Energy-Filtering Transmission Electron Microscopy (EFTEM)

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29 Feb, 2020

Energy-filtered transmission electron microscopy (EFTEM)

is a family of imaging techniques that utilize properties of the energy loss spectrum to increase contrast, remove the effects of chromatic aberration and create unique contrast effects in the image.

Principle:

The principle behind EFTEM is based on the illumination of a very thin specimen with a beam of high energy electrons. When the majority electrons pass unhindered through the specimen, some will interact with the specimen and result in elastic or inelastic scattering. Inelastic scattering results in both a loss of energy and a change in momentum, which in the case of inner shell ionization is characteristic of the element in the sample.

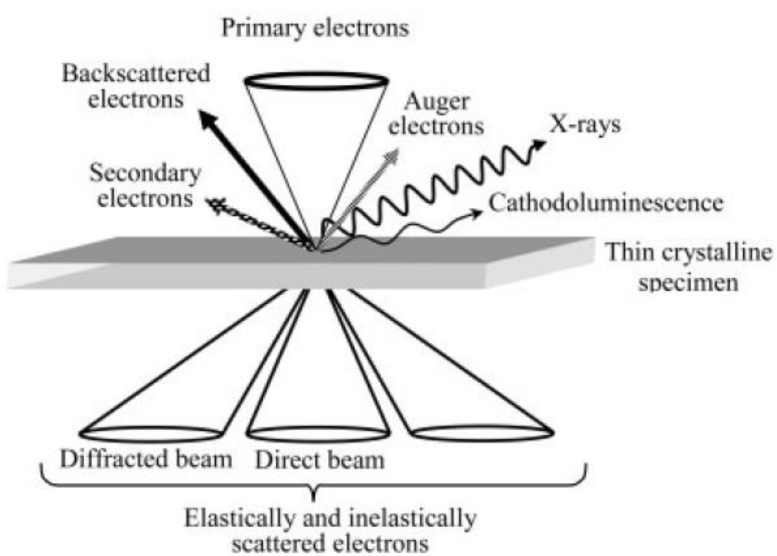
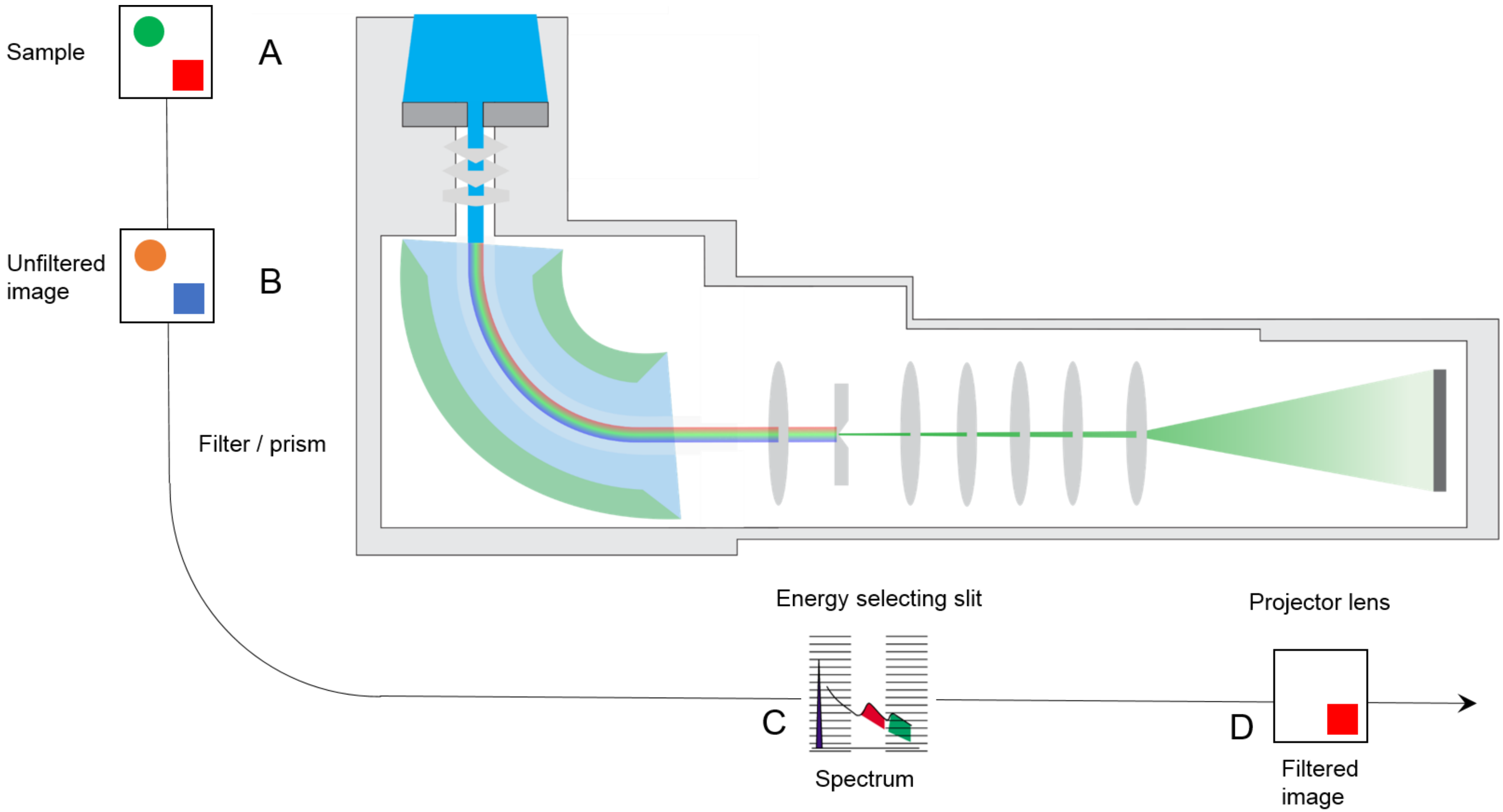


