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The Future of EELS

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The combination of an electron energy-loss spectrometer and a TEM provides us with physical and chemical information in the form of energy-loss spectra and energy-filtered images. The field-emission electron source has made an energy resolution below 1 eV possible and, combined with improvements in the design of electron spectrometers and detectors, it is now feasible to obtain useful data with a spatial resolution close to atomic dimensions, given the right kind of instrumentation and specimen [1,2].

The use of an electron-source monochromator promises a further improvement in instrumental energy resolution [3], perhaps down to 0.1 eV. How can we exploit this capability? The resolution of core-loss data is limited by the natural width of the inner-shell energy level, which is below 0.5 eV for K-edges below 2000eV or L- edges below 1000eV (see Fig. 1). A more common use of a monochromated EELS/TEM systemmay be for valence-electron spectroscopy, where a reduced incident-beam intensity is less of a problem and there is often a need to resolve fine structure, when measuring the water content of tissue [4] or distinguishing peaks due to chromophore dyes [5]for example. Structure below 2 eV loss has been particularly hard to measure because it lies within the tail of the zero-loss peak. High energy resolution would therefore benefit EELS studies of the local electronic structure at defects and interfaces in semiconductors [6,7] or of the electronic structure of carbon nanotubes or small particles [8,9]. Below 0.1 eV, there are vibrational modes of energy loss, as studied by IR spectroscopy and by Geiger et al. [8] using a monochromated source and transmitted-electron analyser, which achieved 3meV resolution at 30 kV. This concept has not yet applied to the TEM or applied to practical problems, but might become a useful additional tool for characterizing nanostructures.

The Heisenberg uncertainty principle suggests that high energy and spatial resolution are mutually incompatible. In fact, the wave nature of the electron imposes a spatial localization limit that approaches 1 nm at energy loss below 100 eV (see Fig. 1). In this energy region, a spherical-aberration corrector (which can reduce the point resolution for TEM imaging to below 0.1 nm) will not improve the spatial resolution of the inelastic signal. However, the corrector should increase the current available in a small probe, which will benefit the core-loss signal in fine-probe microanalysis or STEM imaging.

Although EELS has excellent spatial resolution in relation to other techniques, it has not been so successful for measuring low atomic concentrations. A large part of the reason is the high background underlying core-loss edges, plus the problem of edge overlap. One solution has been to employ multiple least squares (MLS) fitting to spectral quantification [11] and it is to be hoped that this procedure can be simplified and become more widely adopted in the future. An alternative approach to low-concentration analysis is to modify the background-extrapolation procedure, putting constraints on the background fit [12].

As always, the ultimate limit to spatial resolution and detection limits is set byradiation damage to the specimen, more severe for EELS than for x-ray absorption microscopy, even if less than for x-ray emission (EDX) spectroscopy. Does the damage depend only on the accumulated dose, or is the dose rate important? This question is relevant to the choice of TEM or STEM imaging, particularly for beam-sensitive specimens.

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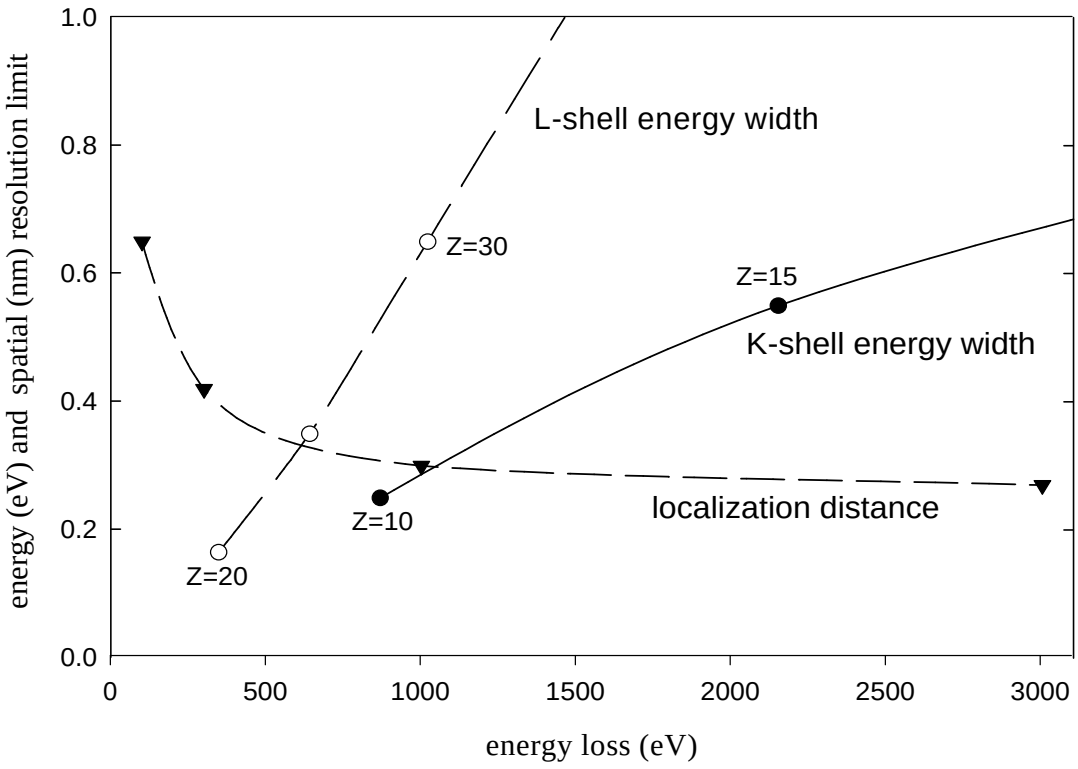

FIG. 1. K- and L-shell core-level widths [13] and localization distance d_{50} containing 50% of the inelastic scattering [14], as a function of energy loss and atomic number Z .

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