doi:10.1017/S1431927619012170
Microsc. Microanal. 25 (Suppl 2), 2019

The Major Developments in Camera and Electron Energy Loss Spectrometer Technology Since the Turn of the Century

Adam Papworth[1*] and Lothar Houben[2*]

[1.] Gatan UK, Abingdon UK.
[2.] Weizmann Ins., Rehovot, Israel.
* Corresponding author: apapworth@gatan.com

At the turn of the century the standard spectrometer was the Gatan 666 Parallel Electron Energy Loss Spectrometer (PEELS), and for the Energy Filtered Imaging (EFTEM) was the Gatan Imaging Filter (GIF) GIF200 filter/spectrometer. For the next 10 years there was very little change in spectrometer design. The Tridium GIF (the third adaptation after the GIF200), came on the market in 2005/6, still had the same prism and drift tube design as the 666 PEELS, the main difference was the addition of extra lenses. However, there were big changes in camera design. The biggest of these changes were in the CCD size and readout speed.

The spectrometer had not really changed in design, it had the problems with spectrum defocus and limitations in maximum collections. For example, the prism has hysteresis and therefore moving the prism would mean that you could never really be able to say that the Zero Loss Peak (ZLP) was at zero. In addition, the edge energy onset would also move and therefore any changes in edge energy due to chemical shifts, would not be known accurately.

In 2010 Gatan released the Quantum family of imaging filters, the Quantum filter had a complete redesign using eight multi-pole lens groups. The redesign also included a different prism and built in fast electrostatic shutters and a 2000eV fast drift tube. However, the quantum still used the same CCD design of camera as used in the Tridium, although with much faster electronics. The CCD camera is not the limiting factor in energy resolution, which was the case with the 666 PEELS YAG sensor. With the addition of the ability to do Dual EELS, low and core loss spectra can be obtained simultaneously from the same point. Allowing core loss spectra to be corrected for energy shift as measured by the ZLP, in addition, the removal of plural scattering from each core loss spectrum within a data set.

In 2012 direct electron detectors were commercially available, at first it was thought that the sensor would not have a long-life span or take a high dose. However, this was not the case. Tests were conducted to see if direction detection cameras could be used for spectroscopy, and a new family of spectrometers were born.

Direct electron detectors offer a superior detection quantum efficiency (DQE) compared to CCD cameras when operated in counting mode. For spectroscopy the major requirements for a good detector are to provide high energy resolution, a large number of channels and spectral range, a high signal-to-noise ratio (SNR) and dynamic range. For EFTEM the demand is for a large field of view, high spatial resolution, and a high SNR.

Owing to the better DQE direct detection is able to provide a larger number of energy loss channels for EELS at the same energy resolution. With the same argument more pixels are available for EFTEM at the same spatial resolution.

The most significant impact, however, is the effective suppression of non-signal related noise in a counting mode. Figure 1 shows the case of spectroscopy. In this example the Sr $L_{2,3}$ edge at 1940eV can be detected with ease using a direct detector rather than the conventional CCD detector. When a direct detector is used for EFTEM the unrivalled SNR allows to record high-fidelity elemental maps with low electron doses. Fig. 2 shows the example of boron nitride and black phosphorous layers on top of silicon oxide. The oxygen K-edge profile taken with a signal of just one electron per pixel and second shows the unrivalled signal-to background noise of direct detection that is not achievable with a CCD camera.
At present the optical and energy resolution is not defined by either the spectrometer or the camera but by the microscope. However, for weak signals in spectroscopy or EFTEM the resolution is limited by noise and the applicable dose. Here, the superior SNR due to direct detection leads to better energy and spatial resolution.

