SALVE I FEASIBILITY STUDY COMPONENTS AND FEATURES

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Available components that can be used for SALVE microscopy

Illumination system
Flexible Koehler illumination of the LIBRA-TEM is well suited for operation at 20 kV.

Energy filter
The usage of an in-column (integrated into the column) Omega-Design energy filter for EELS and EFTEM at 20 kV was tested. The filter works already very successfully at 15 kV in the SMART microscope [5]. It works very stable with very good energy resolution, transmissivity, and isochromaticity. 0.5 eV and smaller energy windows can be used at 20 kV. The resolution of highly resolved ω-maps and lateral resolved EELS is feasible.

Detector system
Detailed simulations of electron detection have been performed during SALVE I on a wide range of imaging detectors that were considered to have a potential use for SALVE II. We worked together with Angus Kirkland and Greg Moldavan for direct electron detection at low electron energies. Direct and indirect detectors are presently commercially available. For instance the camera TVIPS T416 works well at all voltages.

Components developed during SALVE I

Electron Source
The electron source should be a Schottky field emitter with high brightness and low energy spread providing high beam current even for SALVE operation with the monochromator.

Monochromator
The monochromator should allow adjusting the energy spread of the beam by varying the width of the energy selection slit. Especially for low beam energies the electrostatic omega principle for monochromatization and the corrected in-column technology are beneficial for filtered images with low energy width and highly resolved spectroscopy [1]. In a spectrometer of the Ω type the symmetry of the path of rays and of the electric field with respect to the central energy selection plane produces a non-dispersive image of the source behind the monochromator. The spectral beam brightness (spektraler Richtstrahlwert) of the source should be preserved because the second-order aberrations than cancel out too. Owing to the large dispersion (12 µm / eV @ 4 kV) at the energy selection plane, energy widths down to 0.1 eV should be achieved (usually 0.2 eV (FWHM) for EELS and exposure of 10 s). Such a monochromator has been developed by CEOS. It provides an energy resolution < 100meV at 80 kV. For 20 keV electrons the monochromator [2] creates high image contrast at high spatial frequencies: slit widths of 2.5 and 2 mm result in a full width at half maximum (FWHM) of 0.17 and 0.15 eV for the incident electron beam, respectively. The monochromator design by CEOS has been used.

Components to be developed in SALVE II

Cryo sample stage
The required high-precision three axes cryo sample stage with a target resolution of 80 pm in 5 seconds is technically very challenging, but feasible.

SALVE CC/CS aberration corrector
The TEAM CC/CS corrector has been developed by CEOS to provide ultra-high resolution and a large field of view at 300 kV. Because this corrector cannot operate optimally at 20kV, a new corrector design is developed which will be simpler and shorter than the TEAM corrector. This development is feasible and will be carried out in SALVE II.

Vacuum system
HR-TEM studies at low voltages put high requirements on the vacuum system because residual contamination and the water content will effect surface investigations. Protocols and a method for water etching rate determination have been developed and demonstrated the need for improved vacuum. This will be accomplished by using improved metal seals in SALVE II.

Column design
After the design of the CC/CS-corrector has been finalized, the column design needs to be optimized for SALVE operation.

Environmental conditions
We have shown that the high stability of the microscope allows high contrast imaging resolving lattice fringes and the stability of EELS spectra with time (Fig. 5). The stability requirements for a CC/CS corrected low-voltage TEM are considerably higher. However, the improved stability is technically feasible at present, by using a dedicated vibration-damped TEM room and increasing the stability of the power supplies.

Components considered unfeasible for development in SALVE II

Phase plate
A feasibility study for a newly designed obstruction-free phase plate [4] has been included into SALVE I for HR-TEM of low-Z material. This work is done in collaboration with the Cryo-EM group (R.R. Schröder) of the Cluster of Excellence "Cell Networks" of the University Heidelberg. In the phase plate principle the beam split after the sample in two optical paths by diffraction is used to add an optical path difference, so that a recombining occurs with opposite sign, which causes the cancellation of the scattering structure in the image. An electron intensity distribution as a function of empty space (called "Spatial frequency") between the scattering structures is created. A mathematical Fourier transform can then reconstruct the original sample with contrast differences that depend on the phase plate spatial frequencies. The result of the feasibility study was that the development of a phase plate will not be part of SALVE II as it is too complex and needs to be developed in a separate project.

Coma-free objective lens
At the beginning of the SALVE project, we favored the coma-free lens design for the objective lens. This lens type (which will not introduce anisotropic off-axial coma) was proposed by H. H. Rose in 1971 [6] and was thought to allow a simpler design and an easier alignment of the CC/CS corrector than those with the already existing CEOS CCOR corrector, which has been developed in the frame of the TEAM project because the anisotropic coma cancels out. Moreover, the possibility of a new high-resolution Lorentz mode was considered. The study in the frame of SALVE I proved that the achievement of sub-Angstrom resolution at 60 kV with the coma-free lens is technically unfeasible at present. Therefore the standard symmetric condenser-objective lens ("Einfeldlinse") design of the Riecke/Ruska-type has to be used.