Spectroscopy in STEM/TEM

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Spatially resolved EELS of FeCr layers - an example for processing TEM images with ImageJ

M. Entrup[1], H. Kohl[1]

[1]WWU Münster , Physikalisches Institut, Münster, Germany

michael.entrup@uni-muenster.de
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Electron energy loss spectroscopy (EELS) is used to obtain chemical information in the transmission electron microscope. From a selected area a single EEL spectrum is acquired. When using spatially resolved EELS (SR-EELS), a part of the spatial information is preserved. Several 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. In this work we apply SR-EELS in a TEM with in-column Omega filter to a FeCr layer system. Some of the remaining aberrations of this filter can be corrected by processing the recorded SR-EELS images. We will show how the open source software ImageJ [1] can be used to perform this task.

A TEM equipped with an energy filter allows us to create a three-dimensional data cube (Fig. 1). In single measurements we can only cut two-dimensional slices out of this data cube. With SR-EELS we can record images that contain both, spatial information and energy loss information. SR-EELS was first described by Reimer et al. [2]. The energy filter determines how to set up the TEM. The in-column Omega filter of the Zeiss Libra 200FE uses hexapole elements to suppress axial aberrations and the resulting caustic [3]. Therefore SR-EELS data can be recorded directly in the EEL spectrum mode. It is the same data that is used to create an EEL spectrum by summing all pixels of each energy channel. As shown in Fig. 2a, the spatial extension decreases with increasing energy loss. This distortion results from a geometrical aberration and can be corrected by processing the recorded data. Another experimental aspect has to be considered. A round aperture at the filter entrance plane results in a change of intensity along the spatial axis. By using a well aligned slit aperture the uniformity of the intensity is ensured. The narrow slit that is installed in our microscope results in a low overall intensity and therefore long acquisition times are necessary. We therefore decided to use a round aperture to gain as much intensity as possible, to observe the core loss energies of chromium and iron.

ImageJ is used to perform the processing of the recorded data. The advantages of this open source software are the support for a wide range of file formats, the easy to learn macro language and the possibility to write complex plugins with Java. To correct the distortion of the SR-EELS data a plugin has been implemented. At first a partially manual method can be used to apply a linear fit to the inclined border. Applying a linear model to describe the distortion leads to a small error. Therefore the plugin provides an alternative, automatic method that measures the spatial extension of each energy channel separately. This results in a slightly curved fit. The second step is to scale each energy channel to the same spatial extension (Fig. 2b), while preserving the over all intensity of each channel. Intensity variations due to the use of a round aperture can be corrected at the same step.

In combination with EFTEMj [5] - an ImageJ plugin for elemental mapping - it is possible to further analyse the corrected SR-EELS data. At core loss energies we can subtract the background signal to extract the elemental signal. EFTEMj can handle an arbitrary number of pre- and post-edge images, being the ideal tool to analyse the SR-EELS data. But it requires a stack of ESI images (see Fig. 1a). To fulfil this requirement the SR-EELS data are converted to a stack of line traces (see Fig. 1c. One line trace is highlighted by a darker colour). Fig. 2c shows a montage of such a stack. The resulting elemental signal of iron is shown in Fig. 2d.

Further studies have to show if SR-EELS can compete with normal EFTEM analysis of the same specimen. A higher energy resolution will be the main advantage of SR-EELS. Compared to elemental maps of EFTEM images data acquisition times are shorter with the disadvantages of a higher experimental effort - orienting the specimen - and more sophisticated processing of the data. If the spatial resolution is high enough and image processing does not add artefacts to the data, SR-EELS can become a helpful tool to analyse interfaces and layer systems.

1. C. A. Schneider et al., Nature Methods 9 (2012), 671-675.
2. L. Reimer et al., Ultramicroscopy 24 (1988) 339-354.
3. S. Lanio, PhD thesis (1986), TH Darmstadt.
4. https://github.com/EFTEMj/EFTEMj (11.04.2013)
5. The authors gratefully acknowledge funding from the Deutsche Forschungsgemeinschaft (DFG) under grant number Ko885/8-1.

