Carl Zeiss NTS - Nano Technology System Division

ΣIGMA™
Field Emission
Scanning Electron Microscope

Instruction Manual

Enabling the Nano-Age World®

ZEISS

Operator's User Guide
ΣIGMA™ FESEM

Original instructions

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A Carl Zeiss SMT AG Company

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Contents

1 About this manual

This instruction manual is part of the ΣIGMA™ field emission scanning electron microscope (FESEM).

Read the instructions carefully. Keep the instruction manual near the FESEM and give it to future owners and operators of the FESEM.

This instruction manual is for users who have been trained to operate the FESEM by an authorised Carl Zeiss expert. Operators of the FESEM must use the FESEM only as instructed in this manual.

Related documents

For details on the options fitted to your installation, refer to the relevant manuals supplied with the FESEM. You will find these manuals in the FESEM document folder.

For detailed information regarding the operating software refer to the Software Manual for SmartSEM®.

For details on technical data refer to the Product Specification and to the Installation Requirements.

At a glance

This instruction manual contains the following chapters:

1. About this manual	Explains the function and structure of this instruction manual
2. Safety	Summarises important safety details
3. Overview of the system	Describes the structure and principle of operation of the FESEM
4. Detectors	Describes the types of detectors available for use with the ΣIGMA™.
5. Transport and storage	Gives details on transport and storage
6. Installation	Refers to Carl Zeiss service staff
7. Operation	Introduces fundamental operation procedures
8. Maintenance and repair	Describes preventive maintenance and repair tasks
9. Troubleshooting	Summarises clues to solve possible problems
10. Shutdown and disposal	Summarises notes on shutdown and disposal
11. Parts and tools	Lists consumables, spare parts, tools, and accessories
12. Abbreviations	Alphabetical list of abbreviations used in this instruction manual
13. Glossary	Alphabetical list of important technical terms
14. Declaration of conformity	Important declaration
Index	Alphabetical list of key words that are referred to in this instruction manual

1.1 Safety instructions in this manual

This instruction manual includes warning and caution notices. You MUST read, understand and follow the instructions and guidance in these warning and caution notices.

DANGER
This safety symbol and signal word indicates an imminently hazardous situation.
Disregarding this warning WILL result in death or serious injury.

WARNING
This safety symbol and signal word indicates a potentially hazardous situation.
Disregarding this warning COULD result in death or serious injury.

CAUTION
This safety symbol and signal word indicates a potentially hazardous situation.
Disregarding this warning MAY result in minor or moderate injury.

CAUTION
This signal word used without a safety symbol indicates a potentially hazardous situation.
Disregarding this warning MAY result in property damage.

Important:
This symbol and signal word draws your attention to important and useful information.

Note:
Notes provide additional information that can help you to understand the system and its operation more fully. The information included in a note is NOT safety critical.

1.2 Typographical conventions

For the description of software, the following typographical conventions are used:

Typography	Meaning
Push **<ENTER>**.	Press the **ENTER** key on the keyboard.
Type **<key1, key2>**	Type key **1** first, then type key **2** on the keyboard.
Type **<Ctrl + Alt + Del>.**	Press the **CTRL** key and the **ALT** key and the **DEL** key at the same time.
Click on the **Magnification** icon. Select **File/Exit** from the menu.	Icons, buttons, and menus are printed in bold.
Enter *10 kV* in the **EHT target** field.	Values to be selected are printed in italics.

Text	Meaning
Click...	Press the left mouse button.
Right-click...	Press the right mouse button.
Double-click....	Press the left mouse button twice.

1.3 Definition of terms

The following terms are used in this instruction manual:

FESEM	Field emission scanning electron microscope. ΣIGMA™ is an FESEM.
SmartSEM®	Operating software for ZEISS field emission scanning electron microscopes. This instruction manual refers to the operating software SmartSEM® v05.05.
Carl Zeiss service engineer	Specially trained service expert. The person may be either Carl Zeiss staff or part of a team from an authorised service partner of Carl Zeiss NTS Ltd.
Operator	A trained person, who is assigned to operate the FESEM. • *Basic operator:* A person who has been trained to perform fundamental operation sequences. • *Advanced operator*: An electrically skilled person who has been trained to perform basic maintenance tasks.
User	A person or organisation that uses products of Carl Zeiss NTS Ltd.

2 Safety

2.1 Intended use

The FESEM is a microscope that scans a focused beam of electrons across a specimen to generate an image or to analyse the specimen.

The FESEM is designed to analyse surface structures and near-surface structures of appropriate specimens. For that purpose the specimen must be located in an evacuated specimen chamber.

Commercial use only

The FESEM is to be used in a laboratory environment for commercial purposes only. Do not use the FESEM for any other purpose. Use the FESEM only as instructed in this manual.

You will void the warranty if you use the FESEM for any purpose or in any manner for which it has not been designed.

2.2 Prevention of accidents and of improper use

WARNING

Risk of injury to the operator, or damage to the instrument due to improper operation of the FESEM.

Read the user documentation carefully.

Do not operate the FESEM until you have completely read and understood this instruction manual and the entire user documentation delivered with the FESEM. The user documentation is supplied in the FESEM document folder.

Operator training

When a Carl Zeiss service engineer installs and commissions the FESEM, they will provide basic operator training. The basic operator training covers fundamental operating procedures and includes safety instructions.

In addition to the basic operator training, advanced operators are also shown how to perform some basic maintenance tasks. For this reason, advanced operators must be electrically skilled. Appropriate documentation is supplied with the training.

Carl Zeiss NTS Ltd offers special application training sessions on request.

IMPORTANT:

This instruction manual includes some basic maintenance and servicing instructions.

Those maintenance and service tasks that are NOT described fully in this instruction manual must be performed ONLY by authorised Carl Zeiss service engineers who have received the proper training from Carl Zeiss NTS Ltd.

