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Energy Filtered STEM Imaging at 30kV and Below – A New Window into the Nano-World?

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Energy filtered imaging has been available for many years for TEMs. Both, the in-column filter by Carl Zeiss [1] and the Gatan Imaging Filter [2] have proven useful and are well documented. Compared to TEM, energy filtering combined with BF-STEM has seen less publicity. This is surprising because BF-STEM by itself has an advantage over TEM: inelastically scattered electrons have less of an effect on the final image quality when compared to TEM. Furthermore, EF (energy-filtered) BF-STEM imaging has been reported as a promising approach [3]. However, EF BF-STEM imaging is handicapped by the requirement of a fast EELS detector: for acquiring a 512 × 512 pixel image in under 1s, an EELS detector capable of 512 × 512 = 262,144 EELS spectra /s is required.

For this study, the recently announced Hitachi's Low-Voltage STEM/SEM with EELS [4] presents an opportunity for further investigating the differences between TEM and BF-STEM imaging. Its cold FEG (field emission gun) and immersion lens allow for high resolution imaging. It also has two EELS detectors integrated into one system: one for acquiring a typical EELS spectrum, the other using a three-element detector capable of reading the ZLP and two Plasmon peaks in excess of 11,000 times/s. As a result, image acquisition is possible at ~0.2fps for a 256 × 256 image. Thus samples can be investigated with (EF) BF-STEM and Plasmon imaging at relatively low energies at, or close to, atomic resolution. But compared to TEM, 30keV seems a rather low voltage for imaging, but it is not as will be shown.

In its simplest form, energy filtering improves image quality by removing inelastic scattered electrons. In a very recent study [5], C_C corrected images were compared with non-corrected images. As expected, compensating the optical artifacts from inelastically scattered electrons improved the image quality throughout. The benefit of a C_C corrected systems is that the majority of the inelastically scatter electrons remain with the final image and thus the increase in the stochastic noise (due to finite number of electrons) is small. In contrast, non-C_C corrected systems remove inelastically scattered electrons and thus can increase the stochastic noise in the final image significantly. Thus, removal of the inelastically scattered electrons causes a loss of electrons (bad) but also causes less artifacts (good) for (EF) BF-STEM. Therefore we ask: how would a 30keV (EF) BF-STEM compare to a higher-kV TEM?

We are presenting here our first results comparing 30keV BF-STEM, EF BF-STEM and Plasmon images with TEM images at 80keV and 120keV. The comparison is presented in Figure 1 where, to the left, the standard 30keV BF-STEM image is shown; on the right the 30keV EF BF-STEM image and Plasmon image appears; and in the middle of Figure 1, the corresponding TEM images are shown with the 120keV TEM image above the 80keV TEM image. These initial results indicate that 30keV (EF) BF-STEM images compare less with 120keV TEM images but compare well with 80keV TEM images.

Why is this important? The advances in nano-technology, the use of nanostructures like carbon nanotubes, graphene and similar devices together with the advances in sample preparation techniques produce samples that, on average, become smaller and thinner. At the same time, the behavior or functionality of such samples is defined more and more by the surface of such samples. Therefore, we believe that there is a growing need for electron microscopes that can do both: imaging in transmission (volume information) and imaging the surface – preferably in combination with elemental analysis (EDS) and band structures or nearest-neighbor bonding-types (EELS). Since many of the typical nanomaterials require 80keV or lower for TEM, a fully analytic 30keV LV-STEM/SEM can be an viable alternative for research and development of nano-materials.

