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MerlinEELS

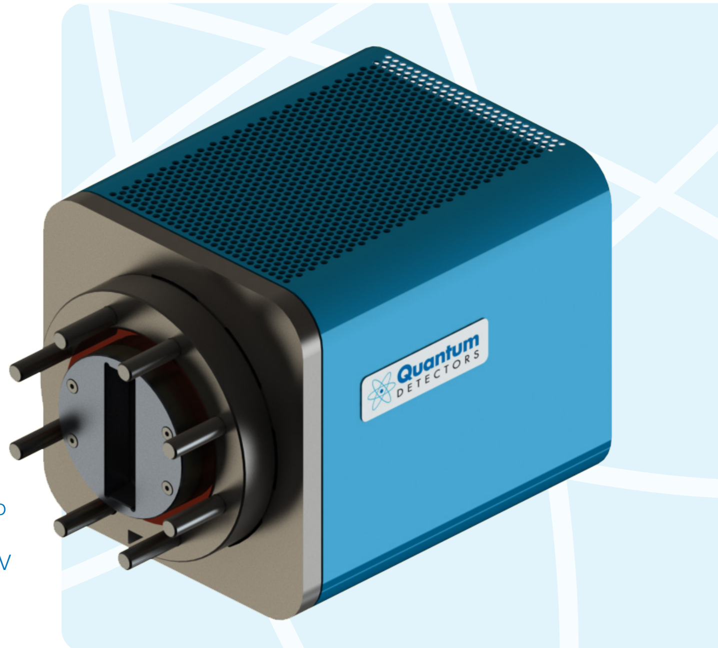
Application Note

MerlinEELS - direct counting detector for electron energy loss spectroscopy

Key benefits in EELS:

- **Electron counting**
- **Zero read-out noise**
- **High dynamic range**
- **High kV core-loss imaging**

MerlinEELS key specifications: noiseless readout, zero dark counts; no dead time with 1-bit (18,800 fps), 6-bit (3,200 fps) or 12-bit (1,600 fps) imaging; 30 keV - 300 keV operation; pixel size 55 x 55 µm; active area: 56 x 14 mm (1024 x 256 pixels); DQE at 60 keV: 1 at Zero frequency, 0.45 at Nyquist; MTF at 60 keV: >0.62 at Nyquist.



Electron energy loss spectroscopy (EELS) is a widely used analytical technique in transmission electron microscopy. It is based on detection of energy distribution of inelastically scattered electrons after they are transmitted through the thin sample. The energy of these events can be used to measure concentrations of atomic species, the optical properties, band structure, electronic properties and thickness of the sample. A spectrometer with a magnetic prism is used to disperse the electron beam which is then detected by an electron detector. CCD cameras are traditionally used for this purpose. However, some characteristics of CCD cameras are not desirable such as multiple signal conversions associated with an additional Poisson noise, intrinsic read-out noise, thermal background noise and speed of acquisition.

In this note we will show the advantages of using a direct electron detector, MerlinEELS, to collect EELS spectra. The main advantages of the detector are: zero read-out noise, hardware based electron counting and high dynamic range. These will be demonstrated by the following practical examples:

- Imaging of **low loss electrons** and the **zero loss peak** can only be done with a detector with **high dynamic range** - the number of electrons in the zero loss peak is large. Additionally, if a monochromated probe is used it is crucial to have a detector with a small point spread function. The detector needs to image details of the spectrum even if the local change is small compared to the number of detected electrons. Example of this is shown in Fig. 1.
- Imaging of **high core loss** electrons can be used to resolve the composition of the sample with atomic resolution. However, **single electron sensitivity** is crucial here as the number of high loss events can be very small. See example in Fig. 2.

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Dynamic range of MerlinEELS in low loss EELS

We will demonstrate the dynamic range and low loss resolution in spectrum imaging of the SrTiO3 and LaMnO3 interface. The imaging was done at 100 kV acceleration voltage with 30 pA probe and convergence semi-angle 7.5 mrad on the Nion USTEM200 microscope at LPS Orsay. MerlinEELS camera (256x1024 pixels) was attached to the back of the Gatan ENFINA spectrometer. The spectrum in Fig. 1 demonstrates the dynamic range of the camera in the low loss area of the spectrum from zero loss peak to ~1.2 keV energy loss. Fig. 1 also compares dark field, zero loss peak (bright field) and elemental peaks information. The probe dwell time was 1 ms and scan step size was 50 pm. It is clear that MerlinEELS offers high dynamic range and is suited to image low loss EELS capturing all the details within the spectrum.