2.3 Safety summary

Follow the safety instructions carefully as they are explained in this instruction manual. This is essential to protect yourself and others against accidents and unsafe practices, and to prevent damage to the FESEM. Do not deviate from the instructions in this instruction manual.

This section summarises possible hazards and the recommended safety procedures. You must take care to recognise and avoid hazards associated with the use of the FESEM, even if this instruction manual does not identify the hazard specifically.

2.3.1 Hazards to personal injury

Service tasks

The following information describes some hazards and risks of personal injury.

DANGER

Danger to life: There are hazardous voltages inside the FESEM.

Only service engineers who have been trained and authorised by Carl Zeiss NTS Ltd are allowed to service the FESEM.

Radiation protection

X-rays are generated inside the FESEM during operation. This is unavoidable, because X-rays are always generated when accelerated electrons hit any material.

WARNING

Radiation hazard: The FESEM generates X-rays inside the chamber during operation.

Only authorised Carl Zeiss service engineers are allowed to service the FESEM.

DO NOT remove any parts, and DO NOT disable any parts of the interlock system.

Use only genuine ZEISS parts in the FESEM.

Follow all safety and X-ray protection regulations.

In the UK, operation of the FESEM is permission-free because the following requirements are fulfilled:

- The acceleration voltage is limited to 30 kV.
- The local dose rate at a distance of 0.1 m from the accessible surface of the FESEM does not exceed 1 µSv/h.
- A respective label is attached to the FESEM.

Outside the UK, the user of the FESEM must comply with the local regulations of the country where the FESEM is operated.

The FESEM is equipped with several radiation protection devices. These devices ensure (under regular operation conditions) that the FESEM operates in accordance with the Ionising Radiations Regulations 1999, as well as with the EC Directive 96/29/EURATOM.

Electrical connections

The FESEM has a high leakage current. A proper ground connection to the equipment is essential.

CAUTION

High leakage current: You must ensure the FESEM has a separate connection to an effective ground point.

DO NOT operate the FESEM unless there is separate connection to an effective ground point.

Gases

Dry nitrogen gas is used to ventilate the specimen chamber during specimen exchange.

Compressed air is used to operate several valves and the auto levelling system.

CAUTION

Suffocation hazard: The specimen chamber is ventilated with dry nitrogen gas. Breathing pure nitrogen will cause unconsciousness.

During specimen exchange, keep the chamber door open for as short a period as possible.

Do not breathe in the gas from inside the specimen chamber.

Make sure the area around the FESEM is sufficiently ventilated.

IMPORTANT:

For more information about the hazards of nitrogen installations and the associated safety precautions, refer to guideline IGC Doc 44/xx: Hazards of inert gases and oxygen depletion, published by EIGA (European Industrial Gases Association). You can find this information through the EIGA homepage www.eiga.org.

CAUTION

High pressure gas: There is a risk of injury to operators, or damage to the instrument due to the high internal pressure in gas cylinders (for example those containing nitrogen or compressed air).

Read and obey all safety labels on the gas cylinders and all safety instruction given by the manufacturer of the gas cylinder.

Operation

There are risks of injury and of damage to equipment if you operate the FESEM incorrectly.

CAUTION

Risk of injury: Fingers could be trapped in the moving specimen stage.

Always close the chamber door before you move the specimen stage.

CAUTION

Toxic chemicals: There is a risk of injury when you work with aggressive or toxic chemicals.

Wear suitable protective clothing, gloves and eye/face protection. Do not eat, drink or smoke at work. Refer to local safety regulations.

CAUTION

There is a risk of damage to the environment due to caustic or toxic chemicals.

When disposing of waste that has been generated during a service operation (for example, used oil from a rotary pump), obey all national and local safety and environmental protection regulations.

Service procedures

Baking out the gun head has to be performed as a regular maintenance procedure.

Only advanced operators are allowed to perform the bakeout procedure.

CAUTION

Burn hazard: Some parts inside the FESEM become hot during the bakeout procedure. Disconnect power and allow surfaces to cool before you open any part of the instrument after a bakeout procedure.

DO NOT place any flammable objects on the top of the electron optical column.

Only Carl Zeiss service engineers who have been trained and authorised by Carl Zeiss NTS Ltd are allowed to service the FESEM.

2.3.2 Hazards not related to personal injury

CAUTION
Risk of damage to equipment: The FESEM or the specimen might be damaged if the specimen stage is at a short working distance when you open the chamber door.

Always move the specimen stage to long working distance before you open the chamber door.

CAUTION
Risk of property damage: Connect only ZEISS-approved equipment to the instrument.

Make sure the total electrical load connected to the FESEM does not exceed 10 A.

IMPORTANT:
IMPORTANT: Fingerprints can cause virtual vacuum leaks.

Always wear lint-free gloves when you touch the specimen or the inner parts of the specimen chamber.

2.4 Safety equipment

2.4.1 Safety devices

The FESEM has many safety and protective devices to prevent any risk of hazard to human health or of damage to the instrument.

2.4.1.1 Protective cover panels

The plinth, the electron optical column and the specimen chamber have protective cover panels.

WARNING
There are hazardous voltage inside the FESEM. Contact with these voltages may cause burns or electric shock.

X-rays are generated inside the FESEM during operation.

DO NOT remove any parts.

DO NOT operate the FESEM with the protective cover panels removed.

2.4.1.2 Vacuum interlock system

The vacuum interlock is an internal interlock.

It ensures that the gun vacuum and the system vacuum are better than the required thresholds.

2.4.1.3 MAIN circuit breaker

The **MAIN circuit breaker** is located at the rear of the plinth.

It switches the mains electrical power to the FESEM.

2.4.1.4 Main shut-off valves

The user is responsible for the installation of main shut-off valves at the site of installation. Shut-off valves are required on the following services:

- water supply
- water runback
- nitrogen supply
- compressed air supply

The main shut-off valves must be easily accessible. They must close off the connections to the corresponding services when needed. It must be possible to lock the main shut-off valves in their OFF position in order to prevent accidental re-activation.