Figure 4.1 Schematic diagram of the interactions between high-energy electrons and matter in TEM.



The sample, **A**, produces an unfiltered TEM image, **B**. The unfiltered image has a lot of image detail but is hard to interpret. The prism transforms the image into a spectrum. **C**. The spectrum is energy-filtered with an energy selecting slit. **D**. The selected part is transformed back into an energy-filtered image. **E**. The final energy-filtered image is measured by a suitable detector.

Instrumentation and Working Principle

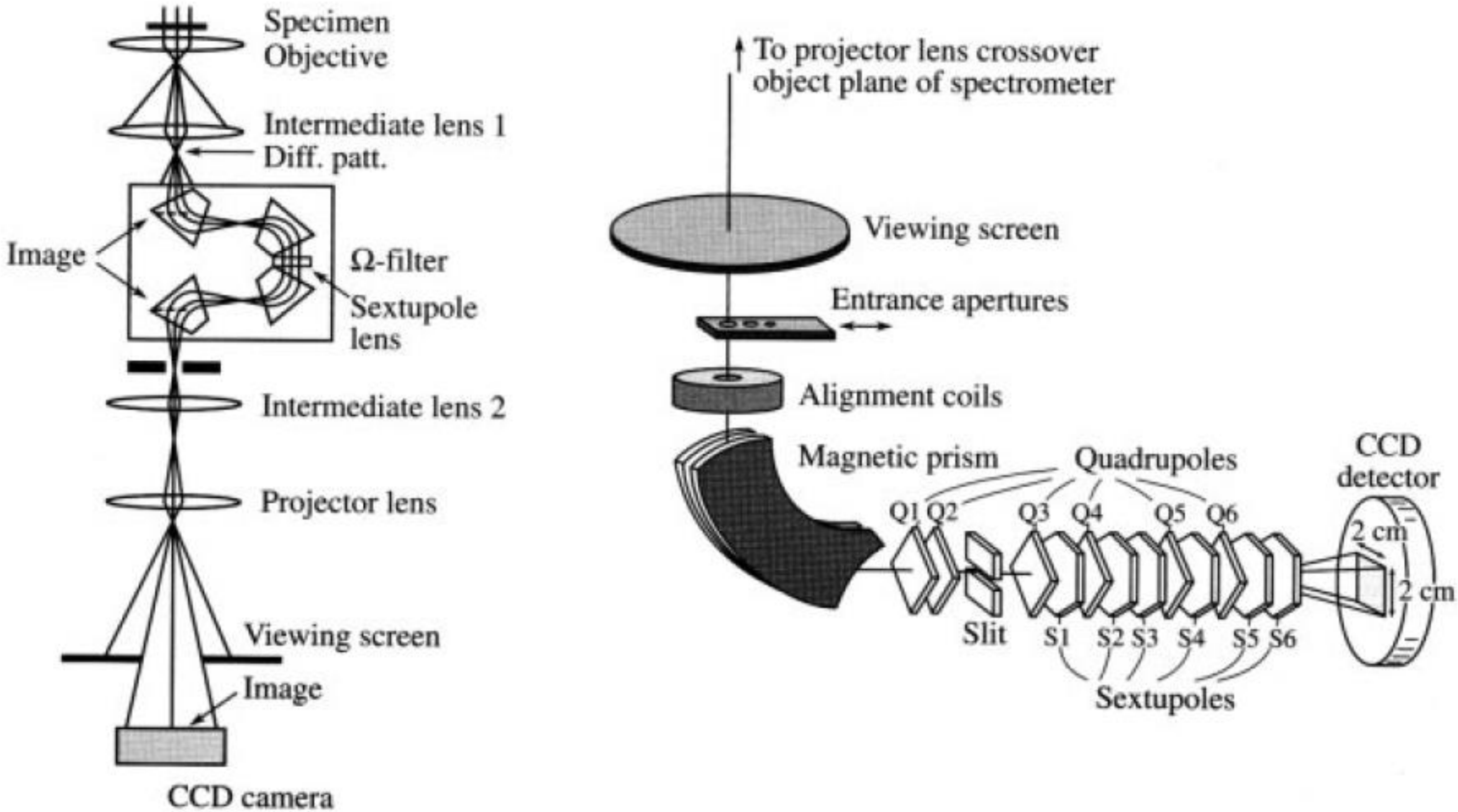


Figure 4.4 Arrangement of in-column (left) and post-column imaging energy filters (right) in TEM [6].

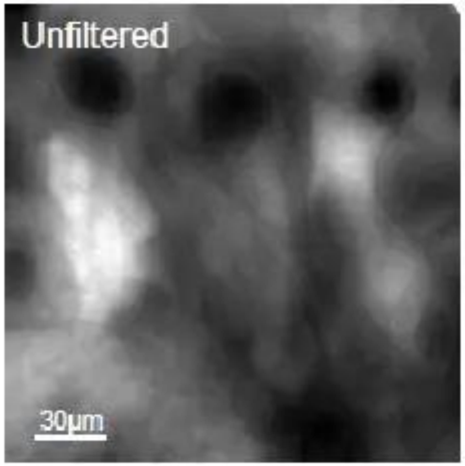
Key applications include:

- Contrast enhancement – Improves contrast in images and diffraction patterns when it removes inelastically scattered electrons that produce background fog
  - Including zero-loss filtering, most probable loss imaging, contrast tuning, and pre-carbon imaging

