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Enabling the Nano-Age World®

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Carl Zeiss SMT – Nano Technology Systems Division

Enabling the Nano-Age World®

ZEISS

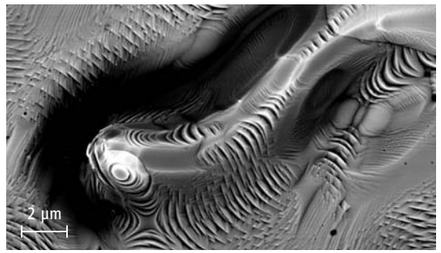
ULTRA

The ultimate nano-scale compositional imaging tool for Materials Analysis, Semiconductor Applications and Life Science

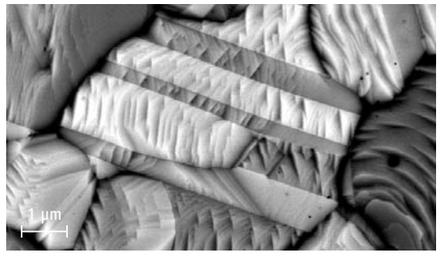
ULTRA

Detection at its Best – Imagine You can See it All

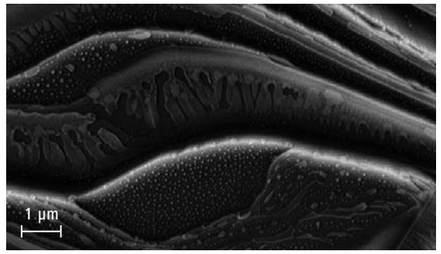
2 see more – ultra high resolution with simultaneous SE and BSE imaging



2 see clear – precise and ultimate imaging capabilities without noise in real time and mixing of SE and BSE signals

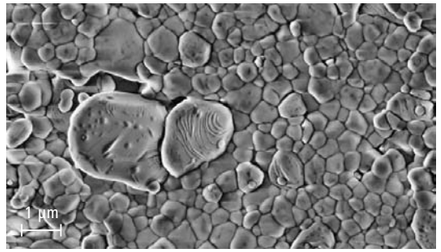


2 see inside – the perfect tool for nano-scale compositional analysis



2 enjoy ease of use – fully in-column integrated BSE and In-lens SE detectors

2 get rid of charging – fully integrated charge compensator in Ultra*plus* for clear and precise imaging of non-conducting samples



The ULTRA with Integrated EsB Detection

The ULTRA series includes the latest developments in the GEMINI® technology consisting of the outstanding high efficiency **E**nergy **s**elective **B**ackscattered detector (**EsB**) for low voltage, ultra high resolution contrast on the sample surface.
The ULTRA comprises the GEMINI® In-lens SE detector for clear topographic imaging and the EsB detector for compositional contrast imaging. Together with the integrated AsB detector onto the objective lens and an optional STEM detector (Scanning Transmission Electron Microscope), the ULTRA can image all different electron signals coming from the sample completely independent.

Precise and clear imaging

- Ultra high resolution BSE imaging
- Less sensitive to charging effects
- Ideal for precise boundary, feature and particle measurements
- Sensitive for ultra low voltage imaging – 20V

High Efficiency EsB detector

- High efficiency direct detection principle for BSE and SE
- Utilises the GEMINI® lens for separation of BSE and SE
- BSE imaging at low working distance
- Compositional contrast imaging

Integrated filtering technology

- Enables true BSE imaging
- Allows energy threshold of BSE
- Suppresses charging effects of non-conducting specimens
- Not sensitive to edge contrast

Ease of operation

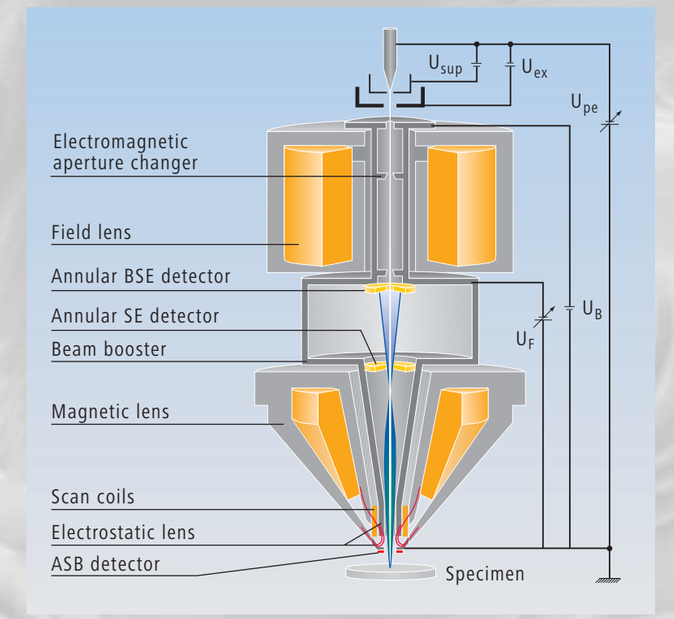
- Fully integrated EsB, AsB and In-lens detectors, no need for adjustment
- Simultaneous operation of the In-lens detector with both backscatter detectors
- Real-time imaging and mixing of BSE and SE signal
- Easy selection of filtering voltage

