investigating the structure of chemical elements with lower noise levels compared to element-wise EDS reconstruction. By promoting consistency between the forward projections of the element-specific reconstructions and the low-noise HAADF-STEM data, reconstructions are obtained that are more accurate in comparison to pure EDS tomography, resulting in a lower discrepancy between the reconstructions and the ground-truth.

Chapter 3 shows that using TNV regularization, it is possible to encourage a reconstruction to have edges overlapping with another reconstruction. The EDS element-specific reconstruction can be augmented by joining it with the HAADF-STEM reconstruction that has higher signal-to-noise ratios and is computed from a larger number of tilts. Alternatively, by promoting shared edges between the EDS and HAADF reconstructions, the number of tilts required for EDS can be reduced compared to element-wise EDS reconstruction, while maintaining similar reconstruction quality.

In Chapter 4, the algorithmic recipes enable to tailor a set of reconstruction algorithms based on the actual experiments, sample, and data. In the experimental section, we demonstrate how to choose suitable ingredients and algorithmic parameters for a variety of data cases. In all these cases, the tailored recipes result in more accurate reconstruction results compared to more naive algorithms.

The above chapters are based on the simple assumption that the projection models are perfectly linear. In practice, this is often not completely valid. The algorithm proposed in Chapter 5 can correct the nonlinear damping effects in HAADF-STEM data. The experimental results show that the algorithm can reduce the cupping artifacts as well as improve further interpretation and segmentation of the reconstruction. For HEBT, correcting the nonlinearity can make the HAADF data consistent with the linear model.

Overall, this thesis provides several approaches to improve the accuracy of element-specific reconstructions made by combining HAADF-STEM and EDS data. An important potential application of this work is the quality inspection in the semiconductor industry. Besides the need of high image quality and the ability to resolve chemical elements, being able to carry out a full ET experiment and the subsequent computational steps in very short time (less than an hour) is crucial for the adoption of these techniques in an industrial R&D setting. In the future, a robust and automated pipeline for the complete tomographic process needs to be developed.

We envision that by extending our proposed methodology with a data acquisition scheme that selects the projection angles in an optimized manner, the time required for acquiring sufficiently many EDS images can be substantially reduced. For further automation of the computational part of the imaging pipeline, automated procedures will need to be developed for setting the values of the various parameters in the reconstruction algorithms in an objective and repeatable manner.

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