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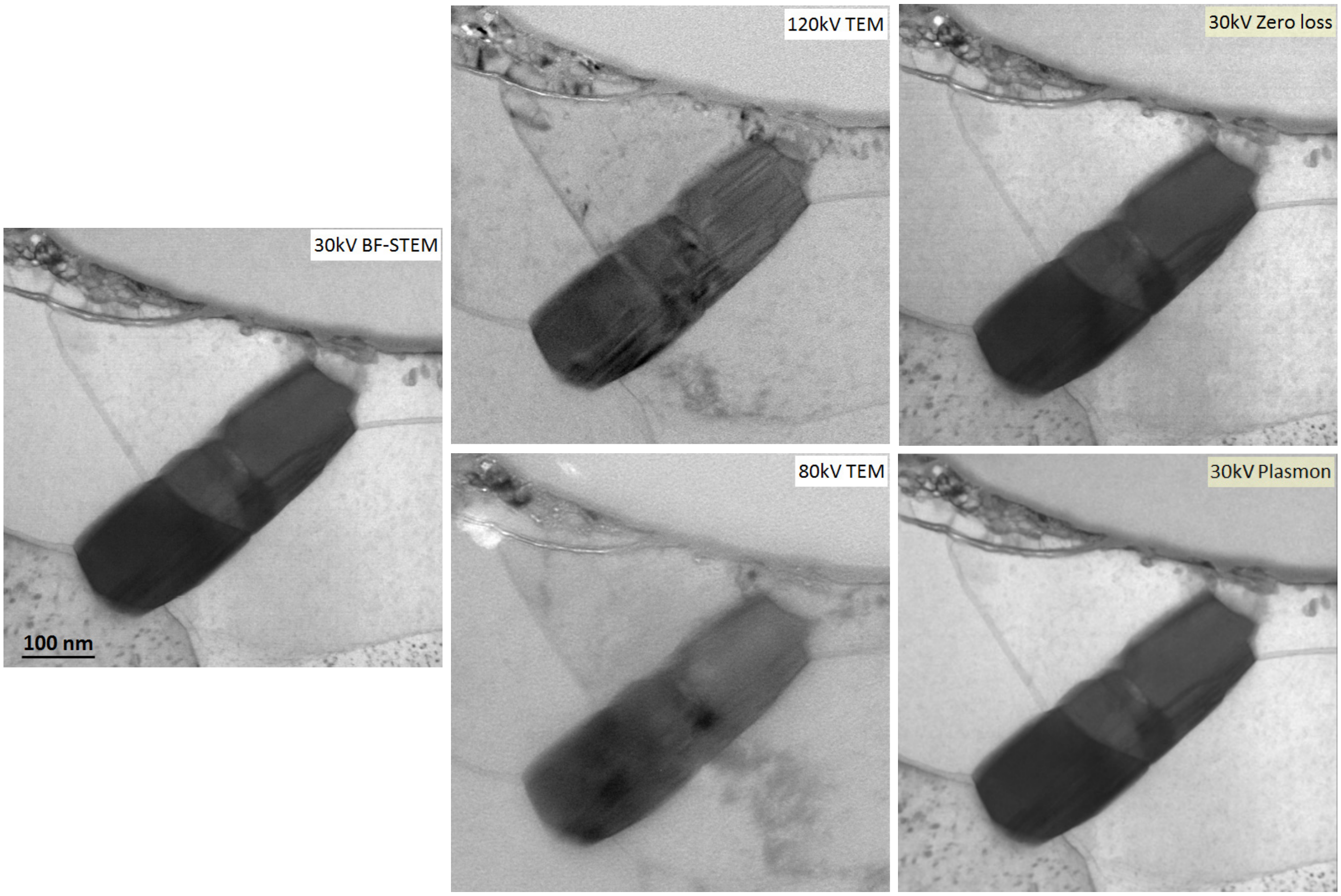

Figure 1. Left: BF-STEM image containing elastically and inelastically scattered electrons. Right: same image but with no inelastically scattered electrons (top) and inelastically scattered electrons only (bottom). Note that even with fewer electrons per pixel due to the elimination of the inelastically scattered electrons (Zero loss) or the use of inelastically scattered electrons only (Plasmon) the contrast is improved. Sample was cut via FIB to a thickness of 50nm. The TEM images were acquired with a 120kV electron microscope with LaB_6 emitter.