A new approach in valence EELS: using slow electrons for optical characterization

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Using low beam energies in transmission electron microscopy (TEM) has a long tradition in biology. For cell studies the spatial resolution at 20 keV is still good enough, but in materials science efforts need to be done in order to improve the instrumental performance. First successful results were presented on the European Microscopy Conference 2008 (EMC 2008), where a C_s corrected high resolution image recorded at 30 kV was shown [1]. Besides resolution also the brightness is reduced, when lowering the acceleration voltage. With the construction of the new high brightness source [1], this problem is less critical.

This work was done on a conventional TEM, showing that lowering the beam energy has also positive effects on valence energy loss spectrometry (VEELS). It focuses on two experimental advantages. One of the positive effects has an instrumental reason: the improvement of the energy resolution, the other one was first described by N. Bohr [2] in 1913: the decrease of the delocalization of the energy loss. A third advantage is the prevention of the excitation of relativistic energy losses in semiconductors as described elsewhere [3].

If no monochromator can be used, the energy resolution in the EELS spectrum can only be improved by a reduction of the filament temperature and an improvement of the point spread function (PSF) of the detector. In the present situation the improvement of the energy resolution in the loss spectrum is only reached by the improvement of the PSF. Figure 1 (left) shows the measured PSF at 200 kV and 20 kV of our GIF 2001 system. For its determination a part of the CCD was blocked in order to have a knife-edge in the energy dispersive direction. Then the CCD was illuminated homogeneously and the PSF was measured. The positive effect of the improved PSF on the energy resolution can be directly determined when the full width at half maximum (FWHM) of the zero loss peak (ZLP) is measured. Figure 1 (right) shows the ZLPs recorded at 200 kV and 20 kV, respectively, normalized by the area. The FWHM of the ZLP is reduced to 0.35 eV instead of 1.1 eV when the TEM is operated at 200 kV.

For the VEELS experiment the GaP/GaAs interface was rotated parallel to the energy dispersive axis of the spectrometer using a double tilt rotation holder allowing recording a ΔE-**r** pattern (Figure 2, left side).

On the right hand-side of Figure 2 it can clearly be seen that for the 200 kV experiment the delocalization is in the range of 10 nm as given by Bohr's cut-off criterion. Although the signal is much noisier for the 20 kV experiment, the delocalization can be estimated to be roughly 4 nm, which is also in good agreement with calculations. This experimental test has a fundamental importance for the determination of the optical properties of non-isolated quantum structures: using 200 keV electrons, a simple Kramers-Kronig Analysis of VEELS experiments fails. Besides the influence of relativistic effects [3] delocalization also hampers VEELS analysis of nano-objects with highly energetic electrons.

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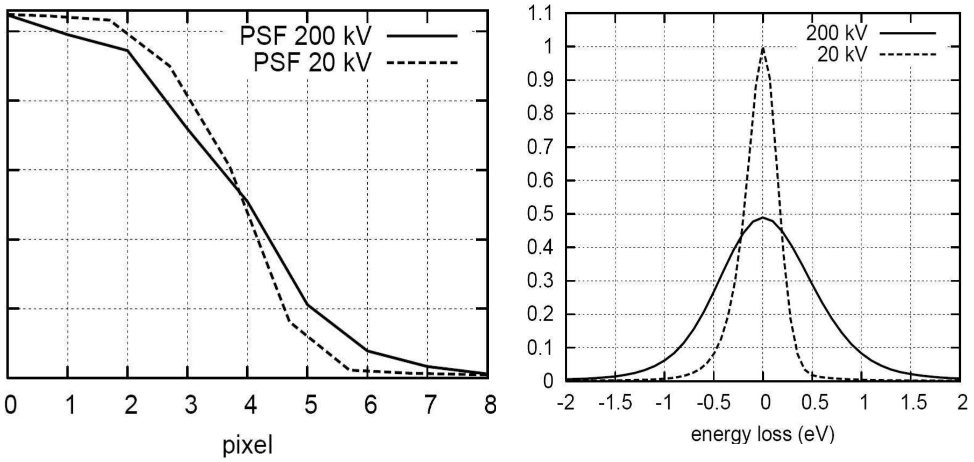

Figure1. Left: PSF of the GIF 2001 at 200 keV and 20 keV beam energy. Right: Zero loss peaks recorded with 200 keV and 20 keV beam energy. The FWHM is reduced from 1.1 eV at 200 kV to 0.35 eV at 20 kV.

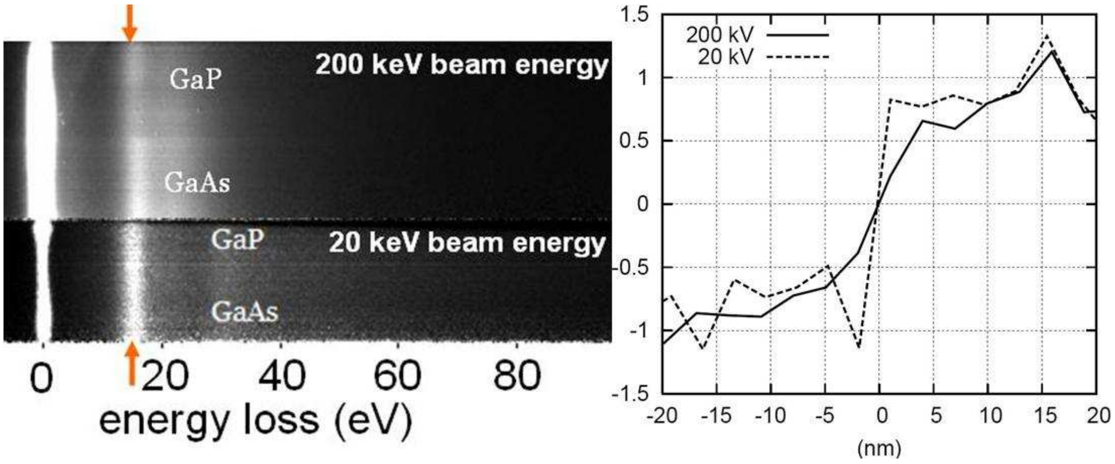

Figure2. Left: Spectrum image of the GaP/GaAs interface at 200 kV and 20 kV. Right: Normalized intensity profiles at the GaP plasmon maximum at 16.4 eV energy loss (see arrow) for the determination of the delocalization of the energy loss.