doi:10.1017/S1431927622011576
Microsc. Microanal. 28 (Suppl 1), 2022

Automatic and Quantitative Measurement of Spectrometer Aberrations in Monochromated EELS

Yueming Guo[1], Andrew R. Lupini[1]

[1.] Center for Nanophase Materials Science, Oak Ridge National Laboratory, Oak Ridge, TN, USA.

Recent developments in high energy-resolution electron energy loss spectroscopy (EELS) in a scanning transmission electron microscope (STEM) have brought about renewed interest in optimizing the performance of the spectrometers [1-3]. Apart from further improvement of instrumental stabilities, minimization of the spectrometer aberrations (including high-order ones) have become demanding. In particular, automatic measurement and correction of the aberrations are necessary for improving the energy resolution of the momentum-resolved EELS in a q-ω mode, which uses a slit aperture to select a string of diffraction spots in the non-dispersive direction at the EELS entrance plane. An automatic EELS tuning is essential because such a mode requires aligning diffraction spots with the slit aperture by adjustment of the projection lenses, which inevitably introduces extra aberrations to the final detection plane.

The first step to EELS tuning is to measure the spectrometer aberrations. Here, we report our automatic and quantitative measurement of the geometric aberrations for EELS in NION's MACSTEM based on the well-known ray tracing technique in geometric optics (Figure 1) or the equivalent Eikonal approximation in quantum mechanics. The accuracy of measurements is compared to our simulation [4], which is based on quantum mechanical calculations (Figure 2). A good match was found by a visual comparison. We also tested the accuracy of the ray tracing technique, which neglects the wave mechanical properties, by extracting aberration coefficients from simulated aberration patterns and comparing them with the input coefficients. We ran the simulation using parameters based on the experimental settings, which consists of 48 independent beam tilts in a range of (-25 mrad, +25 mrad) in both directions. With such practical conditions, we noticed that aberrations up to the third order can be measured accurately and that selection of the regression algorithms affects the accuracy of the measurements.

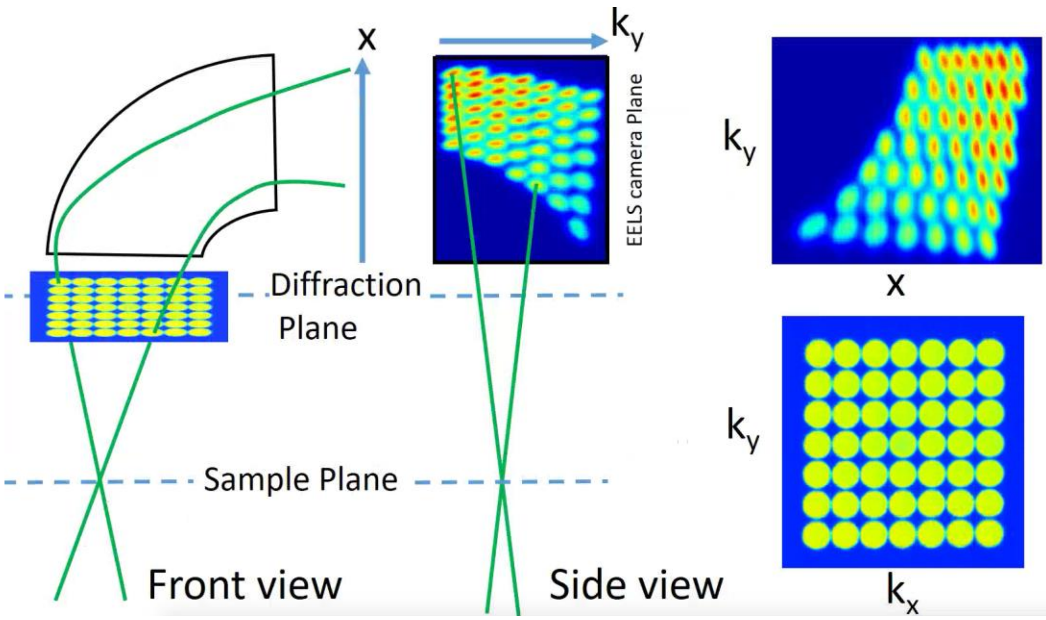

Figure 1. Schematic diagrams of the automatic data collection. A computer program [2] automatically tilts the beam about a pivot point on the sample plane. Images of the condenser aperture at different tilts are recorded sequentially by the Ronchigram camera on the diffraction plane. The same tilt series is then repeated and the patterns on the EELS camera are recorded sequentially. The aperture images and the aberration patterns are summed over time and displayed in the figure.

