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Test and Characterization of a New Post-column Imaging Energy Filter

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Recent developments of detector technologies and new acquisition schemes cause a demand for modular hardware components with flexible interfaces which can be combined according to the requirements of a specific experiment. Post-column energy filters with good performance for EFTEM and EELS analysis are a critical component in this context. Imaging energy filters are a rather traditional and well developed technology. This is owing to decades of research in academia and at Gatan company for post-column filters and at Zeiss and JEOL company for in-column filters. At CEOS we re-investigated the optical design and technology and identified some areas where gradual improvements were possible and design methods, manufacturing technologies and alignment strategies originally developed for aberration correctors can help. Complementary to established fully integrated plug-and-play solutions which primarily allow for a predefined combination of microscope / spectrometer / detector we want to provide an open platform which provides more freedom in the selection of components, both regarding the hardware and the software interfaces.

In our optics design of the CEOS Energy-filtering and Imaging Device (CEFID) we decided for a minimalistic solution. A highly optimized sector magnet is combined with two 12-pole elements one at the exit and one at the entrance plane. All the other focusing elements are pure quadrupoles supplemented by some deflectors and separate two- and three-fold stigmators. This approach already allows for a 12 mm entrance aperture with a non-isochromaticity below 1 eV peak-to-peak at 200 kV and less than 0.35% root-mean-square geometric distortion in imaging mode. In spectroscopy mode dispersions from 2 meV/channel up to 250 meV/channel for a 4k x 4k detector are possible. Additionally, an overview mode with 4 keV spectral range (1 eV/channel) even at 80 kV is available. Reducing the size of the entrance aperture rapidly improves the optically feasible energy resolution to sub-30 meV for a 5 mm entrance aperture and even better for smaller apertures. The use of well-designed quadrupole elements made from high-quality soft iron helps to largely avoid remanence effects and hence improves the reproducibility of alignments. The filter design introduces a clear separation between pre- and post-slit alignments. All second- and higher-order spectrum aberrations can be measured and corrected at the slit plane using identical methods for EFTEM and EELS modes [1]. This simplifies operation and enables to switch between imaging and spectroscopy modes of different dispersions with no or only little 1st-order re-tuning of the optical elements. The sector magnet is powered by a very stable current supply. Electronics measurements for 200 kV operation suggest that the noise level is below 50 meV (fwhm) even for 10 seconds exposure time. Measurements with the filter installed on a JEOL NeoARM with cold-FEG currently show 20 meV (rms) stability of the position of the zero-loss peak at 200 kV in the frequency range 4 Hz - 2 kHz with only 7 meV (rms) for frequencies above 150 Hz. Tracking the position of the zero-loss peak over 12 hours shows a drift of less than 1 eV at 300 kV with stable ambient conditions for the filter mounted on a Hitachi HF-3300S with cold-FEG.

Our Python/Qt-based user software (working title Panta Rhei) controlling the new energy filter is developing rapidly. Instrument operation and automatic alignment is fully implemented. Our preferred detector, the TVIPS XF416 4k x 4k CMOS camera, is widely integrated into our application software. Improved support for direct detectors is under preparation and the simultaneous operation of multiple detectors is possible. The control for different scan generators has been integrated already. The software targets for open interfaces and flexibility for user-scripting of unusual experimental setups [2]. Standard applications for EFTEM and EELS including STEM spectrum imaging are already supported. Automated workflows and more sophisticated data evaluation are under development.

