Applications of a Direct Electron Detector in Electron Energy Loss Spectroscopy and Mapping

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Electron energy loss spectroscopy (EELS) is an invaluable technique to study the detailed structure and the chemical state of materials at unprecedented spatial resolution. Today, this technique is used "routinely" to characterize nanoscale materials used in a myriad of applications from energy storage and conversion, to solid-state devices and biomaterials interfaces. This technique also has the potential to provide insight into much more fundamental problems where the valence state of atoms and their location in the lattice is of critical importance. However, whilst there have been dramatic improvements in the characteristics of the electron probe (size, current) and energy resolution of microscope, there is still a significant need to improve the quality of the spectroscopic data in order to reduce the limitations induced by electron beam damage.

Recently, there have been major developments in detection approaches for scanning transmission electron microscopy (STEM) through pixelated detectors, and in EELS using direct electron detectors [1]. Direct electron detectors have significant benefits in terms of noise levels and point spread function resulting in major improvement in the quality of spectra. Here, we use a retractable Gatan K2 IS camera adapted to a Quantum spectrometer installed on a Titan 80-300 Cubed monochromated microscope to demonstrate the impact of such detectors on materials science applications.

First of all, the better the point spread function results in significant improvements in the quality of spectra and signal, due to the use of lower dispersion during spectral acquisition. Secondly, the noise characteristics are dramatically improved due to the single electron counting mode. This leads to much lower dose for the acquisition of spectra. As a consequence, such instrumentation allows improvements in data acquisition of beam sensitive samples and the detection of core losses signals at energies not normally easily accessible with regular cameras.

Several examples of application of direct electron detectors for spectroscopy will be given in the field of Li ion battery materials where atomic resolved imaging, not normally possible with regular detectors due to the beam damage, will be shown. The application of energy loss spectroscopy to hydroxide phases is also demonstrated providing much better insight on the damage mechanism of these materials. Further examples related to the use of high energy edges (above 2000eV) will be shown for the study of noble metal nanoparticles and nanostructures.

The spectroscopy data, combined with machine learning approaches, will be discussed and used to demonstrate single atom spectroscopy and valence state mapping. [2]

[1] J. L. Hart, A. C. Lang, A. C. Leff, P. Longo, C. Trevor, R. D. Twesten, M. L. Taheri, Sci. Rep. **7**, 8243 (2017)

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