Energy-Filtering Transmission Electron Microscopy
Shedding Light on the Concealed

Energy-Filtering Transmission Electron Microscopy (EFTEM) is an analysis method providing materials scientists, medical specialists and biologists unique insight into their samples. The iTEM Solution EFTEM software has been especially developed for this method. It offers all currently prevailing methods for full- or semi-manual acquisition and subsequent evaluation, such as the quantitative and qualitative analysis of spectra and images. The iTEM Solution EFTEM also facilitates generating and processing ESI series (Electron Spectroscopic Imaging), EELS spectra (Electron Energy Loss Spectroscopy) including parallel and serial EELS, Image-EELS series and spectra, quantification and layer thickness measurements.

As with all other extensions, the iTEM Solution EFTEM is fully integrated with iTEM, the Olympus Soft Imaging Solutions transmission electron microscopy image analysis platform. The base-level version offers numerous functions for processing, analysis, visualization and archiving of images and other data as well as for automation and report generation. With its solution-oriented software extensions, iTEM’s range of functions can be precisely expanded according to the user’s needs.
**Visualizing the difference**

ITEM Solution EFTEM offers acquisition, processing and evaluation routines for all prevailing methods of energy-filtered electron microscopy. This applies to the Image EELS and ESI methods, both being methods mainly used for analysis and visualization of even the lowest levels of element concentration. The software offers fast and effortless generation of highly resolved element diffraction maps accompanied by extensive information on the chemical composition of the structure. Parallel and serial EELS spectra can also be acquired using ITEM Solution EFTEM. When conducting more extensive analysis, spectra can be quantified within the software, and specimen thickness can be determined right away. ITEM Solution EFTEM also offers an impressive variety of spectra-processing functions. This solution includes an EELS atlas with a wide range of reference spectra as well as automatic generation of spectral information.

**Physical basis of the EFTEM advantages**

![Diagram showing the physical basis of EFTEM advantages]

**Differences between EFTEM and TEM**

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**Semiconductor specimen (DRAM):** Respective elemental distribution images were calculated using 3-window power-law method.

a) Elastic brightfield image (EBF)
b) Superposition of O, N and Ti distribution to EBF. Photo: Carl Zeiss NTS GmbH

**A TEM is always imaging with polyenergetic electrons.**

**An EFTEM is imaging with selected electrons of defined energy and band width.**
Electron Spectroscopic Imaging (ESI)

The ESI mode is primarily used for investigating elements of radiosensitive specimens as this approach requires just a few images for generating an element diffraction map – depending on the exact method used. In the ESI mode, the iTEM Solution EFTEM manages and coordinates automatic acquisition, calculation, and subsequent presentation of results. Image acquisition can be greatly simplified using the various options. The number of images to be acquired can be defined interactively and easily in the acquisition dialog in accordance with the respective energy loss.

In order to minimize the possibility of error when defining the energy loss/range, the iTEM Solution EFTEM uses a built-in EELS Atlas, a library containing all known energy windows, ionization edges and reference spectra. For instance, the EELS Atlas can be used to set optimal parameters for acquiring the required image series. This facilitates adding reference spectra during acquisition in order to define the ideal energy loss. After defining these parameters, image acquisition is automatic. A drift correction, which works automatically or manually, helps to align images with one another as needed. R value mapping offers various methods for adjusting the background. Evaluation in the ESI mode is done via today’s prevailing methods: eg, 2, 3 and multi-window method, the latter being used in the linear, potential and exponential application as well. Users can select either ratio or differential methods. The elemental diffraction map is then calculated and presented in a straightforward and easy-to-use way.
Image EELS

Image EELS is a method for the analysis and imaging of very low element concentrations. This method makes it possible to improve local spectral sensitivity to the detection limit. High-resolution element distribution maps can be generated quickly and effortlessly with iTEM Solution EFTEM, providing sample information on a sample's chemical composition. An Image EELS series consists of multiple images of various energy losses. The advantage of this method is that the images and energy losses for generating the element diffraction map (used for subsequent analysis) are defined after the acquisition. iTEM Solution EFTEM’s image EELS method makes it easy to define all necessary parameters for recording the energy loss series. Based on these settings, image acquisition is automatic. And just like the ESI method, the integrated EELS Atlas is a convenient assistant when defining these parameters. The user also has all other evaluation methods and aids such as drift correction, for balancing out lateral and energetic shifts, and R value mapping. When evaluating the images, the user selects the areas of interest, referred to as ROIs or Region of Interest. The areas selected apply to all the images in the series. Intensity is measured within each ROI and entered above the energy loss of the respective image and displayed as an energy loss spectra. These spectra can be more extensively analyzed using a wide range of options. Presentation of results is enhanced by diffractions, mappings and overview images.
Parallel EELS

Parallel EELS is the simultaneous acquisition of energy loss spectra taken with a CCD camera for rapid element identification. Parallel EELS is a method for quickly analyzing radiosensitive samples. A corresponding spectrum can be simultaneously captured in a range of multiple 100 eV. The sample range to be investigated can be selected using a screen or a defined illumination spot. With the microscope in spectrum mode, the spectrum is projected onto a CCD camera, the intensity measured and converted into an energy-loss spectrum. Acquisition, display and evaluation of Parallel EELS can be automatically controlled with iTEM Solution EFTEM. Spectral acquisition offers both spatial and chronological integration. The software automatically calibrates the rotation during acquisition of the spectrum making it unnecessary to rotate the camera itself. The spectral functions integrated with iTEM Solution EFTEM offer a wide range of options for filtering, labelling and printing out the Parallel EELS spectra. These also include functions for more extensive evaluation of the captured spectra. Overlays, comments, labels and spectral data can be added, reference spectra of the element or any other element can be loaded, and the spectrum can be optimized using various filters for noise reduction and background subtraction.

