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# Improvement Path for the Hexapole $C_s$-Corrector towards 0.5 Å Resolution

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Hexapole correctors for the spherical aberration $C_s$ of the objective lens [1] are available for a large variety of transmission electron microscopes (TEM) from different manufacturers. For the conventional transmission electron microscope (CTEM) the $C_s$-corrector integrated into the imaging system enables a reduced delocalization of contrast and a vanishing influence of the spatial coherence close to the Gaussian focus. As a consequence the range of directly interpretable resolution is extended up to the information limit of the microscope. With the present corrector technology and a well-optimized objective lens pole piece the theoretically achievable information limit is about 1.0 Å at 200 kV or below the 1.0 Å barrier at 300 kV accelerating voltage, respectively.

The optical performance of a CTEM equipped with a Hexapole $C_s$-corrector is determined by the chromatic focus spread, electrical and mechanical stability of the entire instrument, and the efficiency of the available procedures for semi-automatic alignment (alignment tools). For the present design of the Hexapole corrector used in a CTEM with standard field emission gun (FEG) the residual intrinsic fifth-order aberrations do not limit the performance.

The product $\Delta E$*Cc of the energy width $\Delta E$ of the primary beam and the chromatic aberration coefficient Cc causes an unavoidable focus spread. This focus spread restricts the achievable information limit even if all noise effects are sufficiently reduced (see Fig.1). Two solutions have been proposed to overcome this limitation and to improve the contrast at high spatial frequencies substantially: Either by employing a gun monochromator (MC) in order to reduce the energy width of the primary beam or to compensate of the chromatic aberration Cc of the objective lens using a Cc/Cs corrector.

A gun monochromator must be designed such that the loss of brightness due to the filtering action is as small as possible. For a proper illumination of the specimen the original coherence of the electron source must be maintained. These two requirements are optimally fulfilled if the monochromator is free of dispersion with respect to the specimen plane and if the rotationally symmetry of the primary electron beam is maintained [2].

For a $C_s$-corrected CTEM equipped with a gun monochromator (MC-CTEM) an information limit below 1.0 Å has already been demonstrated by FEI [3] (with a Tecnai F20ST) and by ZEISS [4] (with a UHRTEM). In both cases a 200 kV CTEM equipped with a Hexapole-corrector and a monochromator has been used. The monochromator of the Tecnai F20ST consists of a single stage Wien-filter [5]. This single Wien-filter introduces lateral and angular dispersion w.r.t. the image of the virtual source. The angular dispersion causes a "rainbow"-like illumination at the specimen while the spatial dispersion enlarges the image of the virtual source situated near the front focal plane of the objective lens in dispersive direction [6]. The gun monochromator for the ZEISS TEM is a fully electrostatic "Omega-filter" with a symmetry plane at the energy filtering slit-system (see Fig.2.). Due to this symmetric design both requirements – no dispersion and a rotationally symmetric beam – can be achieved. Furthermore, due to an additional bore in the first and fourth electrode the monochromator can be switched on and off easily and the unfiltered beam can pass by without any loss of electrons.

To assess the information limit and the optical performance of an advanced MC-CTEM equipped with Hexapole Cs-corrector the influence of noise effects and of residual axial and off-axial aberrations must be analyzed carefully. The theoretical criteria employed to quantify the information limit and the tolerable residual phase shift will be discussed.

The alternative approach to improve the information limit of the CTEM, the correction of the chromatic aberration, is currently under development for the "TEAM" [5] project. This Cc/Cs-corrector should be available for an ultra high resolution CTEM until 2009.

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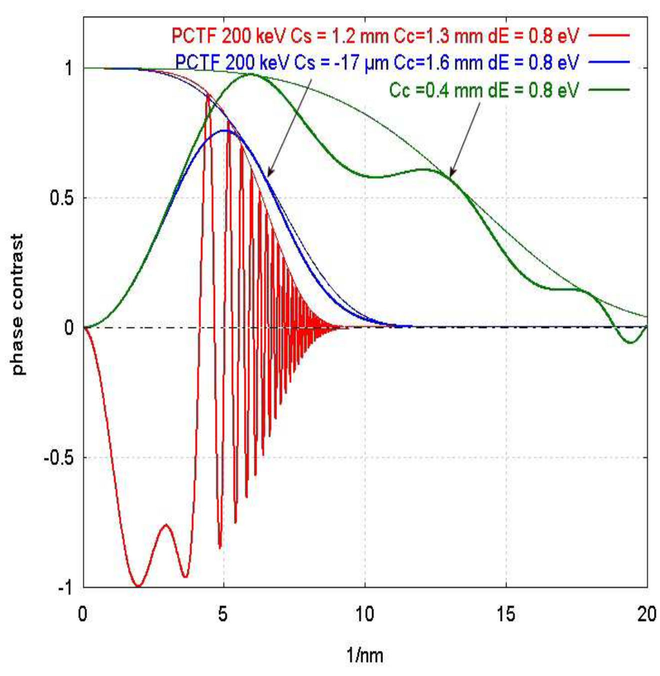


*Fig.1: Phase contrast transfer function of a 200 kV TEM. The oscillating contrast is due the Cs =1.25 mm. In the case of a Cs corrected CTEM there is no contrast reversal and it is strongly enhanced at high spatial frequencies if Cc * ΔE can be reduced.*

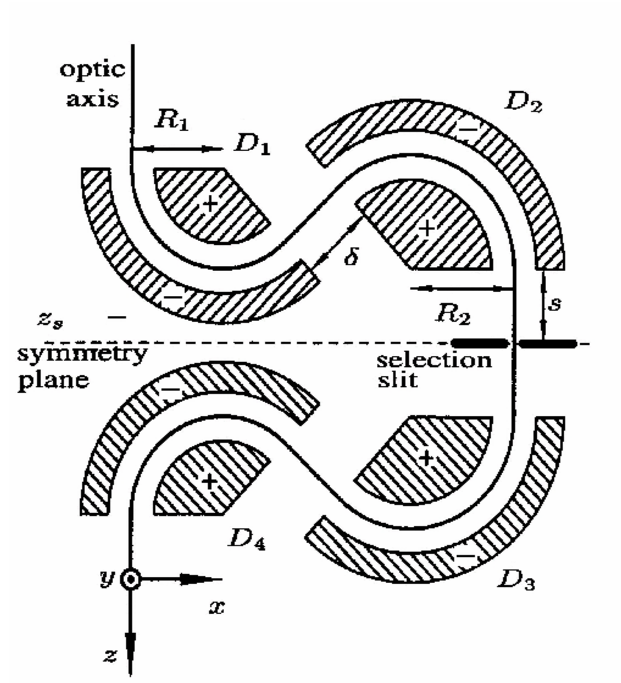


*Fig.2: Schematic drawing of a fully electrostatic monochromator showing the symmetry plane at which the beam has a line focus and where the energy selecting slit is located.*

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