Spatially resolved EELS with an in-column Omega filter – from distorted recordings to corrected results

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Introduction

Spatially resolved EELS (SR-EELS) [1] is a technique to preserve one-dimensional spatial information when recording EEL spectra. Using SR-EELS, many EEL spectra are recorded in parallel as a function of one spatial coordinate, perpendicular to the energy dispersive direction. This method is useful for investigating specimens like interfaces and layer systems. We will show that the used in-column Omega filter [2] of a Zeiss Libra 200FE introduces distortions to the SR-EELS images and we present a work flow to entirely correct these distortions.
A layer system of iron and chromium on silicon oxide and silicon is used to benchmark the method and the image processing. All steps of image processing are performed by EFTEMj [3], a plugin for the open source software Fiji [4], which is written in Java.

SR-EELS in 4 steps

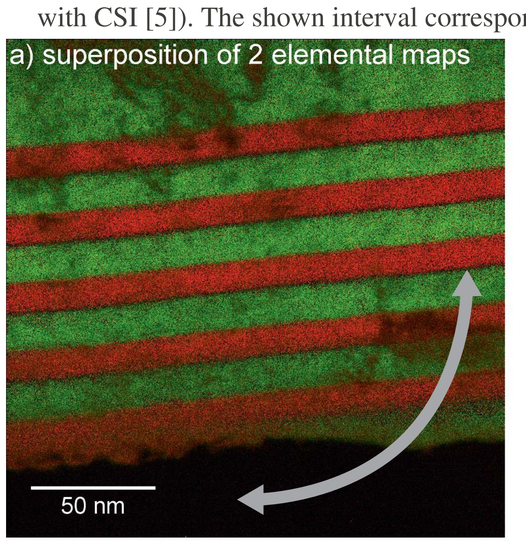
Here we describe the workflow of creating a SR-EELS data set.

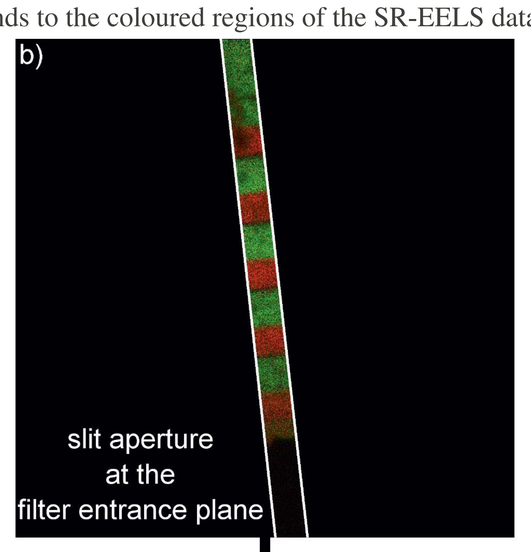
a) Rotate the specimen to get the correct orientation: The layer boundaries have to be parallel to the energy dispersive direction.

b) We use a slit aperture at the filter entrance plane. Compared with a round aperture the intensity along the lateral axis is uniform, but we lose intensity as the slit is narrower.

c) Switch to the EELS mode. Operating with the default energy filter settings, the image at the energy dispersive plane is strongly distorted. Lateral information is visible, but not usable for quantitative measurements. This image can be used to create an EEL spectrum (see red line at the plot on the right).