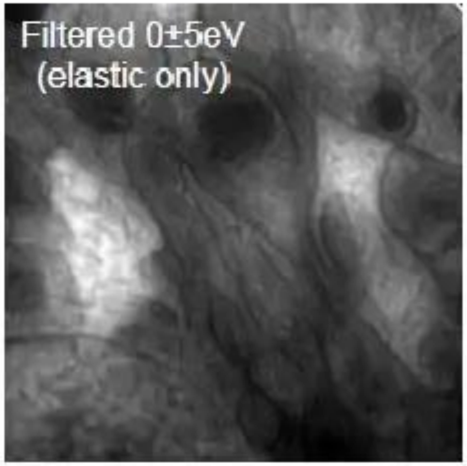
- Mapping – Creates elemental/chemical maps at nanometer resolution by forming images with inelastically scattered electrons
  - Including 2- and 3-window elemental mapping/jump-ratio imaging and chemical mapping – provides fine structure imaging

- Analytical – Records and quantifies electron energy loss spectra (and maps) to provide chemical analysis of TEM samples

Allowing only the elastically scattered electrons (zero-loss filtering) to contribute to the image (or diffraction pattern) removes the "inelastic fog"

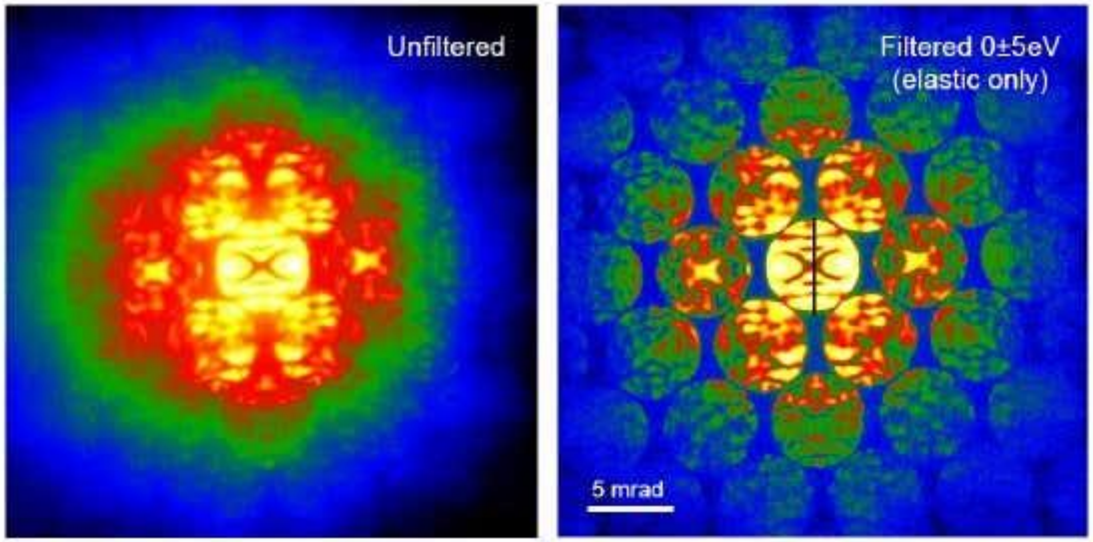


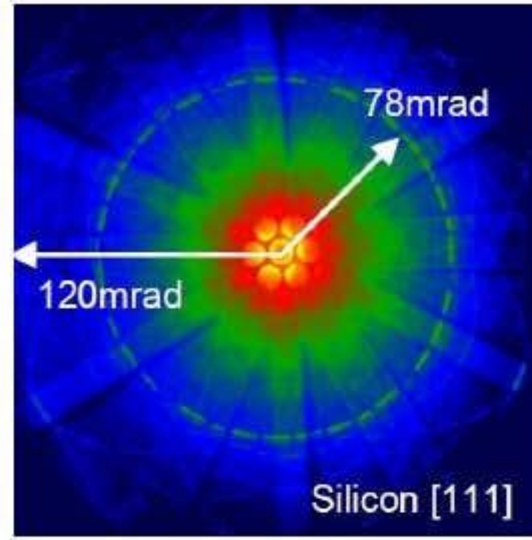
Unstained/osmicated
cebellar cortex
(thickness=0.4 µm, 100 keV)



