

# Chromatic correction: Chances and fundamental limitations of an evolving corrector technology

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Starting with the microscopes for the TEAM project [1], chromatic aberration correction has opened a new field in high resolution electron microscopy. Within this project the main target was the ultimate resolution. At the end of the development project a point resolution of 56 pm at an acceleration voltage of 200 kV could be achieved [2]. Meanwhile there is a growing interest to benefit from other application-specific advantages of this correction technique.

We will discuss several application classes, which benefit most from chromatic correction. In many fields this type of correction enables for the first time atomic resolution with reasonable contrast in Transmission Electron Microscopy (TEM):

- imaging at acceleration voltages below 50 kV as in the German SALVE project [3].
- TEM with a free space of several centimetres around the specimen for in-situ experiments.
- TEM with specimens in a region without a magnetic field.
- Imaging of electrons with an energy window above 100 eV, for example as resulting from plasmon losses or similar interactions, thick samples or closed environmental cells.

In the case of Scanning Transmission Electron Microscopy (STEM) there have been doubts, whether chromatic correction has any benefits compared to pure spherical aberration correction. Experiments and simulations indicate that this might be true, when only the ultimate resolution on thin samples is considered and high acceleration voltages and cold field emitters are used. However, first investigations reveal that chromatic correction can significantly improve the contrast, especially at acceleration voltages below 80 kV.

This is of importance, because the direct visualisation of small features strongly depends on the signal-to-noise ratio.

While chromatic correction offers all these chances for improved imaging, it is becoming more and more difficult to reach the expected resolution of aberration free imaging in real experiments. On one hand the stability requirements are quite severe. However, the electronics and mechanical stability could be significantly improved during recent years. Therefore such instabilities are currently no longer the major limiting factor. Instead, basic physical limitations seem to exist, which prevent a further improvement of the resolution. We have performed a series of experiments and found that the limitation also exists, when the critical optical components are entirely removed from the microscope. We will report about the details of the results of these experiments and the special experimentation technique based on tilted beams and achromatic rings, which allows to measure the image spread far beyond the chromatic aberration limit in chromatically uncorrected microscopes [2], see figure 1.

Because the limit does not depend on the presence of specific optical devices, we have investigated several basic physical effects, which could be the reason for the observed resolution barrier. These effects include

- magnetic domain fluctuations on the surface or in the entire volume of magnetic material.
- Interaction of the electron spin with the optical magnetic fields
- black body radiation in the beam tube
- magnetic field fluctuations due to fluctuation/dissipation phenomena [4]
- effects of mirror charges

Each of these phenomena, if taken alone, may have a limiting effect, which will dominate the resolution limit of an ideal sphero-chromatic corrector. Its residual higher order aberrations play a minor role.

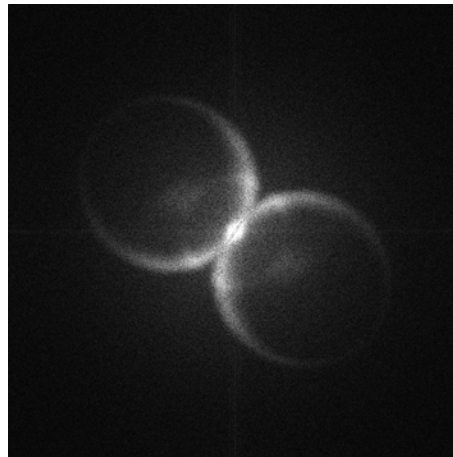
Where the size of the investigated effects has parameters, which are difficult to quantify, we have

performed a series of experiments to find some upper limit for it. We will present details of these experiments in the talk.

Although the effects will compromise the resolution in a perfect corrector, even if taken together they are still too small to explain the currently observed resolution limit. Further research is required to find the cause of this present reduction in resolution.

#### *References*

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**Figure 1.** *Diffraction pattern of an amorphous specimen imaged with tilted illumination. The damping on the so-called achromatic rings allows to characterize the image spread far beyond the chromatic aberration limit, which is given by the width of the rings.*