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Current and Future Developments in order to Approach a Point Resolution of $d_{pr} \sim 0.5$ Å with a TEM

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With the emergence of aberration-corrected transmission electron microscopes [1] equipped with field emitters, a point resolution of about 1.2 Å can be achieved within a single image [2]. This is also the theoretical limit of what can be achieved with the given energy width of a Schottky emitter at an acceleration voltage of 200 kV. A further improvement of the point resolution can only be achieved by an improvement of the information limit, which is set by the relative energy width ΔE/E and the chromatic aberration coefficient Cc, assuming that there are no other additional incoherent aberrations as, for example, stray-fields or mechanical vibrations. ΔE describes the FWHM of the energy width at the object plane, and E the relativistic corrected primary energy. The information limit itself describes the highest spatial frequency at which a certain contrast (e.g. 20%) of the contrast transfer function can be achieved. Therefore, the spherical aberration corrected TEM is mainly limited by the chromatic aberration Cc and the relative primary energy width ΔE/E.

In order to overcome this limitation one has to consider different strategies to reduce the product of Cc•ΔE/E for a given energy, and, hence, to improve the information limit. As one can easily deduce from the above formula one can either reduce Cc or ΔE, or increase E. The latter, increasing E from 200 keV to 300 keV, for example, seems the most straightforward way for a further improvement of the information limit. However, increasing the primary energy is not always the best choice, especially if one considers the objects one would like to investigate. As is shown in Fig.1, the improvement of the CTF when increasing the primary energy is an improvement to achieve 1.0 Å or even below, but it is not an acceptable approach for 0.5 Å.

The reduction of ΔE by means of a monochromator for a Schottky emitter, and the incorporation of a Cs-corrector into a new 200 kV TEM is currently under development. This TEM will have an point resolution improved from 1.2 Å down to about 0.75 Å at 200 keV. This project combines the two components already developed, a Cs-corrector and a monochromator. The latter allows a reduction of the electron energy width down to 0.2 eV (or even further)[3]. In theory, with this monochromator one could achieve a point resolution of d = 0.5 Å if the energy width at the object plane could be reduced to ΔE = 0.1 eV. The main task to achieve this goal, however, would be the improvement of the overall stability of the high tension supply and all other components of the TEM. A somewhat easier way instead would be to increase the primary energy from 200 keV up to 300 keV and to use a monochromized electron source with an energy width of 0.2 eV. Nevertheless, even if only already existing components have to be combined, this is still a very challenging project to approach a point resolution below 1.0 Å.

The third possibility for a further improvement of the point resolution would be the compensation of the chromatic aberration coefficient Cc. This would have several advantages such as offering the opportunity to increase the pole peace gap - allowing, for example, various types of stages - or to use larger energy windows when working with an in-column energy filter. However, this aberration corrector, as it has been proposed by Rose [4], is by far not as easy as a Hexapole-corrector for the compensation of Cs. The Ultracorrector, as it has been called by Rose, consists of two Septuplets (a system of seven Quadrupole elements) and in addition 19 Octupole fields have to be excited. This complicated correction system offers the possibility to compensate for all axial and off-axial chromatic aberrations and also the correction of **all** geometrical aberrations up to the third order.
The development of a Cs-corrected 200 kV TEM equipped with a monochromator is in progress in collaboration with LEO/Germany for their new generation of advanced TEMs.