Because the user is responsible for installing the main shut-off valves, they should also provide instructions how to operate the valves properly.

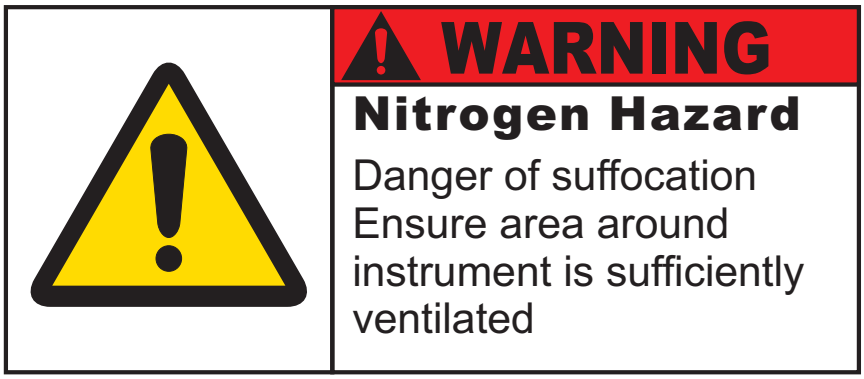
2.4.2 Safety labels and labels

Appropriate safety labels on the FESEM warn you of possible hazards. Each safety label is fixed near to the point where a particular hazard exists.

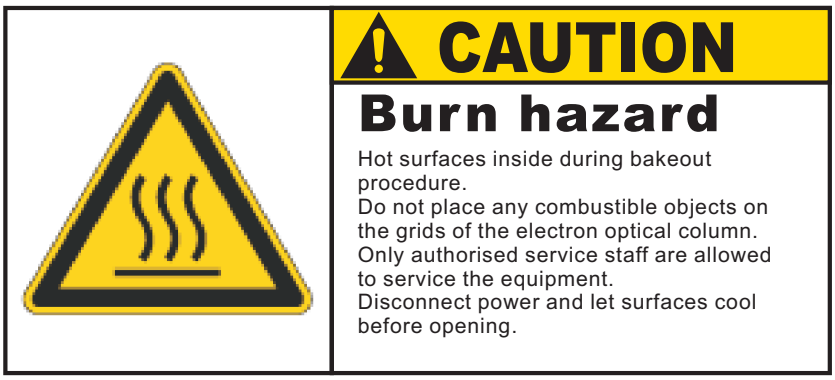
Do not remove labels from the FESEM. If damage occurs to any label so that you cannot read it fully, contact Carl Zeiss NTS Ltd to request a new label. Fit the new label in place of the damaged label.

