# Prospects of future instrumental developments for advanced electron microscopy

Max. Haider

CEOS GmbH, Englerstr. 28, D-69126 Heidelberg

The generally advancement of the electron microscope requires a continuous development of all components which are mandatory for high performing TEM and STEM applications. For high resolution imaging and analytical purposes with high energy resolution some components are crucial, however, the overall stability and sensitivity against external fields are equally important because finally, the weakest part defines the attainable performance.

A detailed investigation of future prospects of instrumental developments has to cover all components from the source of the electrons to the recording detectors in order to get the most out of the interaction process between the electrons and the object. At the electron source not only the electron emitter and its shape has to be optimized but also the electron optical components of the gun which affect the size of the virtual source. The smaller the virtual source size the higher the brightness one can achieve.

A limitation within the electron optical column which was not known before 2013 [1] is the so-called Johnson noise which causes an image spread and, therefore, a fundamental limitation of the attainable spatial resolution. This Johnson noise depends mainly on the distance of the electrons to metal surfaces of pole pieces or vacuum tubes. This distance cannot be lowered arbitrarily because of the required strength of the multipole fields for the compensation of aberrations and, at the same time, the field strengths are limited by saturation of magnetic pole pieces or the breakthrough voltage of electrodes when applying high voltages. This limitation set by the free electrons in metals was first noticed when the chromatic aberration $C_c$ of a 300 kV TEM had to be compensated and the theoretically achievable resolution could not be attained. The required beam diameter within the counteracting electrostatic and magnetic quadrupole fields caused a loss of resolution due to an increased image spread. The only way to reduce the resolution limiting effect of the Johnson noise is to reduce the temperature of all metallic surfaces within the objective lens and the multipole elements of a corrector. This would be possible with super-conducting lenses and multipole elements. However, the effort would be extremely high and also the operation costs later due to the needed liquid Nitrogen or Helium coolant would make the efforts for such a system questionable.

An additional component which needs a certain attention too is a monochromator to reduce the energy spread of the illuminating electrons [2] which would be advantageous for high spatial resolution and, even more important, for high resolution electron energy loss spectroscopy.

[1] S. Uhlemann, et al. Phys. Rev. Let. **111**, (2013) 046101
[2] F. Börrnert, et al., Ultramicroscopy **253** (2023) 113805

Acknowledgements:
We are grateful of having received a Synergy Grant with substantial funding from the European Union's Horizon2020 research and innovation Program under Grant No 951215 (MoRe-TEM).