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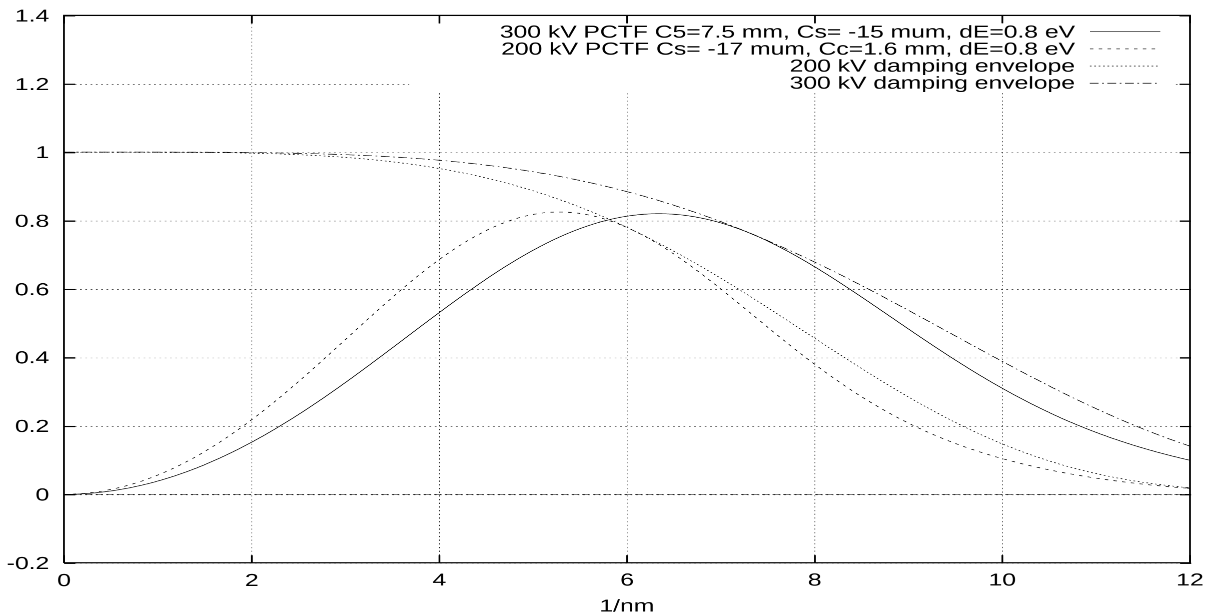

FIG. 1. Phase contrast transfer function (PCTF) and the damping envelope function of a Cs-corrected 200 kV and 300 kV TEM.

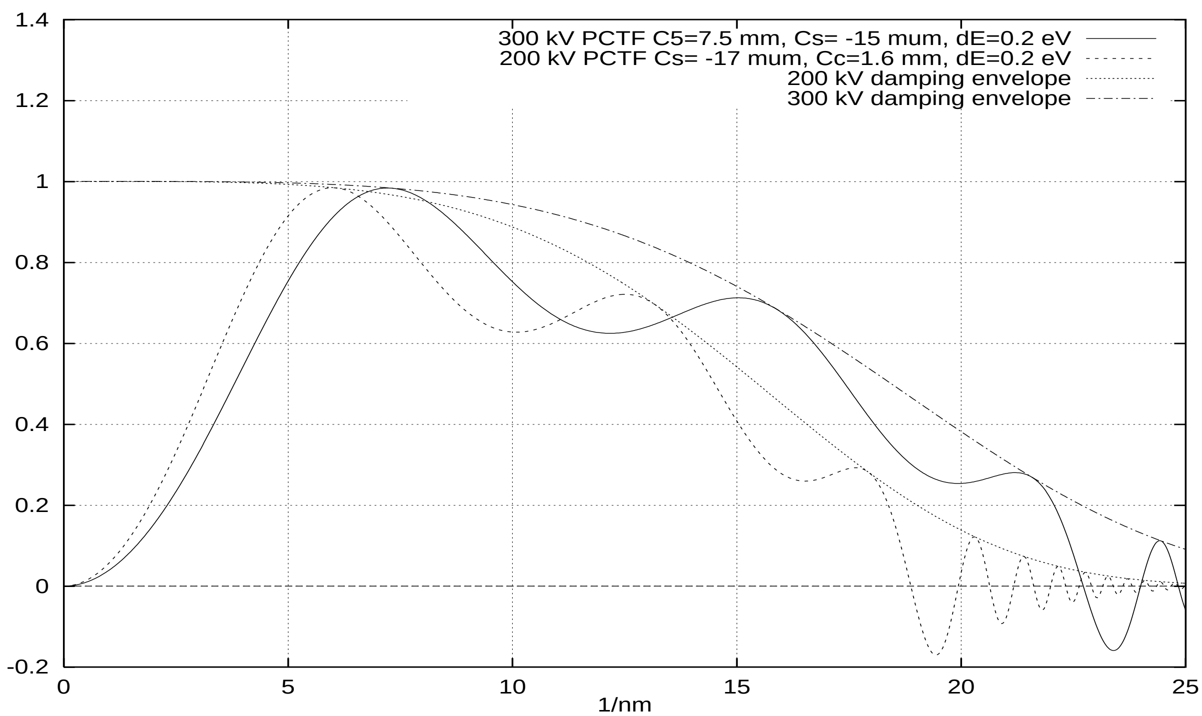

FIG. 2. PCTF of a 200 kV and a 300 kV TEM with a reduced energy spread of $\Delta E = 0.2$ eV.

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