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Digital Super-Resolution in EELS

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Nowadays the term super-resolution is widely used in the field optical microscopy, meaning to enhance the resolution beyond the classical diffraction limit. Techniques like near-field scanning optical microscopy [1] or structured illumination microscopy [2] are meanwhile routinely used to study biological samples. Next to microscopy the principle of super-resolution also found its application in photography.

For the latter multiple-frame super-resolution is one of the standard methods used [3]. This procedure can be adapted to a whole zoo of measurement techniques in microscopy and spectroscopy straightforwardly. The method makes use of the sub-pixel shifts between several low resolution images. By aligning all these single measurements with regard to a common feature, the sum has complementary information and thereby a higher resolution.

We apply this method as a post-acquisition treatment of electron energy-loss (EEL) spectra. With the use of the drift tube, the energy offset of the spectrometer is randomly changed after each recording of one single spectrum. As a result the spectra are always measured on different special positions of the CCD of the spectrometer. After the measurement of all spectra, they are aligned to each other with regard to a spectral feature, e.g. an absorption edge, using cross-correlation [4]. Since the maximum of an absorption edge is not always perfectly aligned towards the center of a single pixel of the CCD (e.g. due to small high tension fluctuations) each single spectrum slightly differs, especially at pronounced spectral features. Careful alignment and summation can recover details beyond the Nyquist limit that are otherwise not visible in the single spectra.

To test the functionality of the procedure, the method is applied to a $SrTiO_3$ test sample. 100 single EEL spectra of the Ti $L_{3,2}$ edge with an acquisition time of 0.1 s and a dispersion of 0.2 eV/px and 0.1 eV/px are recorded (cf. Figure 1). Indeed it is possible to reconstruct a spectrum with a dispersion of 0.1 eV/px from a spectrum with dispersion 0.2 eV/px qualitatively. Even a small dip on the onset of the Ti L_3 edge can be reconstructed, which cannot be found in the raw data (cf. Figure 2).

Furthermore more advanced algorithms, such as compressive sensing, are applied to reconstruct spectral details in greater detail. A comprehensive comparison between the different approaches will be given.

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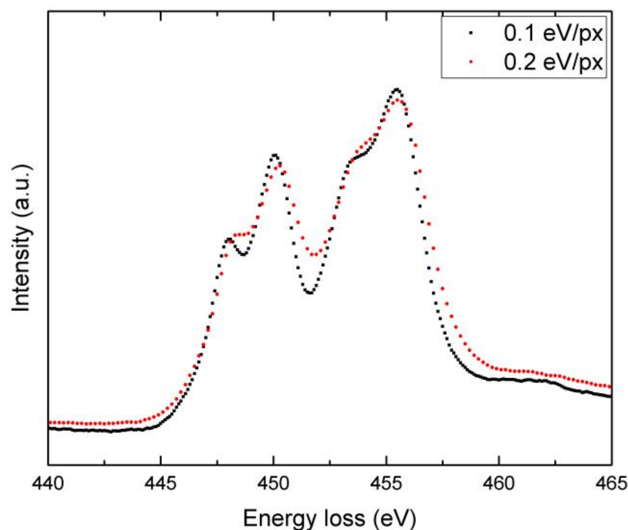

Figure 1. Normalized EEL spectra of the Ti $L_{3,2}$ edge acquired with dispersions 0.1 eV/px and 0.2 eV/px. The spectrum with a dispersion of 0.2 eV/px is used as starting point for the reconstruction and is compared to the measured spectrum with dispersion 0.1 eV/px. To upscale the 0.2 eV/px spectrum to 0.1 eV/px, bilinear expansion and an advanced compressive sensing algorithm is used. The precise alignment of the 100 single spectra is done by cross correlation on a pronounced feature.

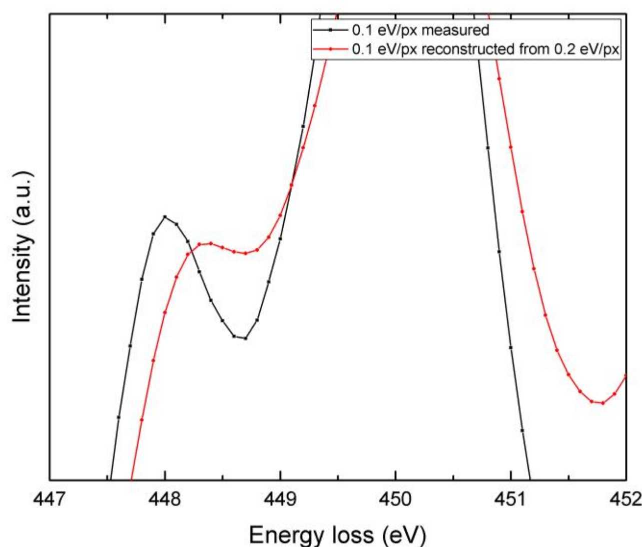

Figure 2. Detailed view of the onset of the Ti L_3 edge for the spectra given in Figure 1. Even strongly suppressed in amplitude, the digital super-resolution procedure is able to reconstruct a small dip at 448.7 eV, which is otherwise lost by simple summation.

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