EsB Filtering Technology

The SEs and BSEs generated at the impact point of the primary electron beam are intercepted by the low electrical field of the GEMINI® column at the sample surface. They are accelerated by the field of the electrostatic lens. Due to the excitation of the objective lens the low energy SEs are *projected* by the GEMINI® lens onto the annular high efficiency In-lens SE detector. The high angle BSEs originated close to the impact point of the primary electron beam, are focussed into a beam-waist at the hole of the In-lens SE detector and detected by the integrated EsB detector.
A small amount of SEs pass through the hole of the In-lens detector and would be observed by the EsB detector. To prevent detection of these SEs a filtering grid is installed in front of the EsB detector.

By simply switching the filtering grid the SEs will be rejected and only the BSEs will be detected. The unique combination of the In-lens SE detector and the EsB detector enables simultaneous imaging and mixing of clear high contrast topography (SE) and pure compositional contrast (BSE).

Below a landing energy of 1.5kV the filtering grid has the additional function of selecting the desired energy of the BSEs. The operator can select the threshold energy of inelastic scattered BSEs to enhance contrast and resolution. For example, with a landing energy of 1.5kV and the filtering grid on 1.4kV, the SE will be suppressed and the BSE landing energy on the EsB detector will be in the range of 1.4 – 1.5kV.



Cross section of the GEMINI® electron optical column utilised in the ULTRA FESEM.

Uex – extractor voltage of first anode
Upe – primary beam voltage
UB – booster voltage
UF – EsB filtering grid voltage
Usup – supressor voltage

EsB and AsB Detection Principle

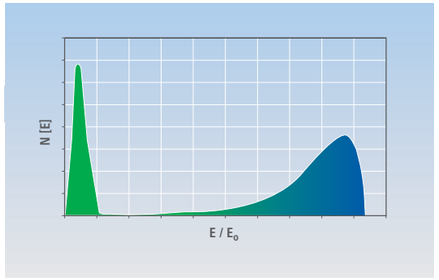
At the impact point of the primary electron beam secondary and backscattered electrons are generated. The secondary electrons, having an energy of less than 50 eV, are emerging from the very surface of the specimen. Backscattered electrons are generated below the surface in a larger volume than the SEs. For high resolution imaging, elastically scattered BSEs have to be detected. These high angle BSEs typically in a cone with a 15° angle to the primary beam are attracted by the electrical field of the GEMINI® column and projected into the column.

For the separation and detection of the SEs and BSEs one has to consider two parameters: energy and angle distribution. The secondary electrons emerging from the top surface of the specimen contain surface information, as their angle distribution is virtually perpendicular to the surface and orientation dependent. Due to their relatively low energy, SEs are attracted by the electrical field of the GEMINI® column and are all deflected by the excited objective lens to the plane of the annular In-lens SE detector.

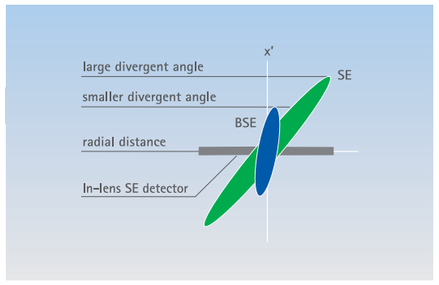
The SEs are detected through a wide angle range depending on the surface of the specimen. The high angle backscattered electrons, carrying an energy close to the landing energy of the primary beam, are projected into the GEMINI® column as well. If the angle is too low they will not enter the column but will land on the objectiv lens pole piece, where they can be detected via the integrated AsB detecor. Because of this **A**ngle **s**elective **B**ackscatter electron detection this detecor is called **AsB** detector.