The CEFID design is compatible with JEOL, Hitachi and Thermo-Fisher microscopes. The integration of software, image acquisition and scan control requires only minimum but benevolent support from the TEM manufacturers. We explicitly express our gratitude to our colleagues from JEOL and Hitachi for very helpful support during the first customer installations which we could already finalize successfully. [$]

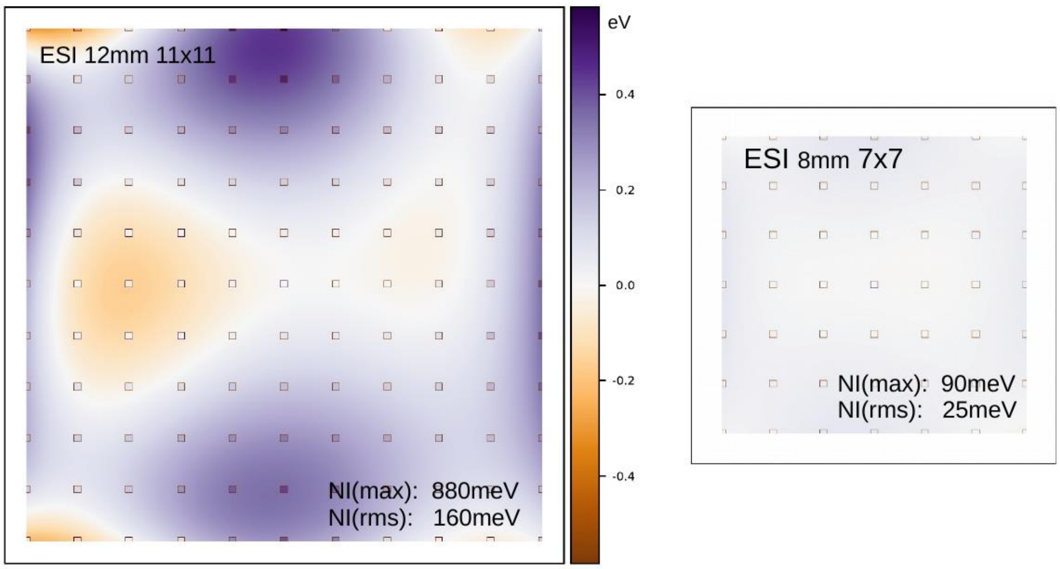

Figure 1. Non-isochromaticity measured at 200kV for the full Ø12mm entrance aperture and after increasing the post-magnification from 7.4 to 11.1 and slight retuning for the inner Ø8mm area. The measurements were done with the CEFID installed to a JEM 2100F 200kV microscope.

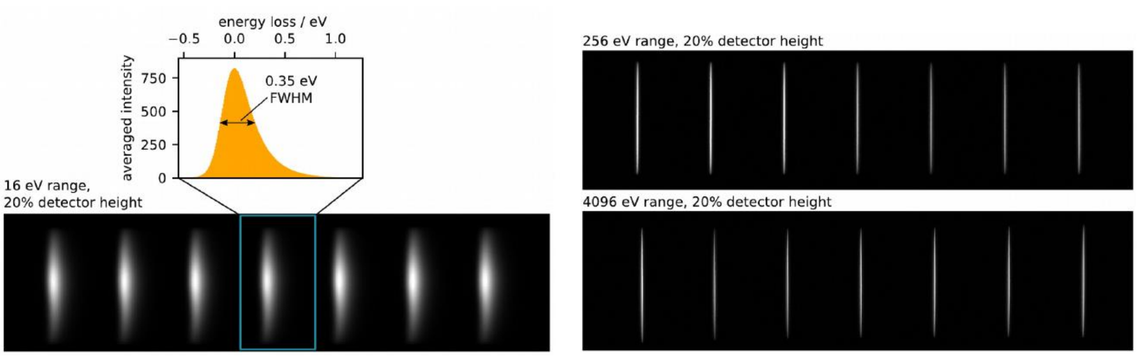

Figure 2. Images of the zero-loss peak for a series of high-tension offsets to illustrate the quality of EEL spectra for different dispersions with energy ranges from 16 eV to 4096 eV. The measurements were done with the CEFID installed to a HF3300S 300kV microscope with cold-FEG.

References
[1] F. Kahl et al. AIEP 212 including Proceedings CPO-10 (2019), p. 35.
[2] A. Feist et al. (2020) submitted at this conference.
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