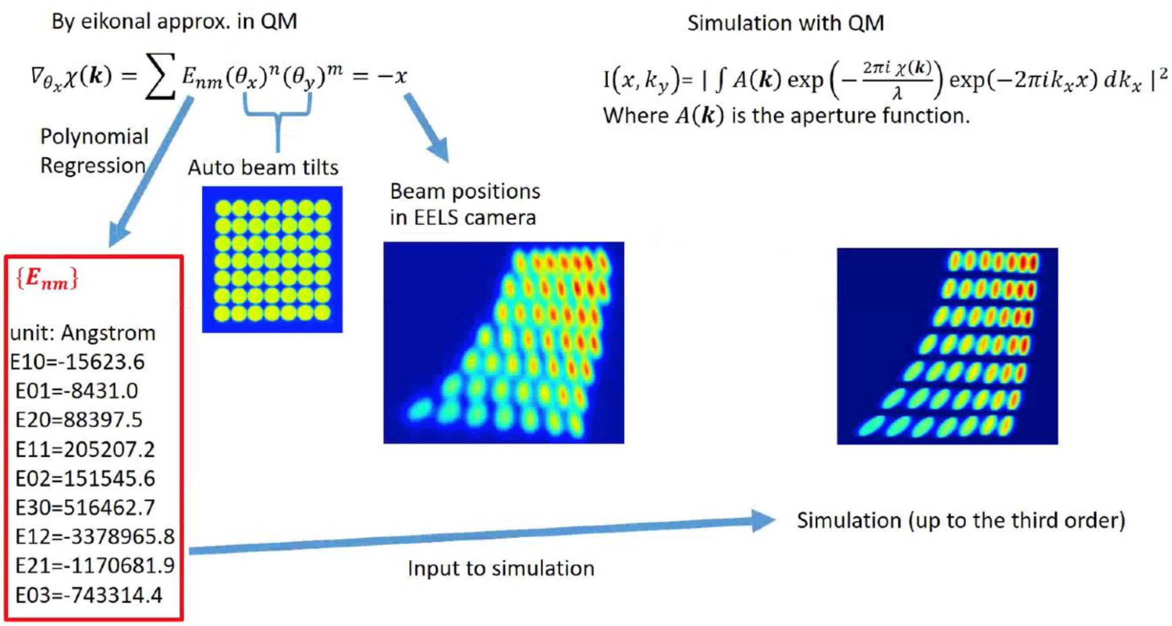

Figure 2. An overview of the EELS aberration measurement and a comparison to the quantum mechanical simulation. The 48 independent pairs of beam tilts and their respective shifts (both derived from the weight-averaged values) are input to the polynomial regression, which gives the aberration coefficients. To check the accuracy of the measurement by a visual comparison, these coefficients are input to the simulation. The beam shifts on the EELS camera plane provide a calibration of the tilt angles at the sample plane.

References:

[1] Krivanek, O. L. et al. Progress in ultrahigh energy resolution EELS. Ultramicroscopy 203, 60-67, (2019).

[2] Kahl, F. et al. Test and characterization of a new post-column imaging energy filter, in Advances in Imaging and Electron Physics, vol. 212, Elsevier Inc. (2019)

[3] Twesten et al. Advances in EELS Instrumentation: A New Design High-Vacuum Parallel EELS System. Microsc. Microanal. 17 (Suppl 2), 2011.

[4] Guo, Y. https://github.com/DrYGuo/EELS-aberration-measurements-and-simulations

[5] Work supported by the U.S. Department of Energy, Office of Science, Basic Energy Sciences, Division of Materials Science and Engineering, and was performed at the Oak Ridge National Laboratory’s Center for Nanophase Materials Sciences (CNMS), a U.S. Department of Energy Office of Science User Facility. This manuscript has been authored by UT-Battelle, LLC, under Contract No. DE-

AC0500OR22725 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for the United States Government purposes. The Department of Energy will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan (http://energy.gov/downloads/doe-public-access-plan).