The BSEs inside the GEMINI® column are deflected by the objective lens, but due to the higher energy they are deflected to a different plane than the secondary electrons.

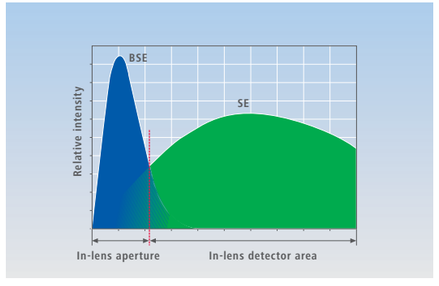
The method of separating and detecting the backscattered electrons is called: **E**nergy **s**elective **B**ackscattered detection, hence the name **EsB** detector.



Energy distribution of electrons emerging from the specimen surface.

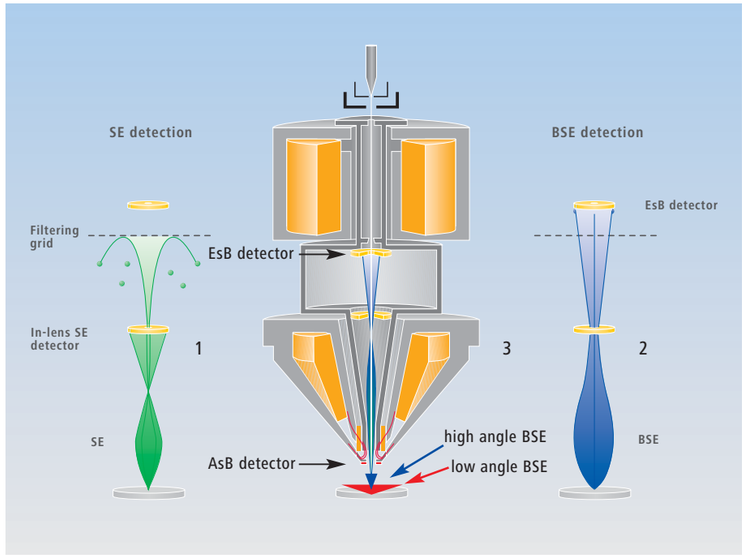


Phase space presentation of the secondary and backscattered electrons showing the difference in angle and energy of the respective electrons.



Radial distribution of BSE and SE in the In-lens detector plane. Clearly visible is the separation of the electrons at the In-lens SE detector plane and the high detection efficiency of both detectors.

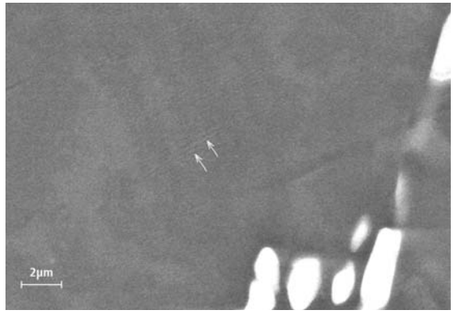
The AsB detector is completely integrated onto the pole piece of the GEMINI® lens. This enables BSE imaging with ultra short working distance without additional alignment of the AsB detector to the optical axis. This detector arrangement in the ULTRA column enables to separate between low angle BSE and high angle BSE.

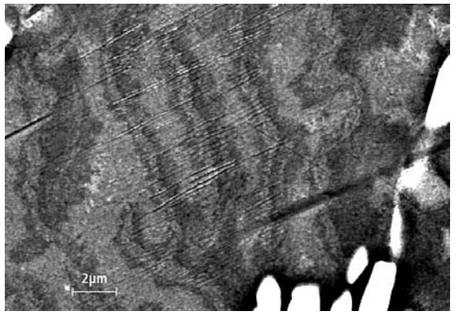


(1) SE imaging with In-lens detector

(2) high angle BSE imaging

(3) The GEMINI® lens seperates between high angle BSE, to be detected with the In-column EsB detector and low angle BSE to be detected with the AsB detector.





"Normal BSE imaging (left) and AsB imaging (right) on the same sample (Al with Cu precipitates). Note: shear stress from recrystallization (arrows mark dislocations) after annealing.

ULTRA*plus*

The new **ULTRA*plus*** is the essential and consequent further development of the ULTRA55. It combines the unique detection capabilities of the ULTRA55 plus a revolutionary charge compensation (CC) system for imaging of most critical non conducting samples. This makes it an ULTRA high end FE-SEM for all aplications in Material Science, Life Science and the Semiconductor world. The fully automatically charge compensator can be used in conjunction with all integrated detectors known from the ULTRA55: EsB, In-lens, AsB and chamber mounted Everhart-Thornley detector. With the unique capability of both In-lens detectors also in the charge compensation mode the **ULTRA*plus*** is a dedicated nanoanalytic tool for high resolution imaging and material analysis.