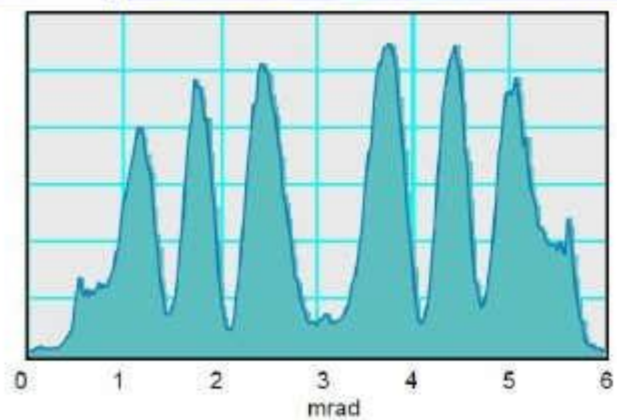
For thin to medium-thick, unstained or lightly stained biological samples

- for $Z \leq 12$ the inelastic cross-section is larger than the elastic cross-section
- limited use for very thick specimens where zero-loss intensity < 1% of spectrum intensity





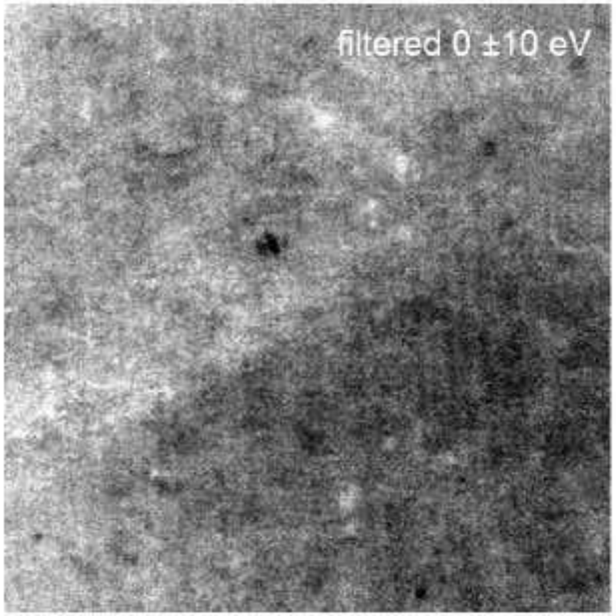
Filtering is crucial for quantitative CBED

