Advancement of Instrumentation for Transmission Electron Microscopy

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The requirements and challenges for advanced high-resolution electron microscopy are different for various applications like ultra-high resolution or in-situ EM. The compensation of aberrations is mandatory to attain atomic resolution in electron microscopy in both, STEM and TEM mode. In TEM not only the axial aberrations are important, but also the off-axial ones have to be considered if a large field of view has to be achieved. The chromatic aberration limits the attainable contrast at high spatial frequencies if a large pole-piece gap is needed or one wants to work at low energies. For this advancement of high resolution transmission EM over the last two decades various aberration correctors have been developed after the first successful development of a Cs-corrected TEM in 1997 [1].

For example, the hexapole corrector for STEM (CESCOR) had undergone a substantial face-lift introducing length-optimized hexapoles for A_5-minimization and new degrees of freedom for full fourth-order axial aberration correction [2]. The next dominant resolution limiting aberration is the three-lob aberration of 6th order D_6. It can be counterbalanced to a certain extend by the three-lob aberration D_4. By means of an appropriately designed new corrector D_6 can be compensated [3]. With this system the usable illumination semi-angle α can be increased to almost 80 mrad which would lead to an improved Z-resolution in STEM. However, a monochromated beam would be needed in order to avoid a loss of contrast due to the chromatic aberration Cc.

If one is interested in the observation of beam sensitive materials at low energies in the range from 20 to 80 keV the compensation of Cc is mandatory. High spatial resolution as well as a large field of view has been accomplished with the SALVE corrector in 2016. At energies between 40 keV and 80 keV even sub-Ångstrom resolution can be achieved [4].

For analytical purposes EELS is an important method in order to obtain more information of a given object and to investigate certain properties. An energy filtering process can also be used to improve the contrast for thicker samples in an electron microscope. For this purpose, we developed a so-called CEFID (Ceos Energy Filter Imaging Device) which shows competitive performance with large emphasis on high flexibility for imaging and spectroscopy [5]. For this CEFID a highly optimized sector magnet is combined with two 12-pole elements and additional quadrupole elements and deflectors. The experience gathered with this development is useful for the new ERC-Synergy project “MoRe-TEM” [6] which aims to improve the energy and momentum resolution by means of a monochromator at ground potential. The possible applications range from fundamental studies on the origin of quantum phase transitions such as superconductivity, the nanometer-resolved performance of nanoscale devices in-situ and in operando, to direct technological applications such as the improvement of battery electrodes.

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