Precise and clear imaging

- Ultra high resolution BSE imaging
- Sensitive for ultra low voltage imaging down to 20V
- Insensitive to charging effects
- Complete detection system with ESB, In-lens, AsB and Everhart-Thornley detector

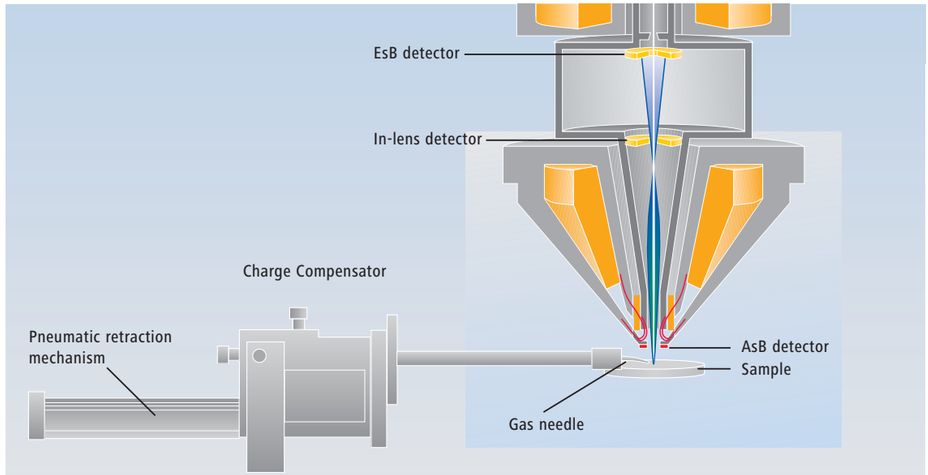
Charge Compensation

- Local dry nitrogen gas jet
- Fully integrated system control
- Fast switching between high vacuum and charge compensation
- Clear material contrast

Ease of use

- Fully integrated detectors without adjustment
- Charge compensation by one mouse click
- Fast image acquisition in CC mode
- Integrated super large scan field mode with Fisheye setup
- Utilises the GEMINI® electron optics for seperation of BSE and SE in real time

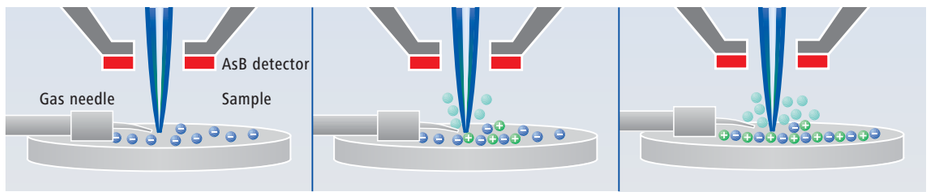
Charge Compensation in ULTRA*plus*



The charge compensator is fully integrated in the complete new vacuum concept of the GEMINI® column in **ULTRA*plus***. A pneumatic retraction mechanism of the charge compensator allows fastest toggle between charge compensation mode and high vacuum operation. The charge compensator is equipped with a local gas jet of dry nitrogen. Through a needle with a small diameter a local gas flow is applied to the sample surface in the e-beam irradiated area.

When a non-conducting material is exposed to the electron beam, charging effects on the sample surface inhibit a clear and stable imaging. The secondary electrons formed build up on the sample surface and a resultant charge across the entire sample surface. The electrons stimulate in all areas and are released from the entire sample surface. The detectors are therefore overwhelmed with electrons from all over the sample surface. The charge compensator operates to neutralise the surface. This is achieved by emitting a gas into the area of interest onto the sample surface. As SE and BSE emitted from the sample surface collide with these molecules, ions are formed which are attracted to the forming charge on the surface. As they fall, they neutralise the surface allowing true high resolution imaging.

Because of the fairly small increase of total chamber pressure the booster voltage of the GEMINI® column can always be switched on. Therefore all standard in column detectors can be used in a regularly way.



Sample with charged up surface by electron (blue) irradiation. Gas flow turned off.

Gas flow turns on. The gas molecules (light green) form a local gas cloud above the sample surface.