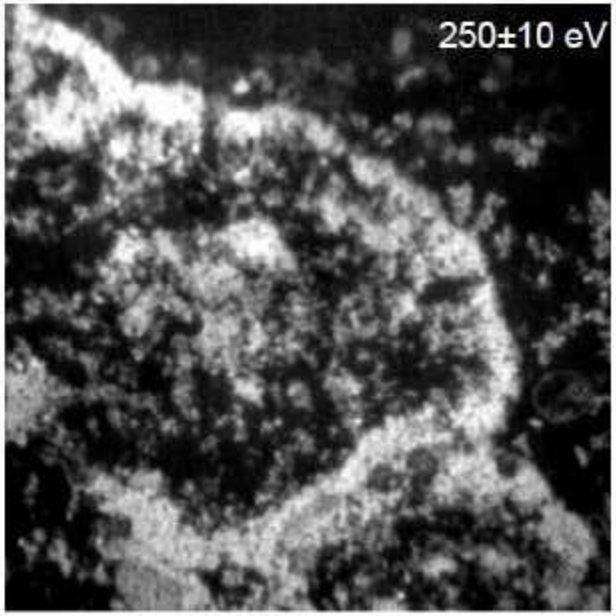


Angular range obtainable on GIF Tridiem

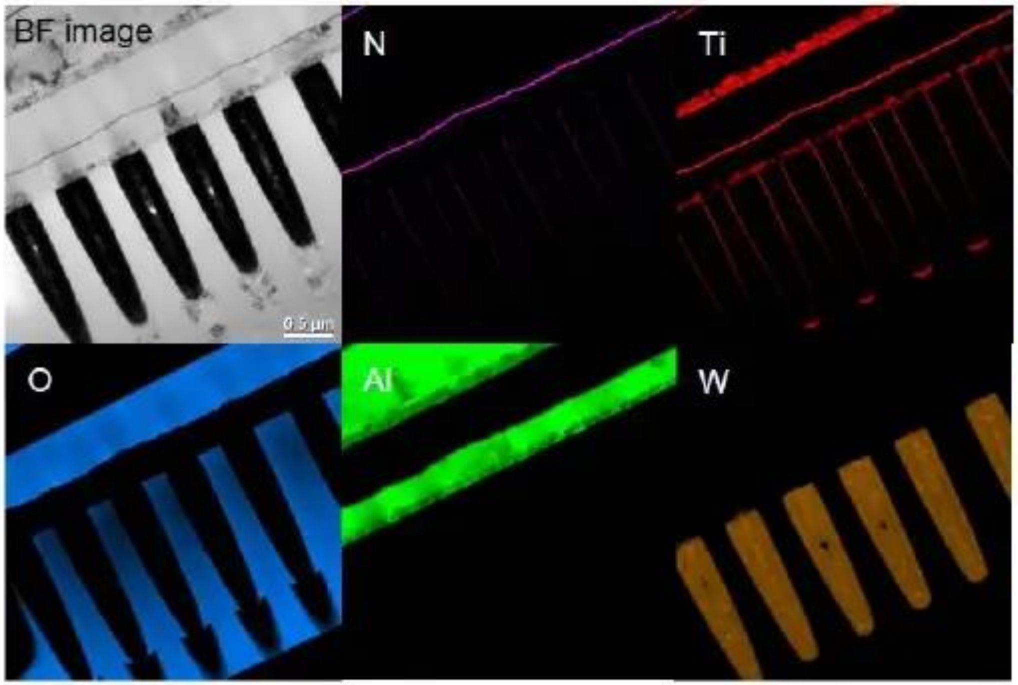
Pre-carbon imaging:

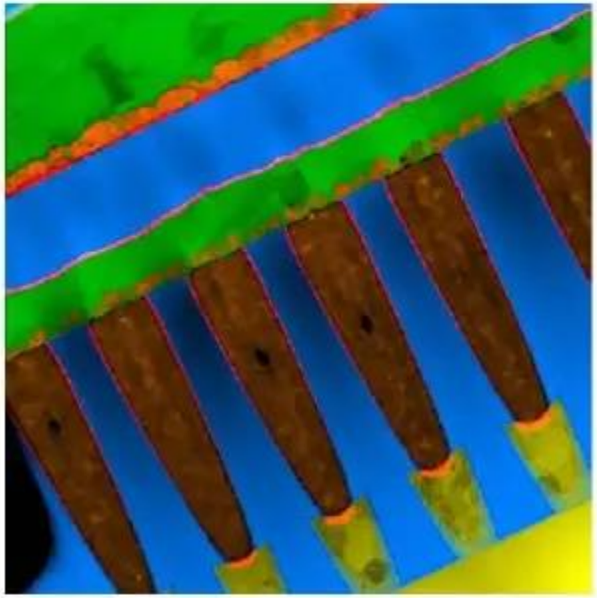
Selecting energies right in front of the carbon K-edge greatly suppresses the carbon signal and enhances other elements





Pre-carbon K-edge energy-filtered image of a cell nucleus taken at 200 keV





Unfiltered bright-field TEM image of semiconductor device structure and some elemental maps formed from ionization-edge signals of N-K, Ti-L, O-K, Al-K, and W-M.

Color composite of the elemental maps displayed on the left, clearly showing the construction of the device.