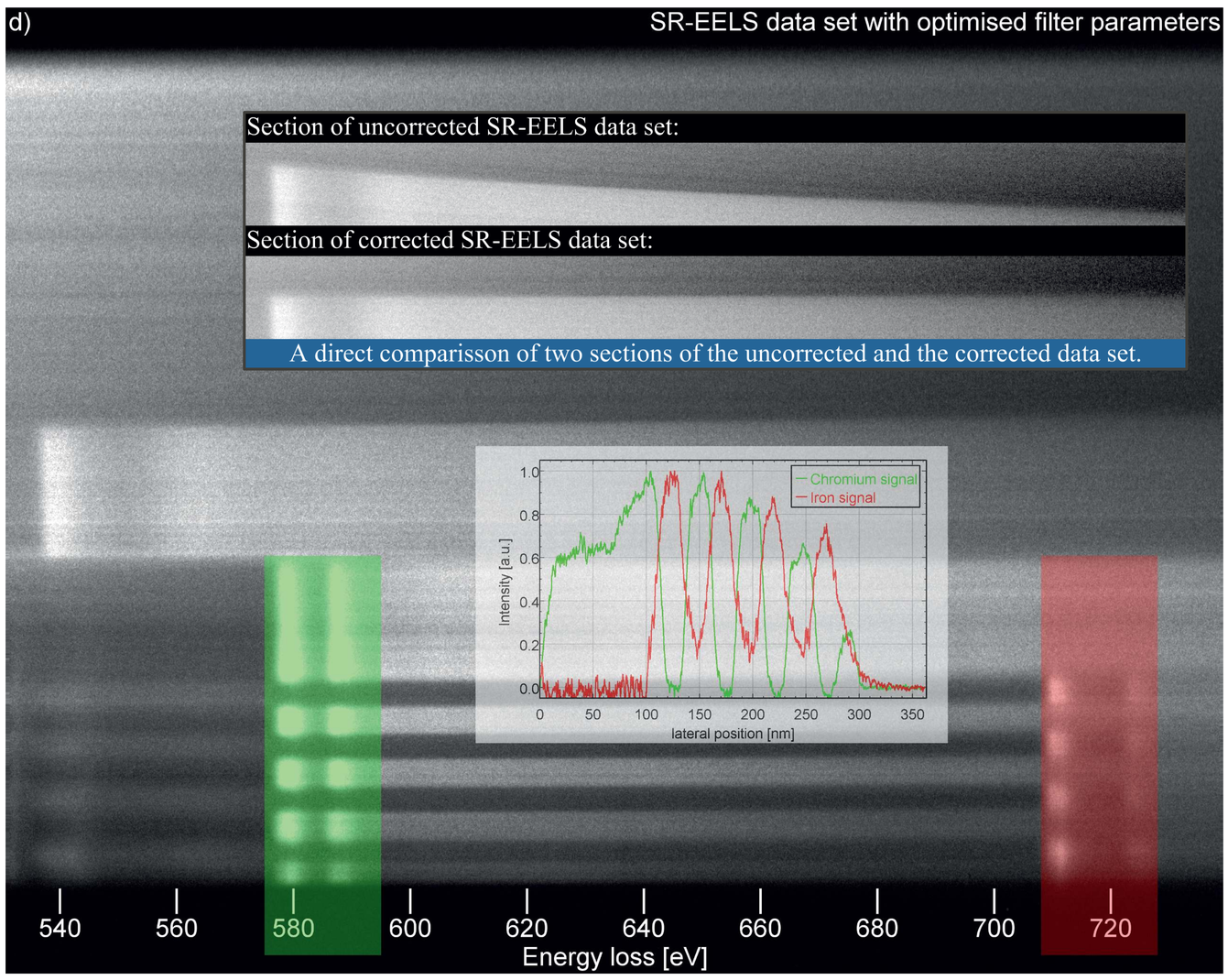
d) After optimising the filter parameters, the image at the energy dispersive plane shows much less distortion (see the figure on the top right). Using our image processing software (EFTEMj [3]), we can remove the remaining distortion and obtain the final result. The inset plot shows the background subtracted element signals (processed with CSI [5]). The shown interval corresponds to the coloured regions of the SR-EELS data set.