SE and BSE from the sample surface ionize the gas molecules. As the positive ions (dark green) fall they neutralise the surface.

New Options for the ULTRA*plus*

OptiProbe
- Continous adjusatble probe current
- Probe current is always displayed in GUI
- Easy probe current change by selection menu

40 nA high current

100 micron beam shift

Laser finder

STEM detector

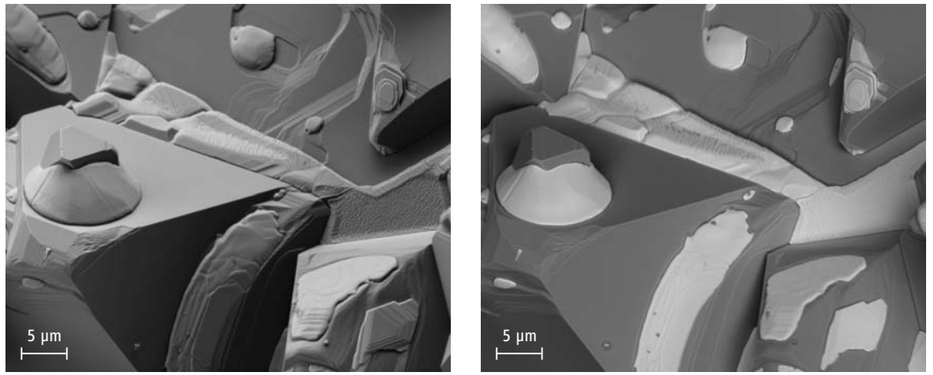
High precision encoder stage
Super eucentric
X + Y = 105 mm
Z = 50 mm
Z' = 20 mm
T = -15° to 70°
R = continous

Quiet mode (on the rear)
- 2 minutes pumping – 2 hours buffer time!
- 98% saving of power consumption of forepump
- Comfortable noise level for operator and microscope
- No disturbing vibrations
- Strongly improved lifetime

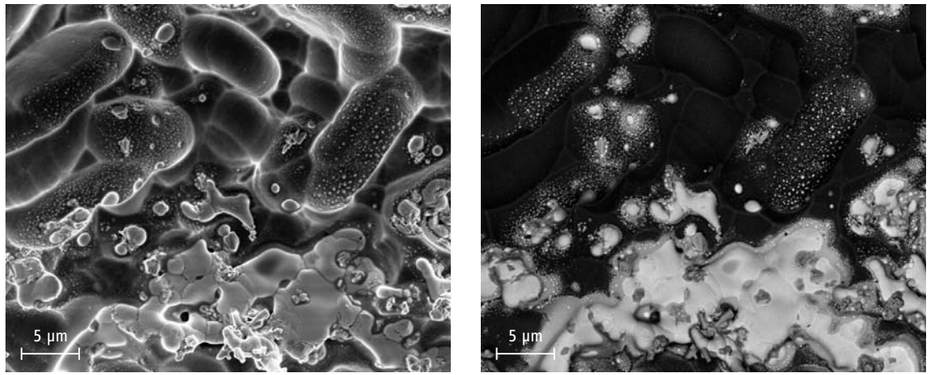
80mm airlock
- 30 seconds pump time
- Fully software intergated
- 80mm gate valve

Additional options available

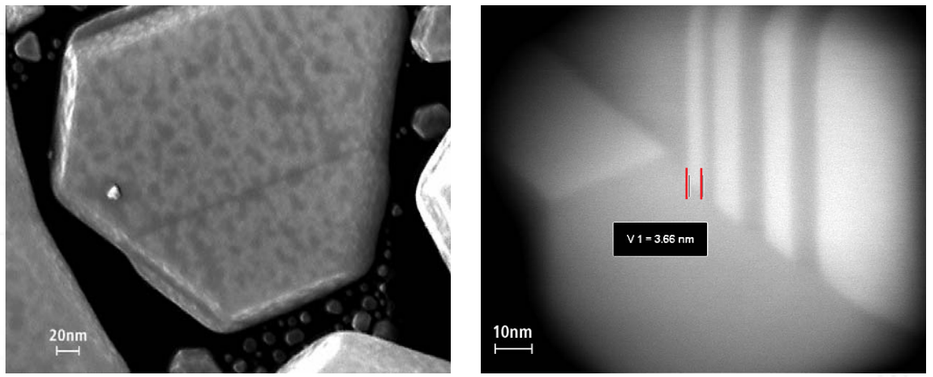
ULTRA Application Examples



Simoultaneously acquired In-lens SE and EsB image from a compound of $Bi_2Ca_2Co_1$.
The In-lens SE image on the left side shows topogaphical contrast. The image taken with the EsB detector on the right side shows independent from topography the compositional contrast generated by the various materials.



