RECENT EDITORIAL

Breaking Through the Barrier

Recent optical design advances in transmission electron microscopy have resulted in significant improvements in aberration correction and resolution.

The resolution of a transmission electron microscope (TEM) is mainly determined by the properties of the objective lens similar to that in an optical microscope. However, lenses are never perfect and exhibit a variety of defects. One defect, called spherical aberration, which is characterized by the spherical aberration coefficient, Cs, describes the effect that rays or electrons away from the optical axis are not focused into the same focal point as those propagating on the optical axis.

In light optics, improved manufacturing quality, sophisticated shapes of lens surfaces, and a combination of lenses have led to high optical properties which result in a resolution close to the order of or even smaller than the wavelength, l, of the visible light.
Since the typical TEM lenses used so far are electromagnetic round lenses, they unavoidably suffer from aberrations and have a positive spherical aberration coefficient Cs. This explains why the typical resolution of a current 200kV TEM is 0.24nm, about two orders of magnitude worse than the wavelength of the electrons (l200kV = 0.0025 nm). Since only the coefficient Cs and the wavelength l determine the (point) resolution, there are only two ways to improve the resolution: to shorten the wavelength by increasing the accelerating voltage or to reduce the Cs of the objective lens. In 1990, Harald Rose showed that, in principle, it is possible to correct the Cs of the objective lens of a TEM. This discovery paved the way towards sub-Ångstrom resolution for 200kV TEMs.

The concept of a UHRTEM

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Carl Zeiss SMT's sub-Angstrom ultrahigh resolution transmission electron microscope with revolutionary column suspension concept.

Key elements of the ultra-high resolution TEM (UHRTEM) include three new electron-optical components. The Cs corrector according to the concept of Rose was developed by CEOS GmbH, Heidelberg, Germany. It consists of two hexapole elements and two lens doublets which provide the complete compensation of the spherical aberration (of the imaging part) in the objective lens.

The second component is a monochromator, also developed by CEOS, and is integrated in the electron sourcetypically a field emission (FE) system. The monochromator reduces the inherent energy spread in the electron beam from typically 0.7eV to values smaller than 0.2 eV. As soon as the spherical aberration of the objective lens is fully corrected (Cs drops by three orders of magnitude to a few microns compared to a value of about 1 mm without correction) the second largest lens defect, the chromatic aberration, Cc, comes into play.
For monochromated electrons, the influence of the chromatic aberration is smaller. Since correction of Cc requires a complex arrangement of electron-optical elements compared to the Cs corrector, the reduction in energy spread is the method of choice. The combination of the monochromated FE source with a Cs corrector for the objective lens enables breaking the barrier of sub-Ångstrom imaging resolution.
Finally, the UHRTEM contains an in-column energy filter of the corrected Omega design. This filter disperses the electrons according to their energy (like a prism disperses the different colors of visible light), thus providing an electron energy loss spectrum (EELS) of the specimen in the dispersive plane

that reveals information on the chemical elements and their bonding.

Furthermore, the in-column corrected Omega filter is also an imaging unit since it generates an achromatic image of the specimen (to which electrons of all energies contribute). By selecting a certain energy range by inserting a slit in the dispersive plane, the image only contains information of specific electron energy losses within the specimen. This can be used to remove inelastically scattered electrons (for contrast enhancement) or to select element specific energy losses for elemental distribution images. Therefore, the in-column corrected Omega energy filter adds analytical capabilities to the UHRTEM without influencing its imaging resolution.

The three new electron-optical components are integrated into a new unique TEM platform which is also used for Zeiss' 200 kV LIBRA FE-TEM. A proprietary support frame with an ultra-stable high voltage supply and stable current sources complete the system.

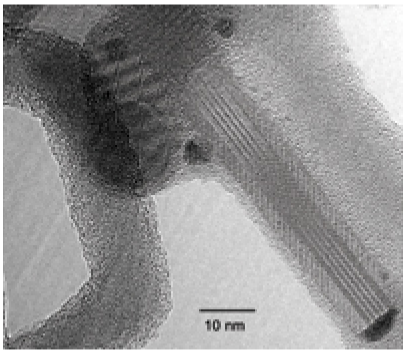

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Image of a single Si nanowire on a carbon support film is revealed with an UHRTEM at 400,000 X and a C_s.

Artifact-free imaging

The ability to reduce the main lens defect, the spherical aberration, by three orders of magnitude to a value close to zero not only increases the resolution, but it also improves the image quality in general since other effects are closely related to the Cs value. In the following, two effects are addressed:

DELOCALIZATION: Due to a non-zero Cs value, electrons from one point of an object are not imaged into a single point, but rather into a small disk smearing out the information (the information is no longer "localized" but "delocalized"). In atomic resolved images of periodic structures delocalization is not easily visible. However, as soon as non-periodic structures are imaged or the periodicity is terminated in at least one direction the effect of delocalization is noticed.

TILT: In a TEM with aberration correction, a small beam tilt does not cause other image faults like astigmatism or coma. High-resolution TEM imaging of crystalline structures requires their precise orientation to the optical axis.

To achieve this by tilting the sample is in many cases time consuming. In a Cs-corrected TEM this final alignment of orientation of the sample towards the electron beam direction can be reversed by tilting the axis of electron beam towards the orientation of the crystalline sample. This makes it much easier to precisely align a specimen area. As a consequence, specimen throughput can be increased.

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