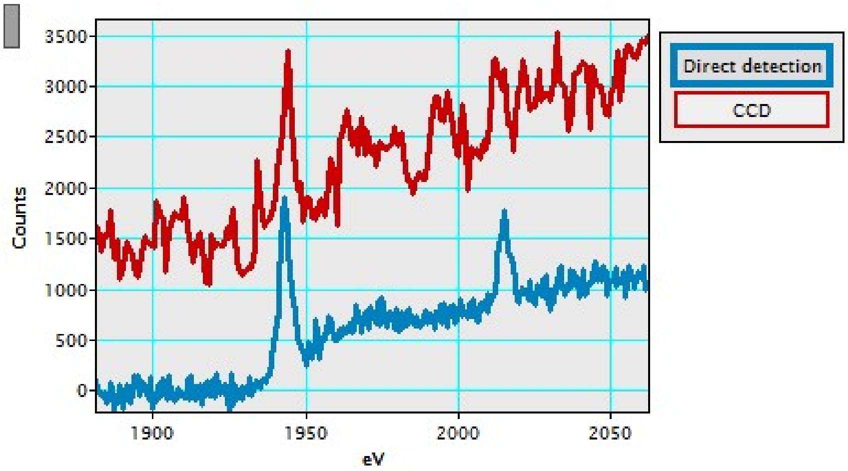

Figure 1. Sr $L_{2,3}$ at 1940eV. The new direct electron detector camera will give much better signal to noise ratio, allowing features not normally seen to be identified with ease.
Data acquired at Drexel University using a JEOL 2100F Microscope at 200keV.

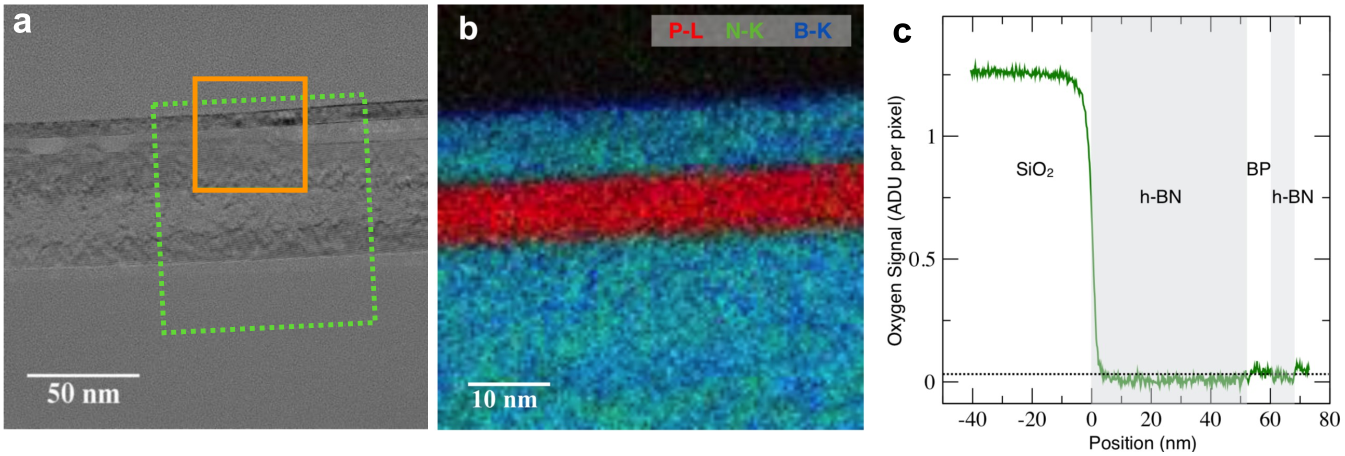

Figure 2. EFTEM data of a black phosphorous (BP) sandwiched between boron nitride (BN). The data was recorded in a FEI Tecnai F20 Twin microscope on a Gatan K2 operated in counting mode in a Quantum GIF 967. (a) Zero-loss filtered image. (b) RGB colormap of EFTEM elemental maps for a magnified part within the solid rectangle in (a). (c) Line profile of the oxygen signal averaged along the plane of the layer interfaces in the dashed region in (a). Note the single electron count rate per pixel for the oxygen K edge. Electron dose rate:150 $e^-/Å^2/s$. Exposure time: 50 s per energy window.