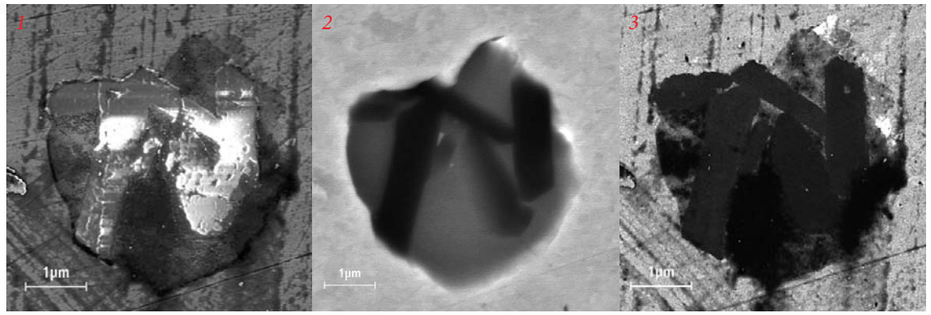
Simultaneous dual channel detection of the surface of a solar cell. Images taken at 4 kV primary energy.
Left: The secondary electron image taken with the In-lens detector shows the structure of the sample surface.
Right: EsB image with material contrast independent of topography.



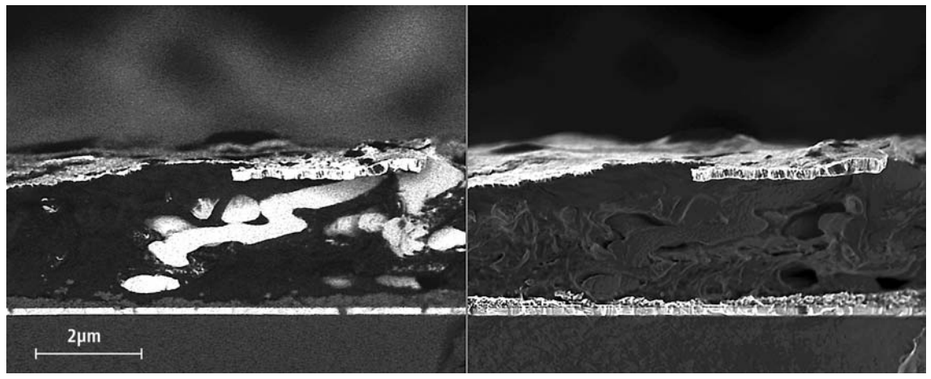
Gold particles seen with the In-lens SE and AsB detector. We see surface contrast with the In-lens SE and crystalline contrast from single elastic scattered BSE electrons. They provide similar resolution like the SE electrons.

ULTRA Application Examples

The combination of the high efficiency In-lens SE detector for clear high contrast imaging of surface details together with the outstanding EsB detector for compositional contrast, makes the ULTRA one of the most versatile ultra high resolution FESEMs currently available. Applications as diverse as uncoated wafers, semiconductor cross-sections, ceramics, plastics, nano-particles, and immuno-gold labelling all benefit from the combination of the EsB and the In-lens SE detector. Simultaneous ultra high resolution imaging and video processing of nano-scale surface details are now combined with compositional information which enables imaging of particle distributions, clear boundary imaging and precise feature measurement. The higher energy backscattered electrons which are detected by the EsB detector are less sensitive to charging on non-conducting samples.

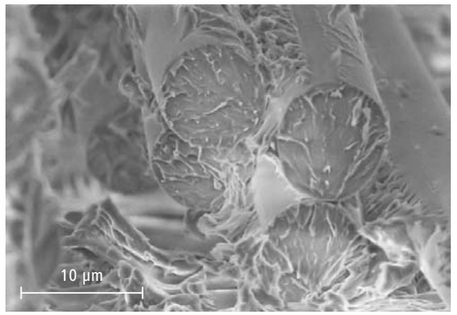


In this comparison of Manganese Sulfide inclusions in magnetic steel the exceptional sensitivity of the EsB detector is highlighted.
In the In-lens SE image (1) only surface information and absolutely no compositional contrast is visible. While the AsB detector (2) shows only two crystalline phases, the EsB detector (3) with its filtering capability senses more than five different phases in the inclusion.

