Measurement of the electron source brightness and the illumination semi-angle distribution in a transmission electron microscope

Börrnert, F.[1], Renner, J.[1] and Kaiser, U.[1]

[1] Universität Ulm, Germany

The brightness of the electron source is one of the central parameters governing the performance of a transmission electron microscope. Not only in scanning transmission electron microscopy (STEM) but also in conventional transmission electron microscopy (TEM) it is a major factor for the practically reachable resolution. In STEM, the source brightness dictates the current in the electron probe for a given probe diameter. While in theory, one can make the probe diameter infinitely small, it does not work in reality since there is no signal left without a significant electron current in the probe. The introduction of aberration correction into STEM effectively improved the usable signal for a given resolution. Also in TEM, the image's signal-to-noise ratio and ultimately its resolution is a function of the total dose in the image. In practice, the acquisition time often is limited due to sample drift, vibration, and damage, therefore, a high dose rate is needed. While the dose rate is related to the total current coming from the source, the brightness additionally affects the illumination semi-angle distribution.

In TEM information transfer, the illumination semi-angle distribution dominates the information dampening in non-aberration-corrected instruments. In these instruments, the knowledge of the semi-angle distribution is needed for quantitative contrast evaluation. This value is also crucial in off-axis electron holography because there it governs the interference fringe contrast and thus the achievable information content.

The assessment of the illumination semi-angle distribution cannot be found in textbooks. For partial spatial coherence dampening envelopes in TEM, the illumination semi-angle distribution is often given or assumed. Albeit there is pioneering work by Joachim Frank from the '70s and Tsuji & St. John Manley in the '80s for how to determine the illumination semi-angle distribution (1,2), it is mostly derived from the brightness given for the electron source and the dose in an image.

Here, we demonstrate a facile and straight-forward way to measure the illumination semi-angle distribution in TEM and subsequently the electron source brightness *via* a simple defocus series of Young's fringes tests, see figure 1. The experiments demonstrated were performed on the chromatic- and geometric-aberration-corrected SALVE (Sub-Ångström Low-Voltage Electron microscopy) instrument (3), however, our method works on any transmission electron microscope; an aberration corrector just adds the convenience of out-of-the-box automated defocus measurement and automated optical image shift. Additionally, the aberration-corrected case demonstrates the effectiveness of the method even when the illumination dampening effect is superposed by dominating other dampening effects and also shows the importance of taking the other dampening mechanisms into account.

(1) J. Frank, Determination of Source Size and Energy Spread from Electron Micrographs using the Method of Young's Fringes. Optik 44, 379 (1976).
(2) M. Tsuji and R. St. John Manley, Determination of the illuminating angle and defocus spread in transmission electron microscopy. Journal of Microscopy 130, 93 (1983).
(3) M. Linck et al., Chromatic aberration correction for atomic resolution TEM imaging from 20 to 80 kV. Physical Review Letters 117, 076101 (2016).

Acknowledgements - A similar method of determining the brightness from the dependence of the information limit on the defocus was presented by Peter Tiemeijer (Thermo Fisher Scientific, Eindhoven) at the SALVE workshop in 2015. We acknowledge funding from the German Research Foundation (Deutsche Forschungsgemeinschaft (DFG)) and the Ministry of Science, Research and the Arts Baden-Württemberg, Germany, as well as funding through DFG Priority Program SPP 1569.

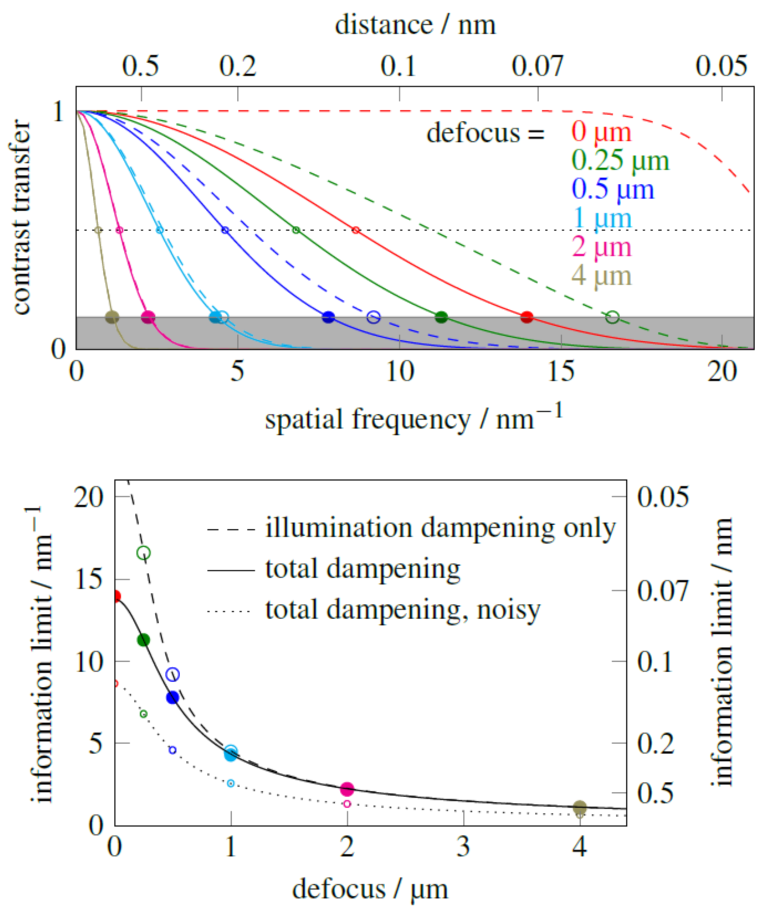

Figure 1. Illumination semi-angle measurement principle *via* an information limit determination in a defocus series. *top panel* - Total contrast dampening envelope function (solid lines) and illumination dampening function only (dashed lines) for different defoci. The gray region is the conventional noise level and the dotted line exemplifies a case of a very noisy image. The different defoci are color coded and indicated in the plot. The respective information limits are indicated by the color coded circles. *bottom panel* - Defocus dependent information limit for the three cases with the same color and line coding. The parameters used are U = 80 kV and a = 0.07 mrad. Lentzen conditions are employed with a C_5 = 3 mm. The focus spread σ_{fs} = 0.29 nm and the image spread σ_{is} = 0.021 nm.