Aberration Correction for Analytical In Situ TEM – the NTEAM Concept.

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Future aberration corrected transmission electron microscopes (TEM) will have a strong impact in materials science, since such microscopes yield information on chemical bonding and structure of interfaces, grain boundaries and lattice defects at an atomic level. Beyond this abberation correction offers new possibilities for in situ experiments performed under controlled temperature, magnetic field, strain etc. at atomic resolution. Such investigations are necessary for solving problems arising from electronic component miniaturization, for example. Significant progress can be expected by means of analytical aberration corrected TEM. These next generation microscopes will be equipped with an aberration corrected imaging system, a monochromator and aberration corrected energy filters. These novel elements have already been designed and partially realized [1,2,3]. Their incorporation alleviates three major obstacles that limit the capabilities of present TEMs:

a) Insufficient space for many in situ experiments.

High-resolution microscopy has been realized for medium acceleration voltages (200 and 300kV) by decreasing the coefficient of spherical aberration C_3, which has been achieved only by a small gap (3 and 5 mm) between the pole pieces of the objective lens. For most in situ experiments this is not sufficient space. High-voltage microscopes combine high resolution with a large gap. Unfortunately radiation damage reduces their usefulness especially for the study of semiconductors. Aberration correction and monochromators offer several solutions. The curves 1 and 2 in Fig. 1 represent contrast-transfer functions for an uncorrected and an aberration corrected TEM, respectively, for a 25 mm gap. Curve 2 applies to a corrector which eliminates both chromatic and spherical aberration. Correction of chromatic aberration has not been demonstrated for a commercial TEM yet. Nevertheless this calculation shows that state-of-the-art power supply stabilities are sufficient for a resolution limit smaller than 0.1 nm even if the high stability requirements for correction of chromatic aberration are taken into account.

b) Insufficient resolution and imaging artifacts.

A resolution limit of about 0.05nm is necessary for atomic resolution in non-periodic structures and crystalline materials along a sufficiently large number of zone axes to enable tomography. Present microscopes are capable of high-resolution only under favorable circumstances, such as appropriate materials in special orientations. For example, in metals only a few low index planes can be resolved. This allows the analysis of special types of grain boundaries, but the great majority of grain boundaries in polycrystalline materials is not accessible. According to calculation (curve 3 in Fig 1) a TEM with monochromator and C_3-corrector has the required optical properties to attain a resolution of 0.05 nm. Furthermore, a C_3-corrector eliminates contrast delocalization which is the origin of many artifact in high-resolution imaging. Additional correction of chromatic aberration would enable a gap width of about 10 mm which is necessary for a large tilting range.

c) The energy width of the incident electron beam is too large.

Electron energy loss spectroscopy (EELS) is a powerful tool for qualitative and quantitative chemical analysis especially for light elements on very small areas. Furthermore, EELS is capable of analyzing the chemical bonding and the coordination of atoms in compounds requiring an energy resolution of about 0.1 eV. In this case it is possible to answer questions about the coordination and the bonding state in catalysts and to measure locally the band gap in semiconductors, for instance. In addition, it is often necessary to obtain such information on an area of atomic dimensions. Aberration

corrected energy filters in combination with a monochromator meet these requirements. The plots of the envelope functions of temporal coherence in Fig. 2 reveal that chemical information can be obtained on an atomic scale using energy filtering techniques, if the chromatic aberration is also corrected. The parameters chosen for this calculation are valid for an in situ TEM with a gap width of 25 mm and chemical mapping using the Si-K absorption edge.

References

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[4] This work was supported by the U.S. Department of Energy, Office of Science, under contract #W-31-109-ENG-38.

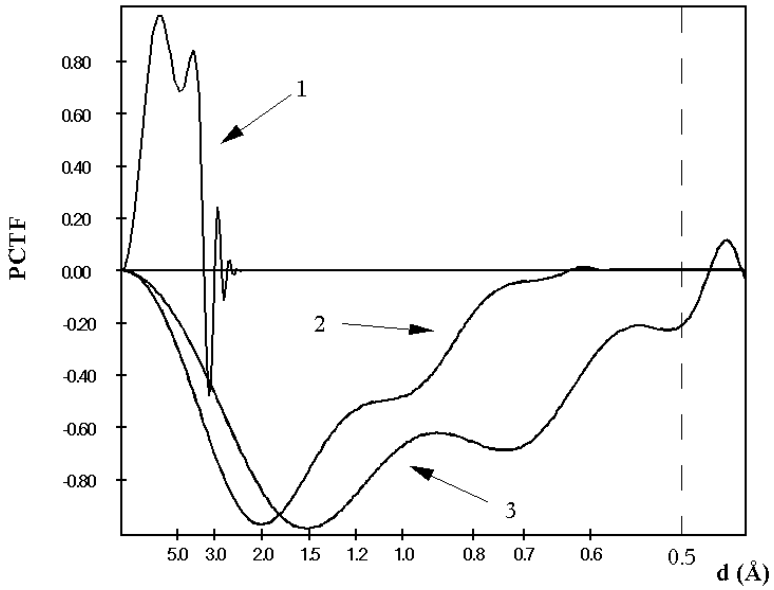

Fig. 1: Phase contrast transfer functions 1) uncorrected $C_c=C_3=5$mm 2) $C_c=0.01$mm, $C_s=-0.03$mm for an in situ TEM with a 25mm wide gap. 3) C_3 corrected with monochromator E=0.15eV.

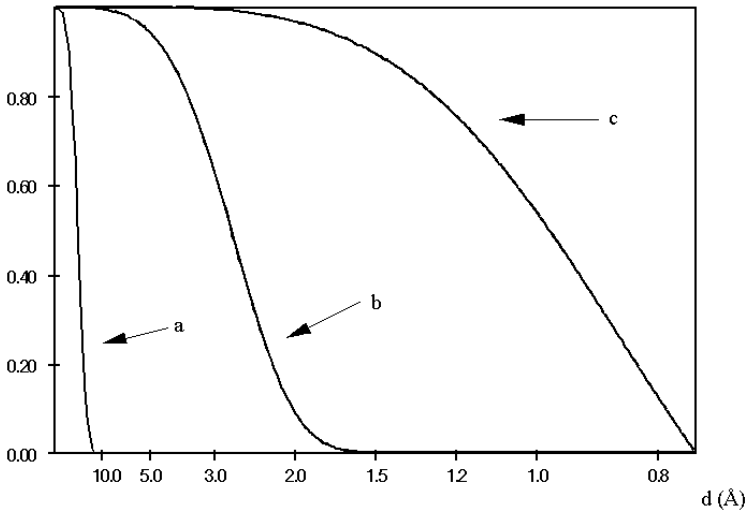

Fig. 2 : Temporal coherence damping envelops calculated for an energy window of 50 eV for a) $C_c=5$mm, b) $C_c=0.1$mm, c) $C_c=0.01$mm.