“Wide-range” parallel EELS

Via “Wide-range” parallel EELS, the iTEM Solution EFTEM offers high spectral resolution over a large energy range in addition to the normal functions of parallel EELS acquisition. This high spectral resolution can be combined with an overview function. This is done automatically by combining and comparing individual, highly-resolved spectra. The analyzable energy range of a spectrum can be increased without restriction – with no loss in detail. This makes analyzing unknown and difficult samples easy and reliable. All parallel EELS functions are available in the Wide Range Parallel EELS as well.

EELS Atlas

The integrated EELS Atlas offers a wide range of reference spectra as well as automatic generation of spectral information.
Serial EELS

Serial EELS (or S-EELS) refers to the precise registration of spectra using a combined scintillator/photomultiplier. These spectra have a high dynamic range and are digitized using a digital voltmeter. This method provides excellent results with more challenging investigations: e.g., having to acquire edge structures at high energy resolution. The S-EELS method within iTEM Solution EFTEM offers spectral acquisition with a range from 0 eV up to 2500 eV and a maximum bit depth of 18 bits. This level of resolution is especially advantageous when evaluating finely structured detail via ELNES and EXELFS. During acquisition, the electron spectrum is directed across the detector opening by gradually changing the high voltage. The intensity is measured by a photomultiplier. iTEM Solution EFTEM controls the entire acquisition process and the subsequent processing, which involves selecting the area to be analyzed, using the same method as parallel EELS. The intensity in the spectrum is recorded sequentially via an electron detector then displayed and evaluated in the image analysis system. The spectrum functions can be used for further processing. Results are presented using diffractions, mappings and overview images.

Spectrum processing

The processing, evaluation and display of one-dimensional data is done within iTEM Solution EFTEM. All information regarding a spectrum is stored within the corresponding tab. This includes: energy loss, energy window, method used, high voltage, camera, microscope, element, edge and user information. In addition to spectrum display, the user can choose from various filters and functions for preparing and processing spectra. These include line or polynomial fits, Z calibration and normalization functions, derivation filter, as well as the anti-spike filter and drift correction. In addition, overlays, comments, labels and spectral data can be appended to each spectrum. The reference spectrum of any element can be appended to a spectrum as needed and peaks are identified automatically.

Quantification

iTEM Solution EFTEM has integrated a wide variety of methods for quantitative evaluation of the spectra. The software can determine the ratio of two elements based on the energy loss spectrum: e.g., the ratio of the Nitride K edge to the K edge of Boron. For the deconvolution of this spectrum the essential prerequisite being that both the zero-loss peak as well as the ionization edges of the two elements are included in the spectrum. Within the framework of this evaluation, the user has numerous background-correction options. The software automatically calculates the ratio value based on other data such as microscope parameters (energy resolution, magnification, acquisition angle or high voltage). The user may also use layer thickness measurement, another quantitative evaluation method.
Specifications

### ESI
- R-Map for direct quality control
- Drift correction
- Analyzing
  - Convenient display of elemental maps by various image mixing/superimposition functions

### Image EELS
- Drift Correction
- ESI mapping
- Quality check (movie of planes)
- Various ROI selection tools (eg, magic wand)
- Spectrum display in real time

### Parallel-EELS
- Direct acquisition of spectra to CCD camera
- Acquisition control: time or surface accumulation
- Automatic calibration and control of gain and energy shift
- Wide range P-EELS supported

### Serial EELS

### Spectra Processing
- EELS Atlas with reference spectra for all common elements
- Auto scaling
- Single or multiple spectra (up to 8 spectra simultaneously)
- Display filters and numerical filters
- Automatic peak identification, automatic element labelling
- Zero-loss calibration
- Integration, background subtraction
- Deconvolution: Fourier log
- Gain-split functionality

### Quantification
- Element ratio and ratio map
- Compute specimen thickness from spectrum and/or image (interactive)
- Automatic generation of spectrum information saved with the image

### ADDITIONAL iTEM SOLUTIONS

iTEM can be further expanded according to your individual needs via a wide range of specially developed solutions. Users can thus put together their own personal software solution for dealing with their particular application. All solutions work together seamlessly. The list of the available solutions is growing continually.

**iTEM Solution Detection** – The iTEM Solution Detection offers simple, fast and flexible particle detection and classification.

**iTEM Solution Tomography** – The iTEM Solution Tomography is the most convenient way to obtain 3-D data from every 2-D tomography tilt series acquired on a TEM.

**iTEM Solution EMarker** – The iTEM Solution EMarker provides you the decisive assistance for counting and analyzing your colloidal gold markers automatically.

**iTEM Solution ASAC** – The iTEM Solution ASAC automatically determines the strain tensor in semiconductor devices using image analysis on CBED image series.

**iTEM Solution Diffraction** – The iTEM Solution Diffraction offers diffraction pattern analysis including calibration, indexing and measuring of single or polycrystalline diffraction images.

**iTEM Solution telePresence** – The iTEM Solution telePresence enables the user to conveniently operate transmission electron microscopes, TEM cameras and motorized stages online unrestricted by time or place.

**TEM camera solutions for iTEM** – Various bottom and side-mounted scientific-grade CCD TEM cameras are fully integrated in iTEM.