Voltage hazard

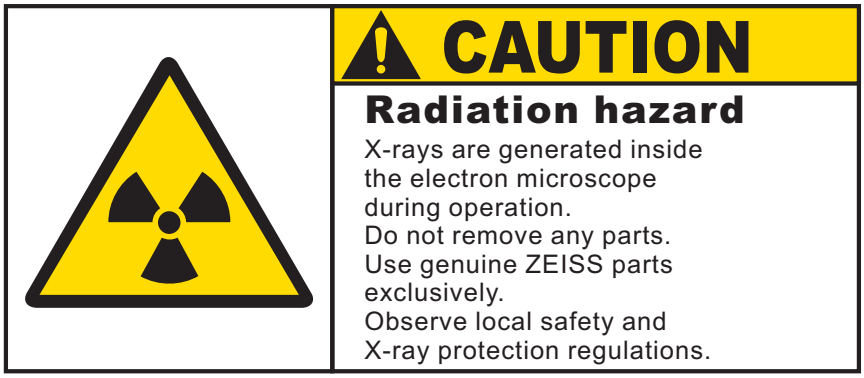
Nitrogen hazard



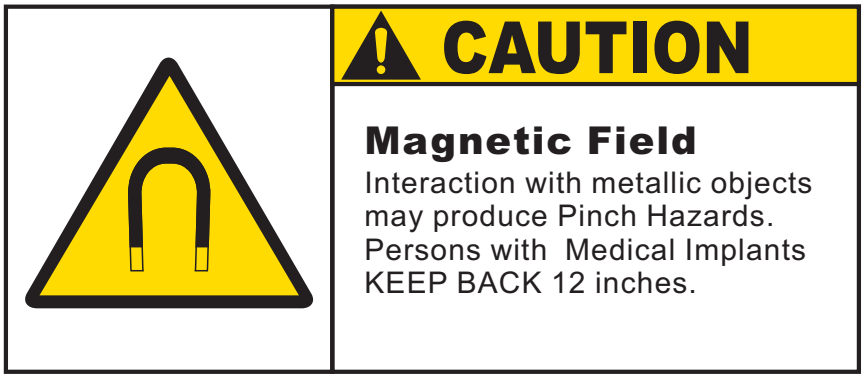
Burn hazard



Radiation hazard



Magnetic field hazard



2.4.2.1 Inside FESEM

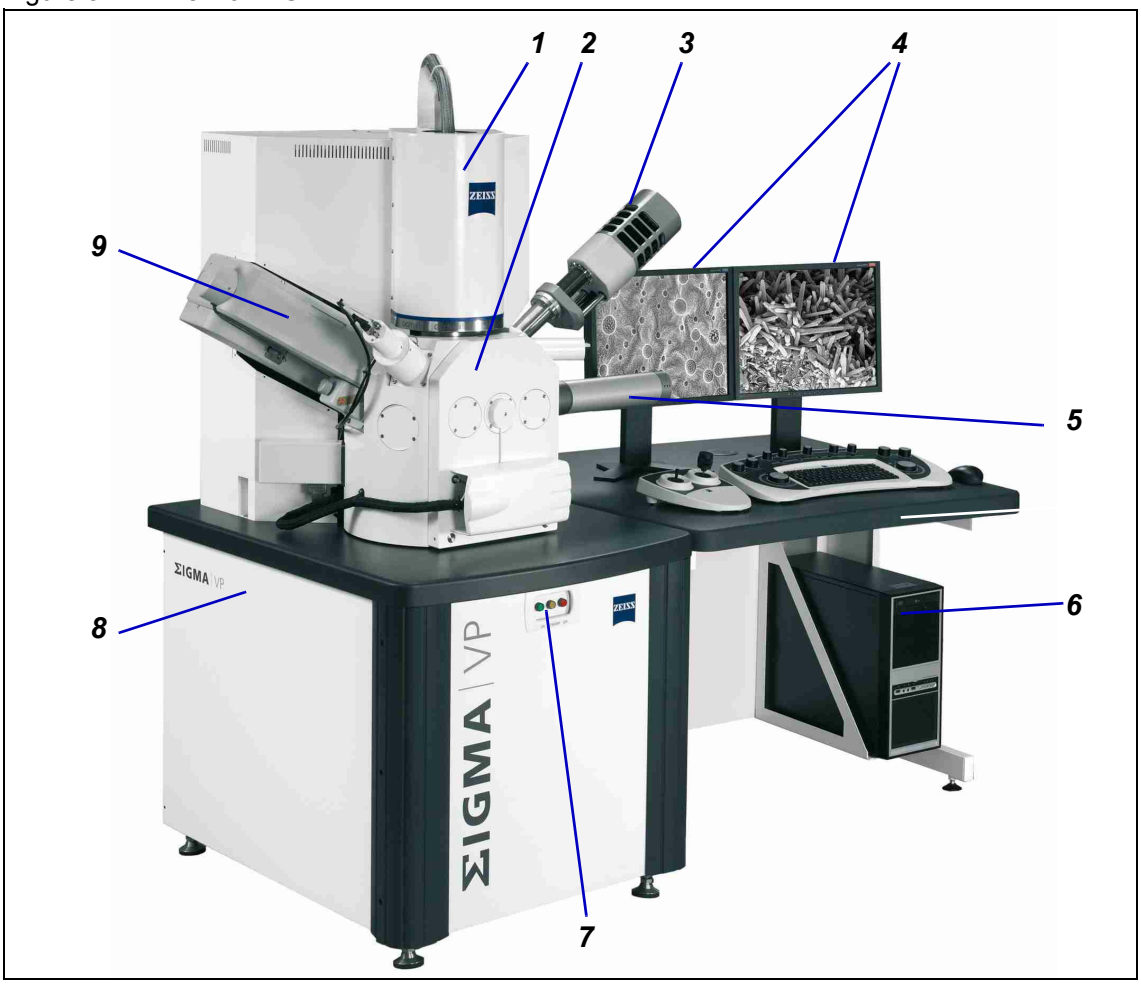
There are more safety labels under the cover panels of the FESEM. These labels are to provide information to authorised Carl Zeiss service engineers. These safety labels are described in the documents for Carl Zeiss service engineers.

2.4.3 Material Safety Data Sheets

Material safety data sheets (MSDS) of chemicals used in combination with the FESEM are contained in the document folder delivered with the FESEM.

3 Overview of the system

Figure 3.1 View of ΣIGMA™



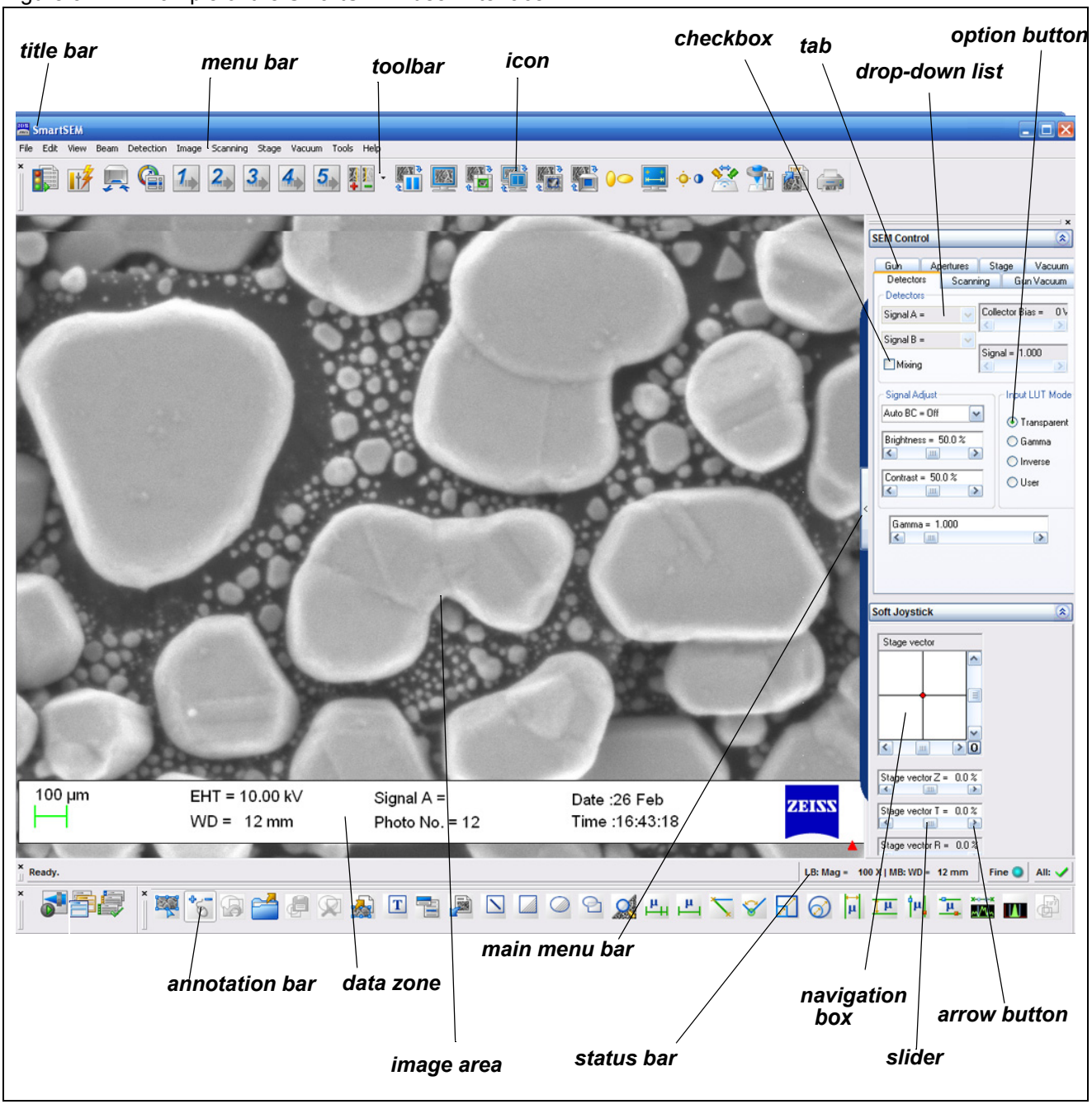
1. Electron optical column, Gemini® column
2. Specimen chamber
3. EDS detector (optional)
4. Monitors (2nd monitor optional)
5. EBSD (optional)
6. Personal computer (PC)
7. ON/STANDBY/OFF button
8. Plinth
9. WDX (optional)