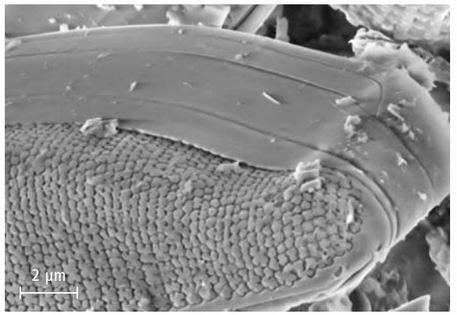


Dual channel detection of multi layers on glass. Left: EsB image with Indium Tin Oxide (ITO), Lantanum Selenide and Polymer layers.
Right: In-lens SE image showing only topography without compositional contrast.

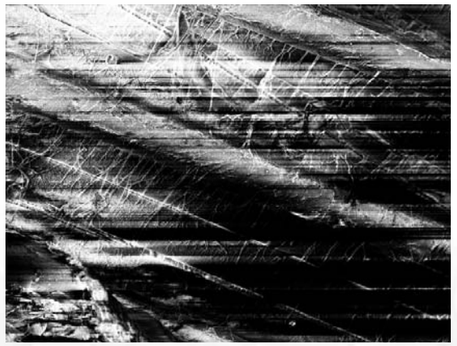
ULTRA*plus* Application Examples

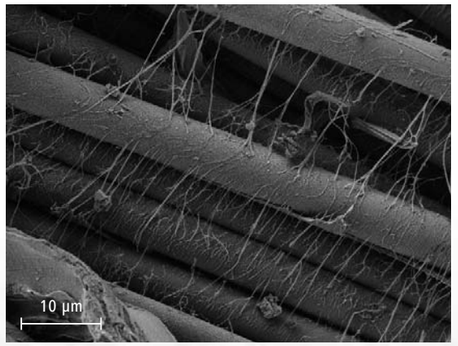


In-lens detector image of uncoated fibre optic cross section which shows clear surface contrast. Image is taken at 3 kV with charge compensator switched on.



In-lens detector image of diatom with embedded minerals showing clear topography contast. Image is taken at 4 kV with charge compensator switched on.





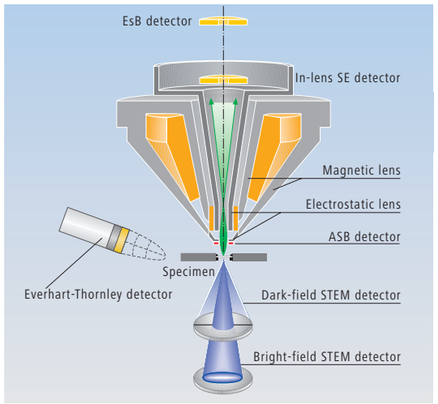
In this comparison of fibre glue sample the excellent benefit of the ULTRAplus charge compensator is demonstarted.
Left: The sample charges up extremely at 5 kV primary energy with gas flow of charge compensation turned off.
The image is disturbed by jittering and arcing.
Right: With turned on charge compensator the fine details of the fibre glue surface are visible.
Image is taken with chamber mounted Everhart-Thornley detecor at 5 kV.

Multi-Mode STEM Detection System

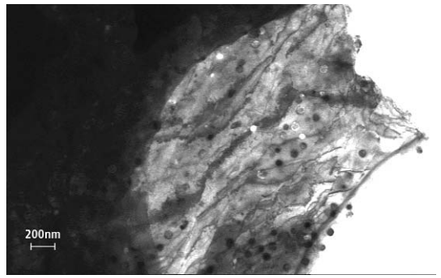
GEMINI® Multi-Mode STEM

The GEMINI® Multi-Mode STEM detection system comprises two parallel diode detector surfaces. The Dark Field (DF) detector surface has been divided into specific areas to allow orientated DF imaging. The specimens are mounted in a carrousel type TEM grid holder, which holds up to nine specimens. The GEMINI® Multi-Mode STEM detector includes a complete retractable assembly with high precision adjustments for optimum alignment and can be used in combination with all GEMINI® detectors.

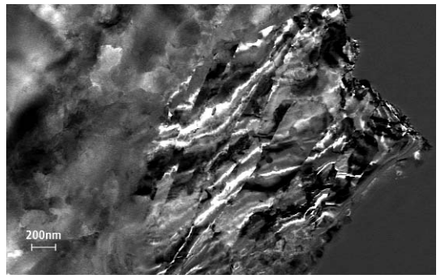
The GEMINI® Multi-Mode STEM detector is available for the current SUPRA™ FESEM, ULTRA FESEM and CrossBeam® range.



