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Automatic correction of spectral aberrations in EELS

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There a number of factors that affect the quality of data acquired with an energy-filter when used for Electron Energy-Loss Spectroscopy (EELS) in a transmission electron microscope. These factors particularly limit the attainable energy resolution and the integrity of data acquired in techniques such as (ω,q) mapping[1]. The multipole optics of a post-column energy filter are ideally suited to obtain a large range of high quality spectral dispersions [2]. Quadrupoles can control magnifications in the dispersive and non-dispersive directions independently and thereby optimize the available dynamic range of the detector for each dispersion. Furthermore, any remaining spectral distortions from the prism, such as spectrum linearity, rotations or barrel distortions can be corrected by higher order multipoles in the projection optics. A fully automated software procedure allows for more precise alignments than can be achieved otherwise and provides validation of alignment states prior to spectrum acquisitions.

The primary goal for spectroscopy auto-tuning software is to reliably adjust the appropriate filter lenses to locate an optimal state for data acquisition in spectroscopy mode. This state may be characterized according to the following criteria : firstly, the zero-loss peak (ZLP) should be focused in the dispersion (x) direction and must have the appropriate height in the orthogonal or non-dispersive (y) direction. The dispersion, or eV-per-pixel, of the spectrometer must be as close as possible to the nominal value to yield properly calibrated spectra. AutoCentering of the ZLP in the y-direction is required to position the ZLP appropriately on the CCD. In addition, two-dimensional distortions that include rotations, second order curvatures and third order barrel distortions also need to be minimized in an automated procedure.

The basis for correction involves an analysis of a frame containing multiple zero-loss peaks, as shown Figure 1. Figure 2 shows the result for auto-centering for data acquired at 200 keV. After centering is performed, then an additional routine performs a simultaneous tuning of dispersion, height and focus, necessary due to significant cross-coupling of the lenses. The effect of this correction is illustrated in Figure 3, which shows that the dispersion may be tuned to with 0.1% of the nominal dispersion, and that the effective width of the ZLP can also be reduced by adjustment of the appropriate lenses. The correction of two-dimensional distortions is demonstrated in Figure 4. In all cases, the routines typically take only a few seconds to complete.

Automated spectrum aberration correction using higher order multipoles particularly improves the quality of the spectrometer alignment for large energy ranges. Spectrum acquisitions with lower dispersion are useful for locating multiple edges in a single frame and allows for higher frame rates for a given signal to noise. High speed spectral acquisitions is of particular interest for spectrum imaging applications.

References

[1] Reimer, Energy-Filtering Transmission Electron Microscopy, Springer New York (1995) 37
[2] Krivanek et al., *Ultramicroscopy* 22 (1987) 103.

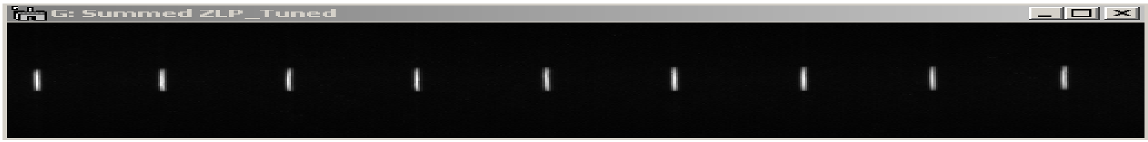

Fig. 1. Summed two-dimensional image with equally spaced zero-loss peaks.

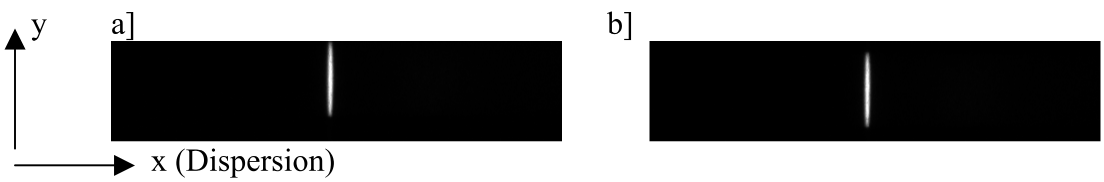

Fig. 2. Initial y-centering of ZLP. The above results are for centering at 200 keV, 1 mm aperture and 0.05 eV/pix (nominal) dispersion. Fig.1a,b] are the initial and final 2d zlp images respectively.

Fig. 3. Dispersion Height and Focus tuning. Fig. 3a] shows the initial, untuned state. The green annotation reflects the target height and dispersion for the 2 zlp peaks. Fig. 3b] demonstrates the result after auto-tuning.

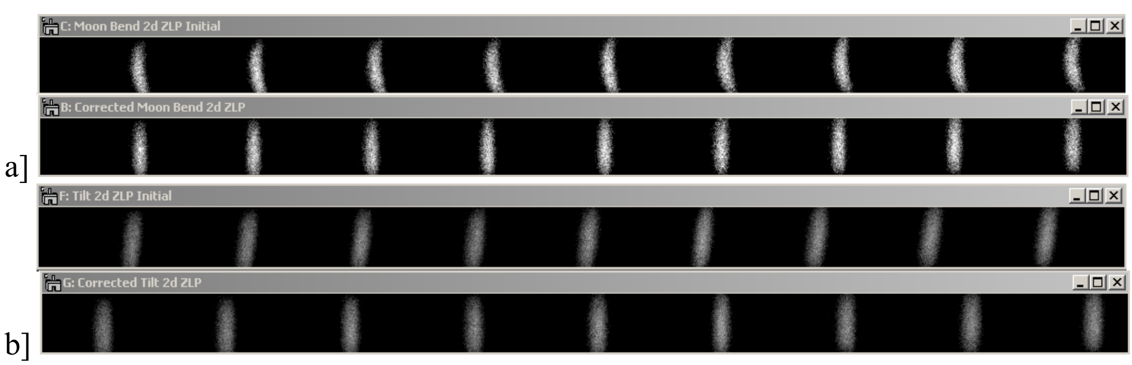

Fig. 4. Correction of tilt and moon bend distortions and. Fig. 4a] demonstrates tuning of the moon bend distortion, while Fig. 4b] shows the corresponding correction of tilt.

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