3.1 Control elements

3.1.1 SmartSEM® user interface

The FESEM is controlled by the SmartSEM® software. The software is operated through a graphical user interface. Figure 3.2 shows an example of the SmartSEM® graphical user interface.

Figure 3.2 Example of the SmartSEM® user interface



3.1.2 Dual joystick option

The optional dual joystick is used for stage control and specimen navigation.

Joystick controls

There are two joystick controls on the dual joystick panel.

The large joystick on the right controls movement of the specimen stage in the X and Y axes. It also rotates the specimen stage.

- Move the joystick to the left or right to move the specimen stage in the X axis.
- Move the joystick forwards or backwards to move the specimen stage in the Y axis.
- Turn the knob at the top of the joystick clockwise or counterclockwise to rotate the specimen stage.

The small joystick on the left controls movement of the specimen stage in the Z axis. It also tilts the specimen stage.

- Move the joystick forwards or backwards to move the specimen stage in the Z axis (up or down) to change the working distance of the specimen.
- Move the joystick to the left or right to tilt the specimen stage.

The dual joystick panel has a ‘Break’ button at the top of the right-hand joystick. You can press this button in an emergency to stop all movements of the specimen stage. This is a safety feature.

Axis movement

All axes are **deflection compensated**: Small movements of the joysticks cause slow movements of the specimen stage. Large movements of the joysticks cause faster movements of the specimen stage.

The X, Y and Z axes are **magnification compensated**: When working at a low magnification, movements of the specimen stage in the X, Y and Z axes are relatively fast. When working at high magnification, movements of the specimen stage in the X, Y and Z axes are slower.

Deflection compensation and magnification compensation give better control of the specimen stage, and allow you to navigate the specimen with greater accuracy.

You can combine joystick movements to move the specimen stage in the different axes simultaneously.

3.1.3 Optional control panel

The control panel is an option available for use with the ΣIGMA™ FESEM. It has a full-sized keyboard and allows direct access to 14 of the most frequently used functions on the FESEM.

The following functions are available through the optional control panel:

Encoders

- Magnification
- Stigmator X
- Stigmator Y
- Aperture X
- Aperture Y
- Scan Rotate
- Shift X
- Shift Y
- Brightness
- Contrast
- Focus

Push buttons

- Reduced
- Wobble
- Freeze
- Exchange
- Resume
- Camera
- Scan Speed +
- Scan Speed –