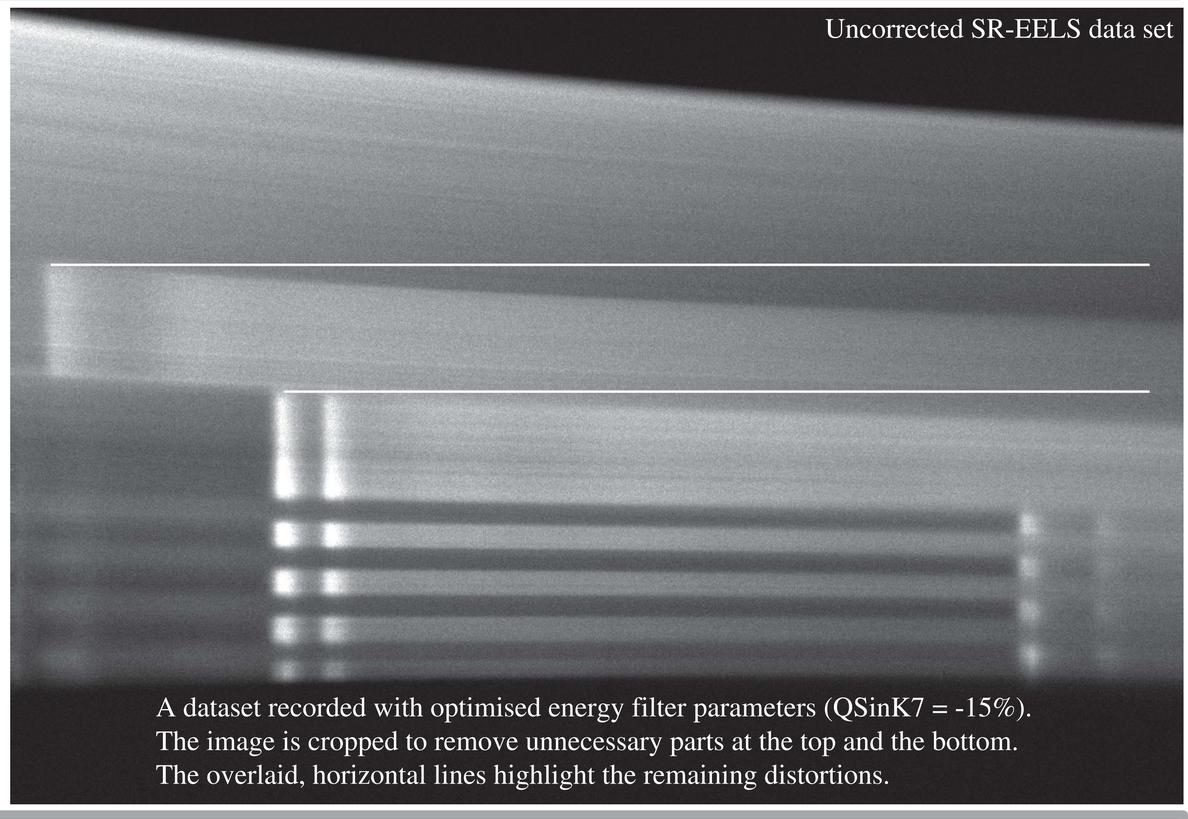




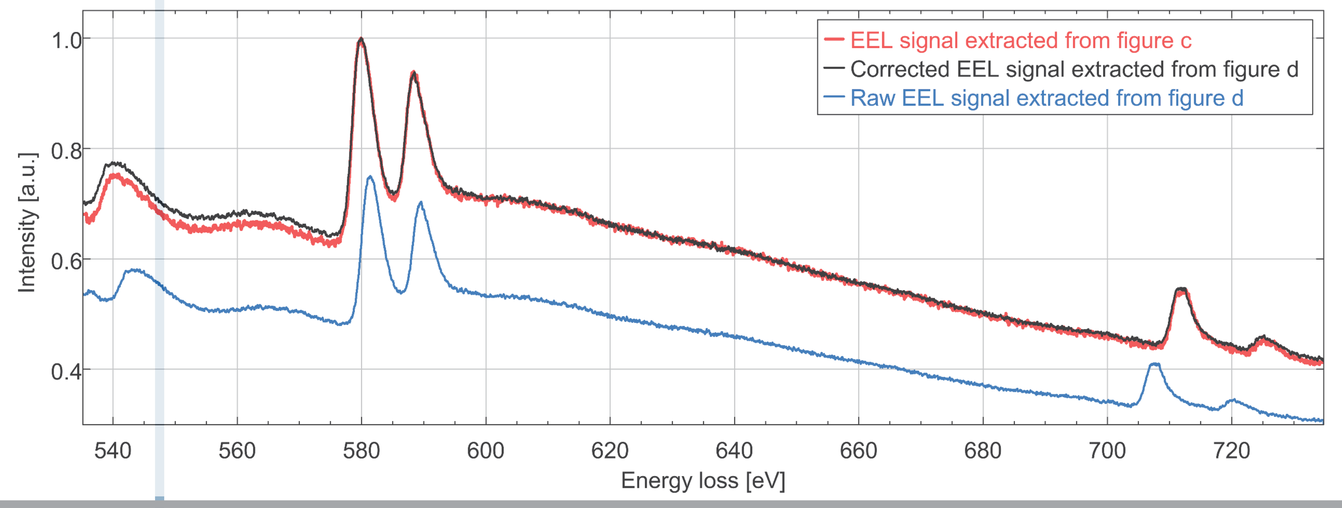
energy filter

oxygen K-edge chromium L-edges iron L-edges



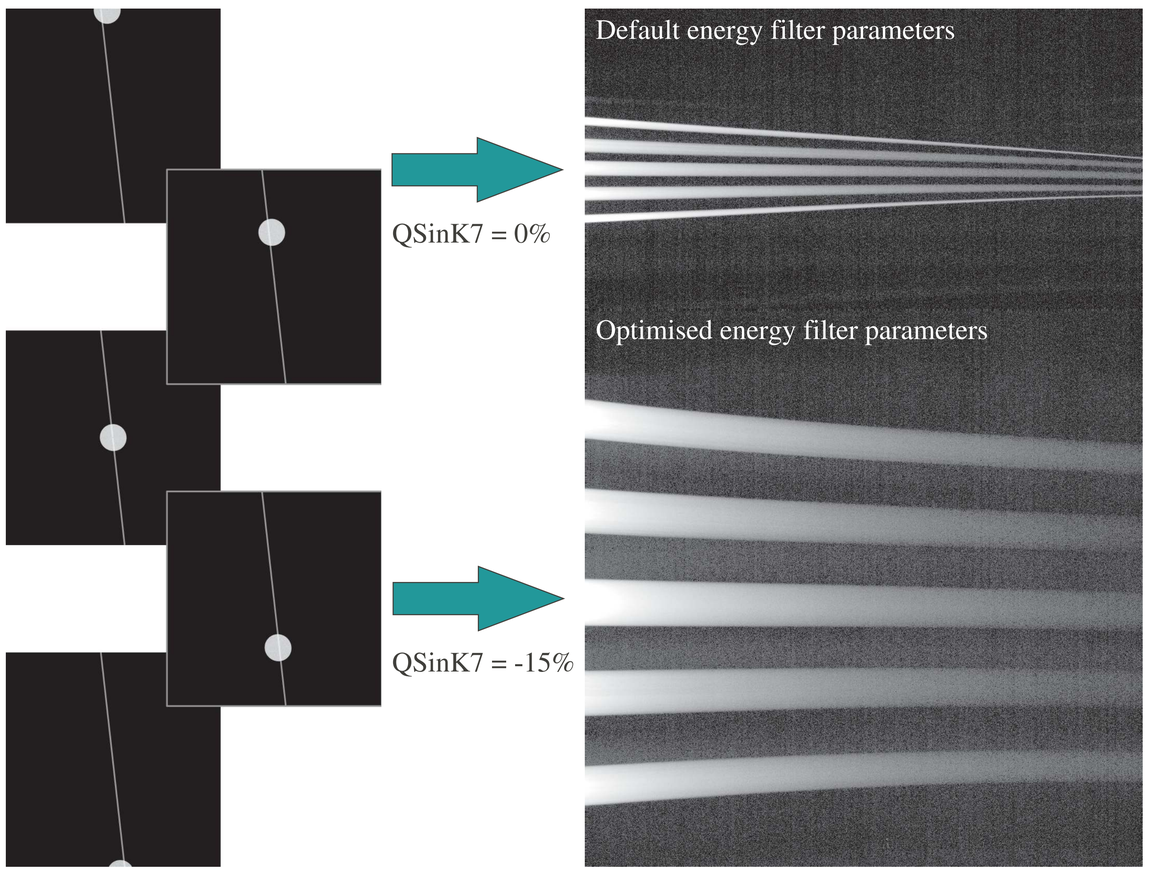


EEL spectra showing the L-edges of iron and chromium. The red and the blue spectra are plotted with the same energy dispersion. By optimising the energy filter for SR-EELS, the energy dispersion changes (blue). The black spectrum shows the same data as the blue one, but the energy dispersion has been corrected. The match with the red spectrum is very good, except for energy losses below 575 eV.

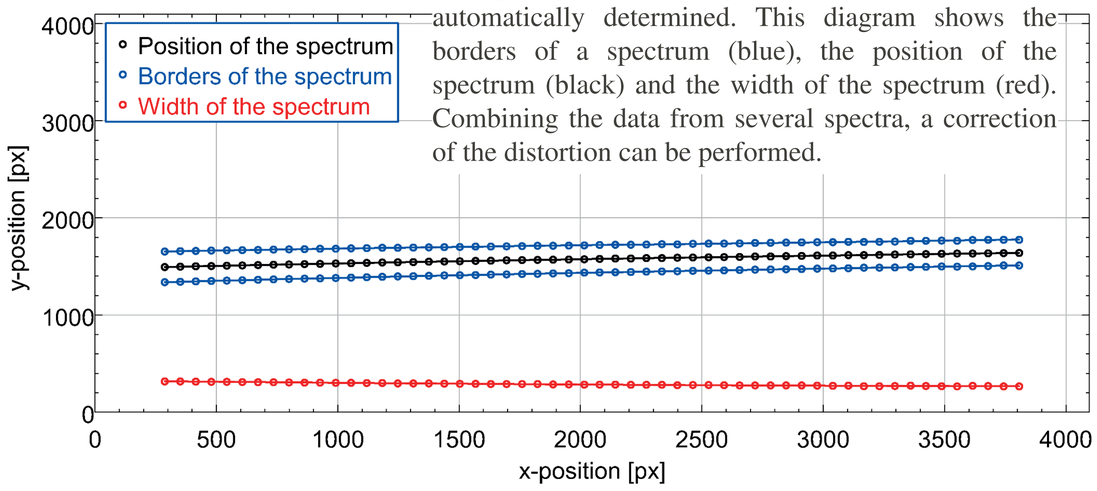


How to perform the correction of the distortion?

We have to do a second measurement that characterises the distortion of the SR-EELS data set.



The characterisation is done by shifting a small aperture at the filter entrance plane along the long axis of the slit aperture.
On the left 5 TEM image are shown that display the position of the 100 µm aperture.
On the right two superpositions of the 5 resulting SR-EELS images are shown. The default energy filter parameters and the optimised parameters are compared to each other.



The position of the spectra and their width is automatically determined. This diagram shows the borders of a spectrum (blue), the position of the spectrum (black) and the width of the spectrum (red). Combining the data from several spectra, a correction of the distortion can be performed.

References

[1] L. Reimer et al., Ultramicroscopy 24 (1988), 339-354.
[2] S. Lanio, PhD thesis (1986), TH Darmstadt.
[3] EFTEMj is available on GitHub: https://github.com/EFTEMj/EFTEMj
[4] Fiji (Fiji is just ImageJ): http://imagej.net/Fiji
[5] P. Cueva et al., Microscopy and Microanalysis 18 (2012), 667-675.
[6] All figures have been created with scripts and macros for Fiji:
https://github.com/m-entrup/MC2015-Poster