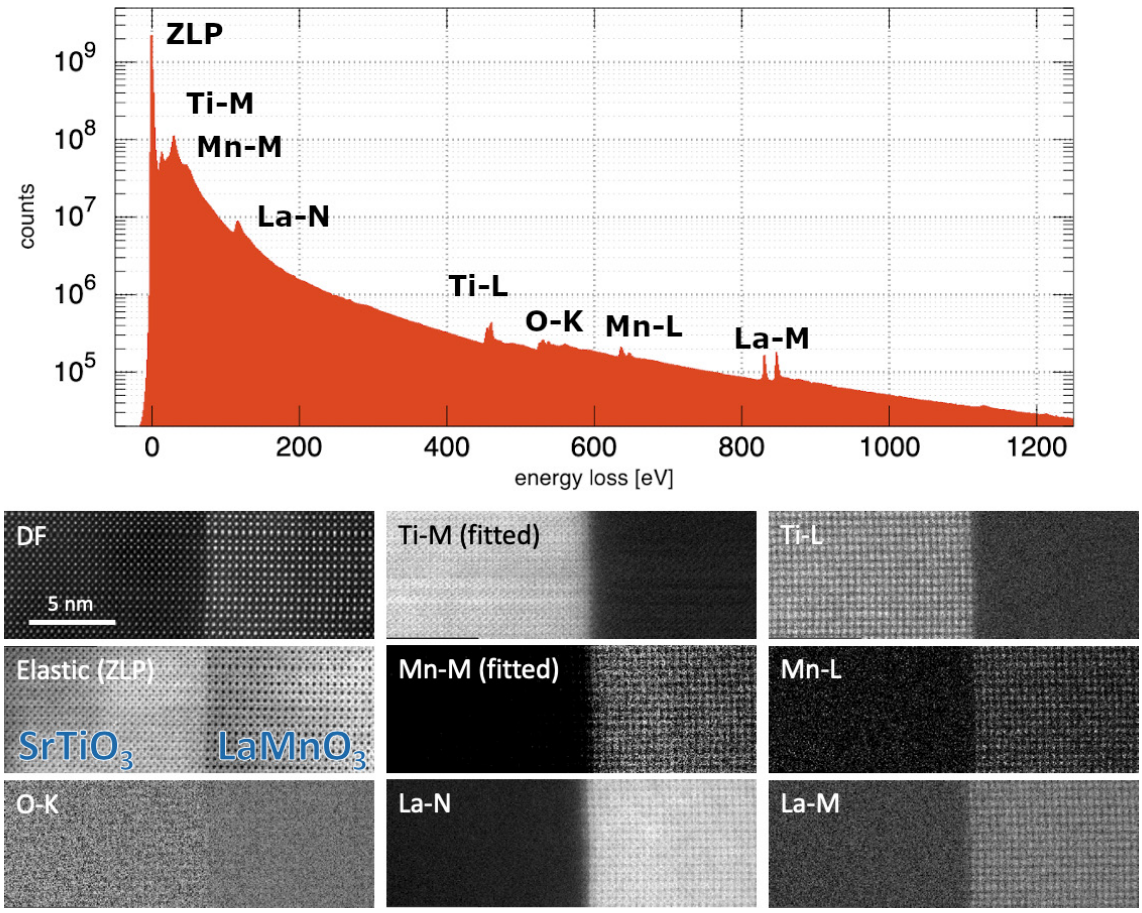

Fig 1: MerlinEELS dynamic range demonstration. Spectrum imaging acquired in low loss EELS (0-1.2kV) and corresponding sample peak maps. The spectrum was generated by summation of all spectra acquired in a 2D scan over the SrTiO3 | LaMnO3 interface. Spectrum imaging was performed with 50 pm scan step size, 1 ms dwell time, probe current 30 pA and convergence semi-angle 7.5 mrad. The imaging was performed with a Gatan ENFINA spectrometer equipped with the MerlinEELS detector on a Nion USTEM200 microscope at 100 kV at LPS Orsay, CNRS, Université Paris-Saclay. Data courtesy of Marcel Tencé and Alexandre Gloter.

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High loss EELS imaging with MerlinEELS

As was mentioned before, collection of high loss EELS requires a high sensitivity detector with minimal noise. Images collected by MerlinEELS do not have any thermal noise background as this is effectively eliminated by recognising separate electron events in the pixel electronics. The advanced analog and digital circuitry eliminate any read-out noise from the system. This makes the MerlinEELS detector highly applicable in high loss EELS. We demonstrate this in Fig. 2, which shows an atomically resolved interface between SrTiO3 and LaMnO3 where high kV loss (4.8kV - 5.7kV) with Titanium-K and Lanthanum-L3 edges were mapped. To quantify the required sensitivity: a single spectrum from the centre of a La atomic column has an average of 2.5 counts with a standard deviation of 2.1.