Figure 3.3 Optional control panel

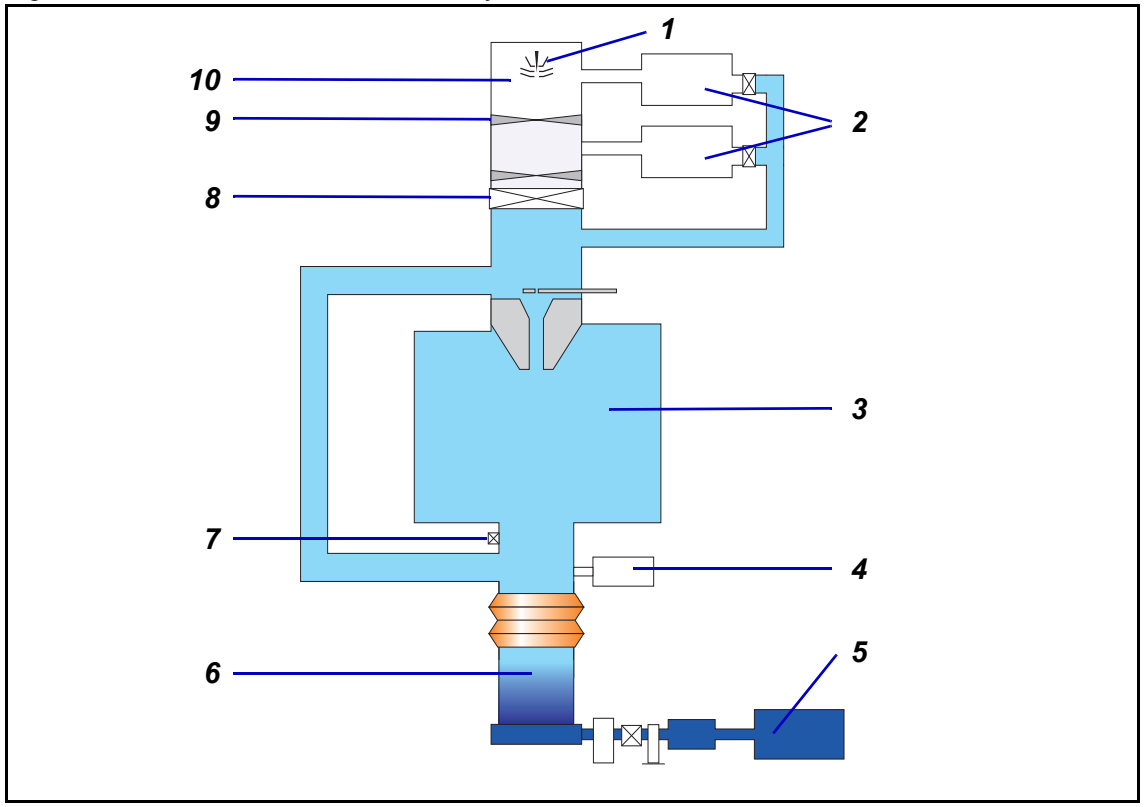
3.2 Principle of operation

The FESEM uses a focused beam of electrons to generate an image or to analyse the specimen. The focused electron beam scans the surface of the specimen.

3.2.1 Vacuum system

For operation of the FESEM, the gun head (***10***), the column and the specimen chamber have to be evacuated. The vacuum is essential to operate the gun and to prevent collision of electrons with gas molecules.

Figure 3.4 Schematic of the vacuum system



1. Gun with filament
2. Ion getter pump (IGP)[a]
3. Specimen chamber
4. Penning gauge
5. Pre-vacuum pump
6. Turbo pump
7. Vent valve
8. Column chamber valve
9. Multi-hole aperture
10. Gun head

a. Note that an HV system has one ion getter pump; a VP system has two ion getter pumps, as shown here.

System vacuum

The pre-vacuum pump (**5**) and the turbo pump (**6**) evacuate the specimen chamber.

The vacuum in the specimen chamber is measured by a Penning gauge (**4**). The detected vacuum values are shown as '*System vacuum*' in the SmartSEM® user interface.

While the detected pressure in the specimen chamber is not ready for operation, the column chamber valve (**8**) remains closed to separate the specimen chamber from the column.

Gun vacuum

In the gun head there is an ultra-high vacuum, which is maintained by either one or two ion getter pumps (**2**). An HV system has one ion getter pump; a VP system has two ion getter pumps.The vacuum in the gun head is called the '*Gun vacuum*'. It should be less than 1×10^{-8} mbar.

Specimen chamber

The specimen is located in the evacuated specimen chamber (**3**).To change the specimen you must break the vacuum in a carefully controlled manner to open the specimen chamber. To do this you must give the **Vent** command from the SmartSEM® user interface.

If you are using the optional control panel, then you can press the **Exchange** button on the control panel to give the **Vent** command instead.

Ventilating

After you give the **Vent** command, the column chamber valve closes and nitrogen gas flows into the specimen chamber through the vent valve (**7**). As soon as the pressure inside the chamber rises to atmospheric pressure, you can open the chamber door to change the specimen.

Evacuating

To continue operation after specimen change, the **Pump** command causes the pre-pump and the turbo pump to evacuate the specimen chamber.

When the vacuum in the specimen chamber is ready for operation, the column chamber valve opens and the '*EHT Vac ready*' message is displayed in the SmartSEM® user interface. After this occurs, you can switch on the gun and the EHT.

Quiet Mode

The **Quiet Mode** option is available as part of the vacuum system. This option consists of a vacuum accumulator and a valve located between the pre-vacuum pump and the turbo pump.

When the pre-vacuum pump has evacuated the vacuum accumulator to the vacuum threshold, the valve between the pre-vacuum pump and the accumulator closes and the pre-vacuum pump stops. The vacuum accumulator maintains the vacuum threshold for the turbo pump.

When the vacuum in the accumulator degrades sufficiently, the pre-vacuum pump starts, the valve opens and the vacuum threshold is restored.

3.2.2 Specimen stage

The standard specimen stage is a 5-axis motorised Cartesian stage that is controlled by the SmartSEM® software. The stage can be operated by the dual joystick controller, or by using the soft joystick in the SmartSEM® user interface.

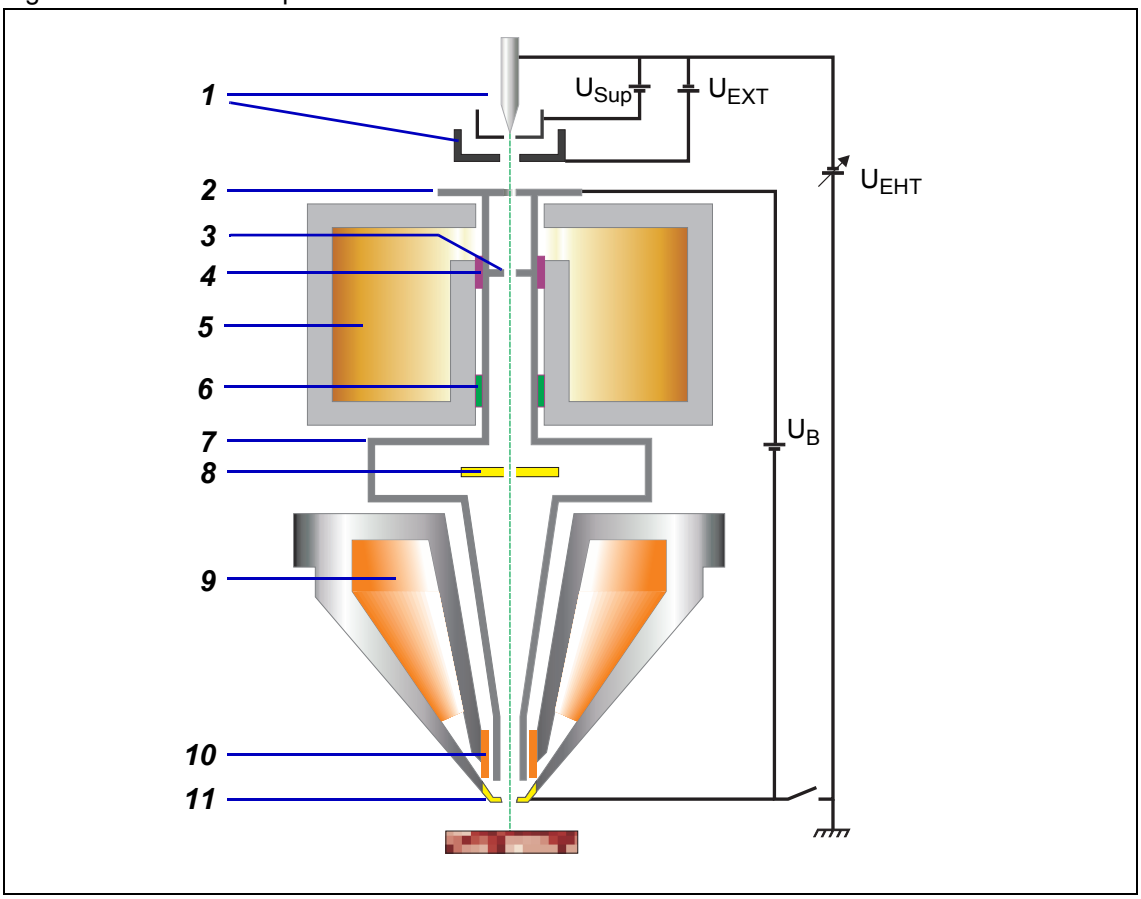
The five axes are as follows:

- X X-axis (left - right movement
- Y Y-axis (forward - backward movement)
- Z Height
- R Rotation
- T Tilt

3.2.3 Electron optics

The Gemini® column is the area of the FESEM where electrons are emitted, accelerated, bundled, focused, and deflected. The main characteristics of the Gemini® optics are the beam booster and an objective lens that consists of combined electrostatic and electromagnetic lenses. Figure 3.5 shows a simplified diagram of the electron optics.

Figure 3.5 Electron optics



1. Schottky field emitter
2. Anode
3. Multi-hole aperture
4. Gun /aperture alignment system
5. Condenser lens
6. Stigmator
7. Liner tube
8. In-lens detector
9. Objective lens / Electromagnetic lens
10. Scan coils and stigmator
11. Objective cap

Schottky emitter

The Schottky field emitter (**1**) emits electrons.

The electrons are accelerated by the acceleration voltage (U_{EHT}), for example 10 kV, that is applied to the Schottky field emitter (**1**). The beam of electrons passes through the anode aperture.

Beam booster

The anode and the liner tube (**6**) are connected mechanically and electrically, to form the **beam booster**.

A booster voltage (U_B) of +8 kV is applied to the beam booster, so that a high beam energy is maintained throughout the entire column. The beam booster technique has two main advantages:

- It minimizes beam widening that might occur due to stochastic interactions between electrons. Consequently there is almost no loss in beam brightness, even at low acceleration voltages.
- The beam booster technique provides better protection against external stray fields.

The function of the beam booster depends on the acceleration voltage (U_{EHT}).

- At acceleration voltages below 20 kV, the liner tube / beam booster is connected to +8 kV.
- At acceleration voltages above 20 kV, the liner tube / beam booster is connected to ground.

Because of the danger of arcing, the beam booster function is **not** available in variable pressure (VP) mode.

Multi-hole aperture

The electron beam passes through the multi-hole aperture (**5**).

The standard aperture is the 30 µm hole (the central aperture). Other aperture sizes can be selected by using the gun / aperture alignment system.

A stigmator compensates for astigmatism in the beam, to make sure the beam is rotationally symmetrical.

Table 1 Column aperture configurations

Column configuration	Size of anode aperture	Probe current	Multi-hole aperture configuration
20 nA (standard)	40 µm	10 pA to 20 nA	30, 7.5, 10, 15, 20, 60, 120 (7-hole)
20 nA (standard)	40 µm	10 pA to 20 nA	30, 7.5, 10, 20, 60, 120 (6-hole)
40 nA (option)	90 µm	10 pA to 40 nA	30, 10, 20, 60, 120, 240 (6-hole)
100 nA (option)	110 µm	10 pA to 100 nA	30, 10, 20, 60, 120, 240 (6-hole)

Objective lens

The objective lens focuses the electron beam onto the specimen. The objective lens consists of an electromagnetic lens (**8**) and an electrostatic lens (**10**), which reduce spherical and chromatic aberrations, especially at low acceleration voltages. The electromagnetic lens is water cooled.

The deflection system consists of a set of scan coils (**9**) that move the electron beam in a point-to-point scan across the specimen. The scan coils deflect the beam in the X and Y directions relative to the electron-optical axis.

At the lower end of the objective lens, the electrons are decelerated to the original acceleration voltage (for example, 10 kV), by subtracting 8 kV.

3.2.4 Signal detection

Imaging in scanning electron microscopes depends most frequently on the detection of secondary electrons (SEs) and backscatter electrons (BSEs). Refer to Chapter 4 for details.

Table 2 Standard detector applications

Standard detectors	Detected signals	Typical application
In-lens detector (annular SE detector)	SE	Surface structure
ET-SE detector (Everhart-Thornley type)	SE2	Topography and surface structure
VPSE G3 detector	SE	On VP systems only

Table 3 Optional detector applications

Optional detectors	Detected signals	Typical application
Backscattered electron detectors, including **4-quadrant CZBSD**, and **5-segment CZBSD** Angle-selected backscattered (AsB®) detector, integrated	BSE	Topographical (crystal orientation), compositional contrast
Angle-selective backscattered (AsB®) detector, integrated	BSE	Topographical (crystal orientation), compositional contrast
Cathodoluminescence (CL) detector	Light photons	Mineralogy
Scanning Transmission Electron Microscopy (STEM) detector	Trans-mission electrons	Transmission imaging of thin sections in biological and mineralogical exami-nations
Specimen current detector	Absorbed electrons	Electron beam induced current (EBIC)