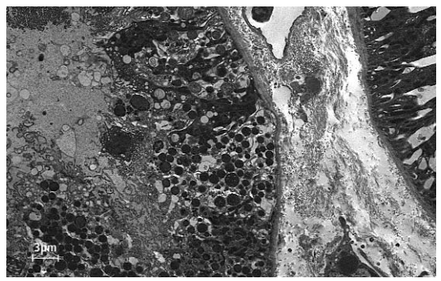
Detector systems for the GEMINI® FESEM.



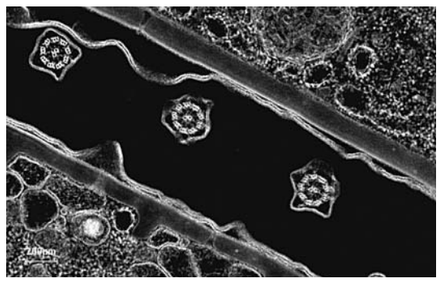
Bright field (BF) image on steel. No alignment is needed for the different imaging modes.



Orientation dark field image (oDF) from the same position highlighting strain and dislocations.



Unstained bright field (BF) image from biopsis of kidney. Note the extraordinary contrast without staining artifacts



BF image of a Ciliate (Psoudomicrothorax dubio) showing microvilli membranes and proteins.

Technical Data

Essential Specifications	ULTRA*plus*	ULTRA 55	ULTRA 60
Resolution	1.0 nm @ 15 kV, 1.7 nm @ 1 kV, 4.0 nm @ 0.1 kV		
Magnification	12 - 1,000 kx in SE mode, 100 - 1,000 kx with EsB detector		
Emitter	Thermal field emission type, stability >0.2 %/h		
Acceleration Voltage	0.02 kV - 30 kV		
Probe Current	4 pA – 20 nA (12 pA – 40 nA optional)		
Standard Detectors	EsB detector with filtering grid (0 – 1500 V) Integrated AsB detector High efficiency In-lens SE detector Chamber mounted Everhart-Thornley detector **all 4 detectors can be used in high vacuum and charge compensation mode**	EsB detector with filtering grid (0 – 1500 V) Integrated AsB detector High efficiency In-lens SE detector Chamber mounted Everhart-Thornley detector	EsB detector with filtering grid (0 – 1500 V) High efficiency In-lens SE detector Chamber mounted Everhart-Thornley detector
Chamber	330 mm (Ø) x 270 mm (h) 2 EDS ports 35° TOA CCD-camera with IR illumination	330 mm (Ø) x 270 mm (h) 2 EDS ports 35° TOA CCD-camera with IR illumination	520 mm (Ø) x 300 mm (h) 2 EDS ports 35° TOA Integrated 8" airlock CCD-camera with IR illumination
Vacuum System	Complete dry pumping system composed of Backing Pump, Turbomolecular Pump and Ion Getter Pump Option: Automatically controlled Quiet Mode to switch off Backing Pump after sample transfer when vacuum threshold is achieved		
Charge Compensator	Fully automated and pneumatic retractable local gas injector	——	——
Specimen Stage	Standard: 5-Axes Motorised Eucentric Stage X = 130 mm Y = 130 mm Z = 50 mm T = -3 to 70° R = 360° (continuous)	Option 1: 6-Axes Eucentric Stage X = 130 mm Y = 130 mm Z = 42 mm Z' = 13 mm T = -4 to 70° R = 360° (continuous)	Option 2: 6-Axes Encoder X = 105 mm Y = 105 mm Z = 50 mm Z' = 20 mm T = -15 to 70° R = 360° (continuous)	6-Axes Motorised Super-Eucentric Specimen Stage X = 152 mm Y = 152 mm Z = 43 mm Z' = 10 mm T = -15 - 60° R = 360° (continuous)
Image Processing	Resolution: Up to 3072 x 2304 pixel Noise reduction: Seven integration and averaging modes		
Image Display	High end 19" flat panel TFT colour display monitor with SEM image displayed at 1024 x 768 pixel		
Image Hardcopy	Choice of Windows® driven laser, inkjet or video print media		
System Control	SmartSEM™* with Windows® XP, operated by mouse, keyboard and joystick with optional control panel		

SmartSEM™ – Fifth generation SEM control Graphical User Interface*