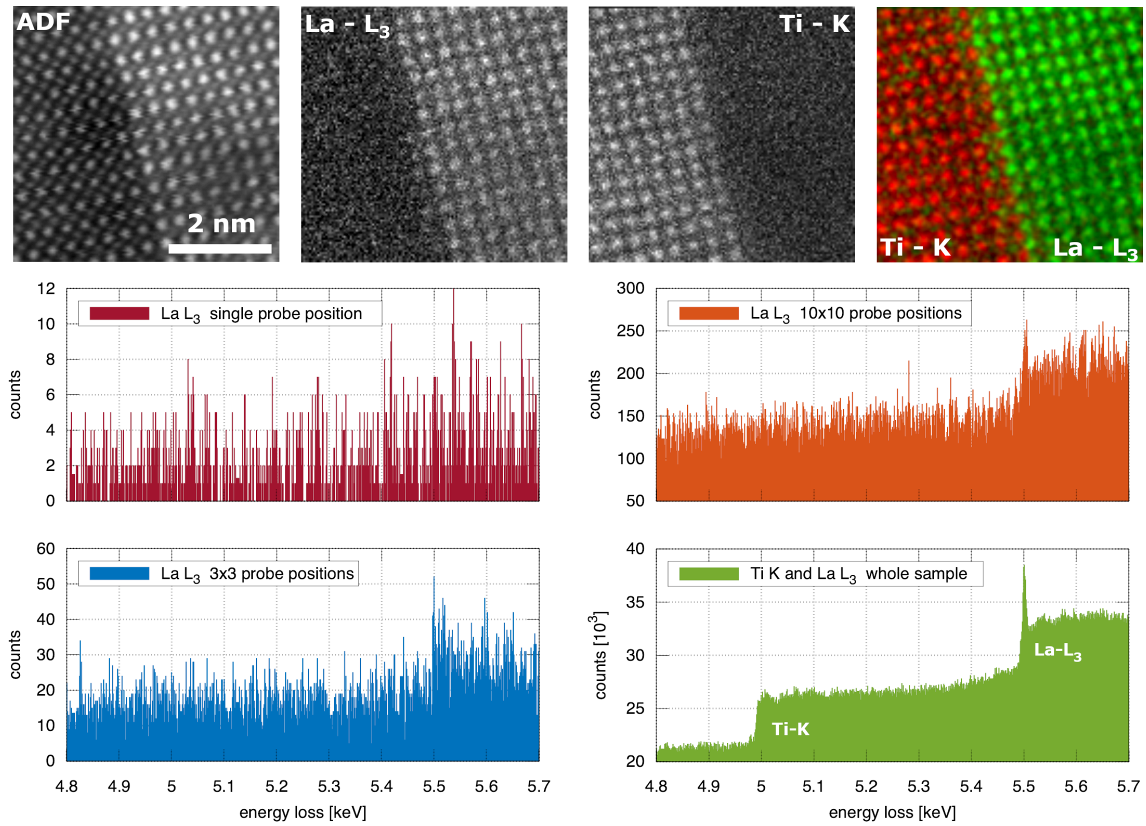

Fig. 2: High core-loss imaging. 4.8 - 5.7kV EELS imaging with MerlinEELS electron counting detector. The imaging was carried out on a Nion USTEM200 with a 100kV probe with 250pA current and a dwell time of 10ms. MerlinEELS camera was attached to Gatan ENFINA EELS spectrometer. Courtesy of Marcel Tencé and Alexandre Gloter, STEM LPS laboratory, Université Paris-Saclay.

Top: Spectrum imaging over SrTiO3 I LaMnO3 interface ADF image compared to images of La-L3 and Ti-K EELS edges. High core loss signal clearly shows atomically resolved images. The right (colour) figure shows a combination of La sensitive and Ti sensitive spectrum imaging - offers a powerful way to study interfaces with core localised EELS signal.

Bottom: Signal to noise demonstration for the same spectrum image where a single, 3x3 and 10x10 probe positions were summed. The bottom right image shows a sum of spectra from the whole sample. The top-left image shows that a counting detector is essential for high core loss imaging - the signal is between 0 and 12 electron counts in a single high loss spectrum.

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