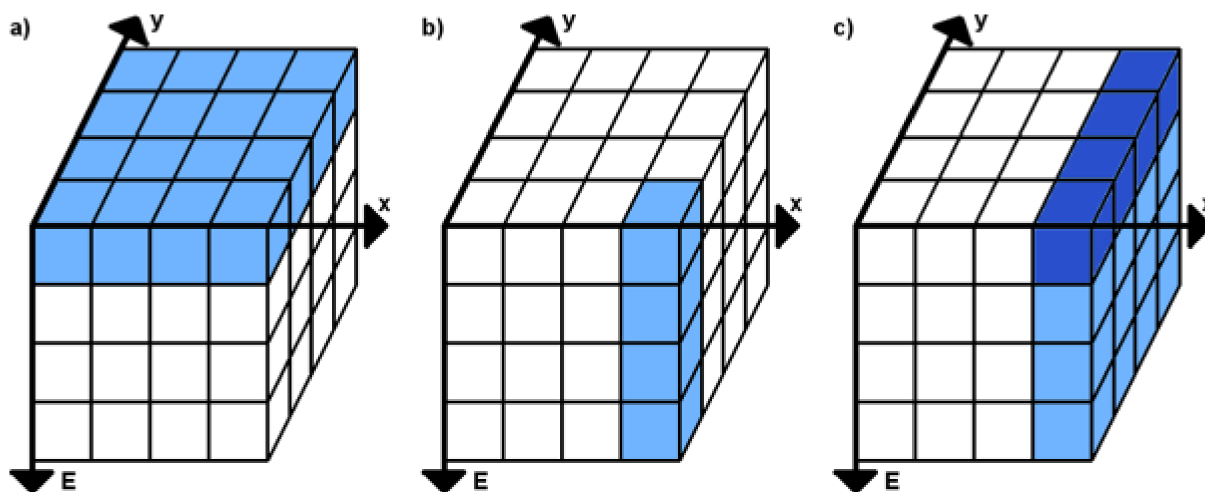

Figure 1. Data cubes for an energy filtering TEM. The highlighted area shows the data that can be acquired with a single measurement by **(a)** electron spectroscopic imaging (ESI), **(b)** EELS and **(c)** SR-EELS

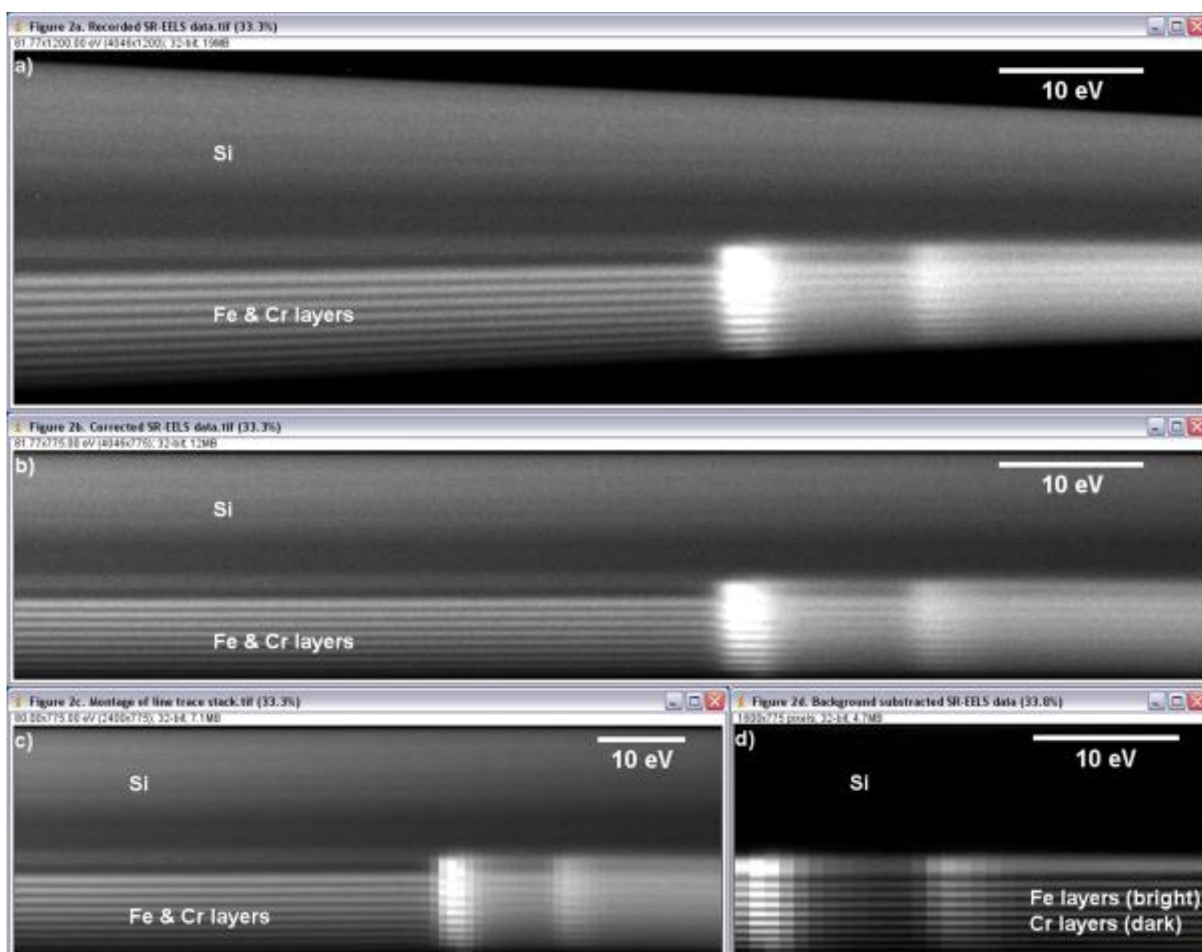

Figure 2. ImageJ workflow for SR-EELS data processing. Fig. 2a - Fig. 2c show an energy interval between 660eV and 740eV. The heights of Fig. 2b - Fig. 2d are 350nm. This results in 0.45nm per pixel. (a) The recorded SR-EELS data. Energy loss as a function of one spatial coordinate, perpendicular to the energy dispersive direction. (b) Corrected SR-EELS data. Each energy channel has been scaled separately. (c) Montage of a line trace stack. The stack has been created by sectioning Fig. 2b into 80 intervals of 1eV width. From each interval a line trace (an image with 1px width and 775px height) has been created by summing all energy channels of the given interval. (d) Montage of the background corrected line trace stack (708eV to 740eV). The stack shown in Fig. 2c has been processed by the ImageJ plugin EFTEMj. All 48 line traces below 708eV contributed to the background calculation. The estimated background has been subtracted from the 32 line traces above 708eV.