Experimental Setup and Verification of the MANDOLINE Filter

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We present setup and experimental results of the new MANDOLINE high performance imaging energy filter as proposed by Uhlemann and Rose [1] that has been developed within the SESAM (Sub-eV-Sub-Ångstrom Microscope) project [2].

Fine structure investigations require very high energy resolution and a high filter acceptance, which is also necessary for applications using large scattering angles such as CBED or RDF measurements. The MANDOLINE filter enables and simplifies such high end energy filtering TEM applications by the high dispersion of 6.2 µm/eV at 200kV, a filter current stability of 2×10^{-7} and an unrivalled acceptance, described by the transmissivity T_{real} [3]. The transmissivity of T_{real} = 3300 nm²/eV for a 1 eV energy window width allows for energy filtered observation of large fields of view and large scattering angles with excellent isochromaticity.

The MANDOLINE filter (Fig. 1) consists of a homogeneous magnet M1, two symmetrically arranged inhomogeneous magnets M2 and M3 focussing the ray continuously in both principal sections and nine symmetrically arranged correction elements C1 - C9 performing up to third order correction. The path of the optical axis intersects itself twice within the homogeneous magnet, resulting in the very short total length of this in-column energy filter and a high mechanical stability of the TEM column. Inhomogeneous magnets are well known from accelerator physics, but their usage in a corrected imaging energy filter is new and more demanding. Higher precision is necessary because of the smaller dimensions and the distortion free imaging in a TEM. Strong quadrupole fields on the correction elements C1 and C9 pose additional practical demands on the filter correction procedure compared to other imaging energy filters.

We are experimentally evaluating the imaging properties of the MANDOLINE filter on two TEM setups. The test bed shown in Fig. 2a serves for the basic investigations and verification of the alignment strategy. The final investigations are performed in the SESAM microscope in which the MANDOLINE filter is very well integrated as shown in Fig. 2b. We present the experimental verification of alignment algorithms and demonstrate experimental verifications of the imaging properties of the filter at 200 kV, e.g. distortion free imaging of a 5 µm specimen area. The experimentally determined dispersion is in excellent agreement with the theoretical value of 6.2 µm/eV.

In the final setup in the SESAM microscope [4] an overall energy resolution of 200 meV is enabled by the high tension stability of 5×10^{-7}, the filter current stability of 2×10^{-7} (peak to peak) and the monochromator [5], which allows for a primary beam energy width of 100 meV.

References:

[1] S. Uhlemann, H. Rose, Optik 96 (1994) 163.
[2] M. Rühle et al., Microsc. Microanal. 6 Supplement 2 (2000) 188.
[3] S. Uhlemann, H. Rose, Ultramicroscopy 63 (1996) 161.
[4] G. Benner et al., proceedings of this conference, this volume (2003)
[5] FEG and monochromator are customer developed by CEOS for LEO;
S. Uhlemann, M. Haider, Proc. 15th Int.Cong.on Electron Microsc. Vol. 3 (2002) 327.

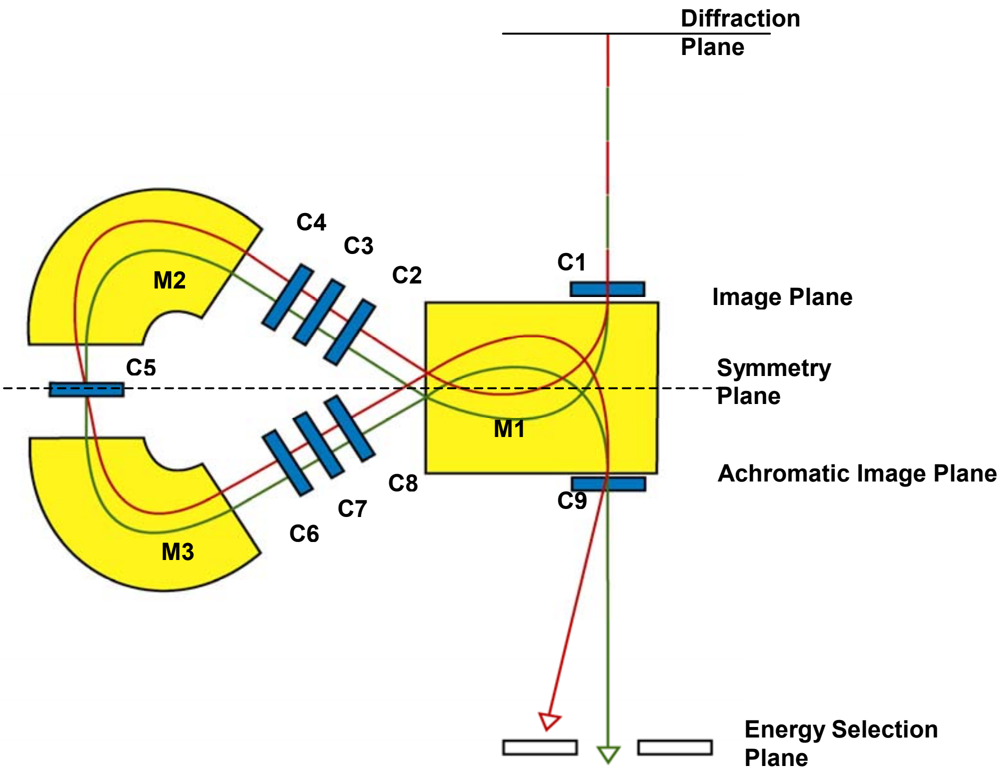

Fig. 1: Main components of the MANDOLINE filter (schematic diagram).

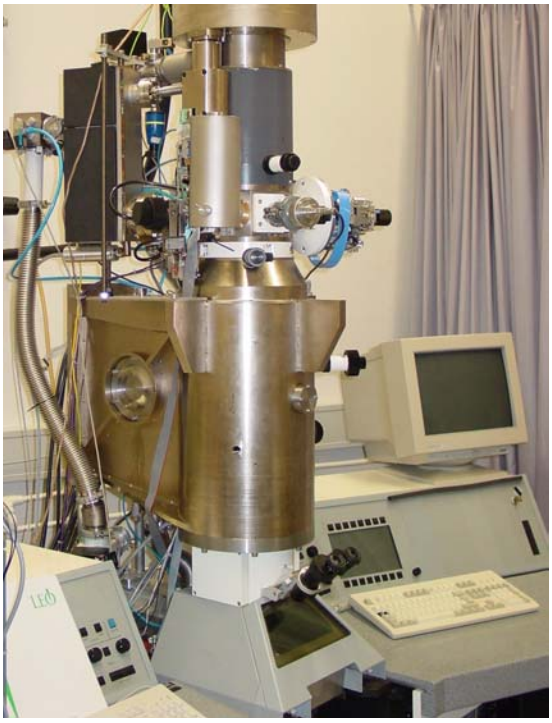

Fig. 2: Experimental setup of the MANDOLINE filter:
a) MANDOLINE in the test bed microscope. b) MANDOLINE in the SESAM microscope.