3.3 Specification

Table 4 Specimen chamber and stage specification

Specimen chamber and stage		
Specimen chamber	Dimensions	330 mm inner diameter 270 mm height
Specimen stage	Type (standard)	5-axis motorised Cartesian, controlled through SmartSEM® software. Other stage types are available as options.
	Specimen weight	Up to 0.5 kg tilted; up to 2 kg not-tilted
	Movement	X/Y = 125 mm Z = 50 mm T = –10° to +90° R = 360° continuous

Table 5 Detector specification

Detectors	
In-lens detector	High-efficiency annular scintillator detector mounted in Gemini® column with optically-coupled photomultiplier.
Chamber detectors:	
•Chamberscope	• CCD-camera with infrared illumination. One is fitted as standard.
•CZBSD	• 4-quadrant or 5-segment BSE detector. The diode channels are controlled independently through a dedicated menu in the SmartSEM® user interface allowing the user to define the topographical and compositional response of the detector.
•STEM	• Scanning transmission electron microscope detector
•VPSE G3[a]	• Variable pressure secondary electron detector (VP systems only)
•CL	• Cathodoluminescence detector
•AsB® detector	• 10 mm² four-channel or five-channel solid-state BSD diode integrated in the Gemini® objective lens for the detection of backscattered electrons.
•ET-SE detector	• Everhart-Thornley detector with optically-coupled photomultiplier.

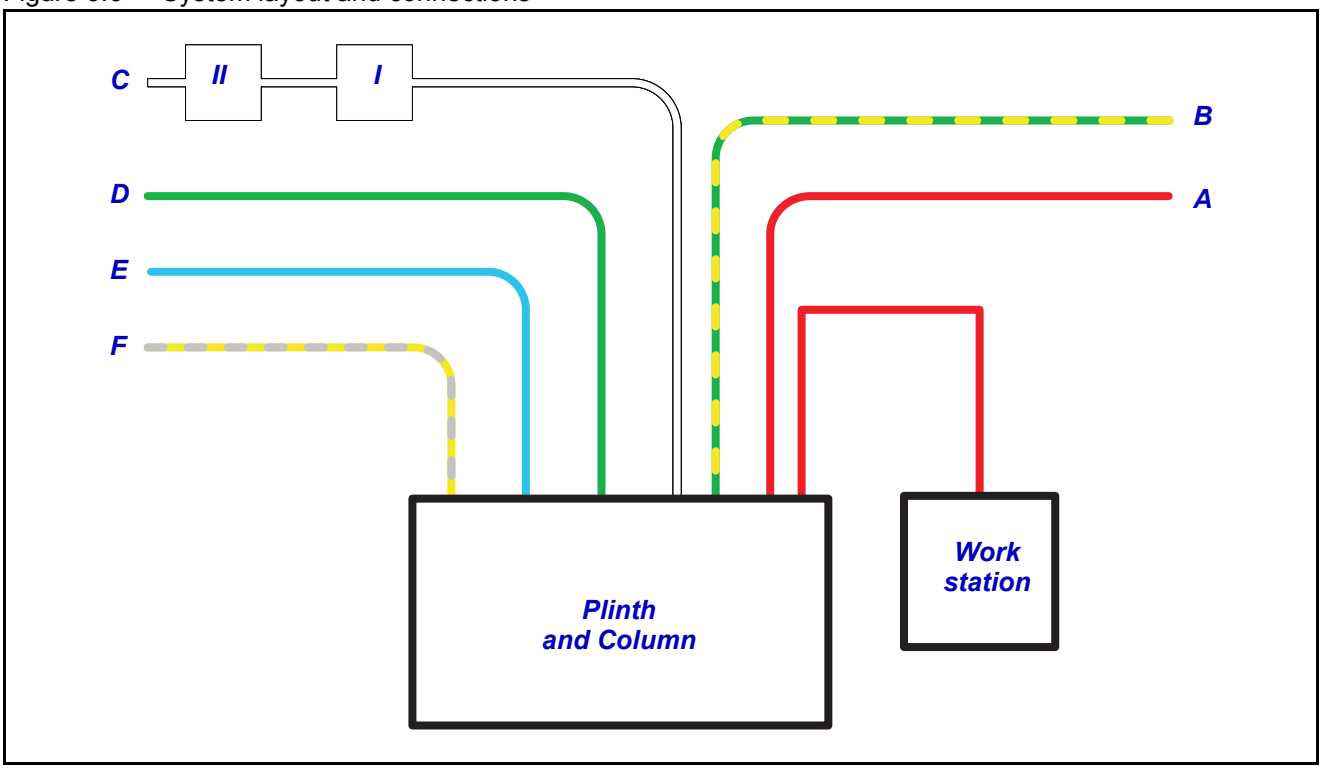
a. The VPSE G3 detector is standard on the VP system.

Note:
For more details refer to the document Product Specification* ΣIGMA™*.

3.4 Technical data

3.4.1 Layout and connections

Figure 3.6 System layout and connections



I	Static vibration damper	A	Mains power supply 208 to 230 V / 25A
II	Pre-vacuum pump	B	Equipotential bonding bar
		C	Vacuum exhaust
		D	Chilled water supply
		E	Dry compressed air supply
		F	Dry nitrogen supply

Table 6 Dimensions and weights

No	Description	Size (mm) approx.	Weight (kg) approx.	Distribution of load (kg)	Foot prints
1	Plinth + column	822 × 980 × 1757	870	4 × 222.5	4 × Ø 80 mm
2	Workstation (Table + PC)	1153 × 980 × 1350	97	4 × 24.3	4 × Ø 50 mm
4	Static damping block	180 × 180 × 160	36.6	1 × 36.6	180 mm × 180 mm
5	Quiet mode option	-	-	-	-
6	Pre-vacuum pump	430 × 250 × 290	24.5	1 × 24.5	200 mm × 180 mm

3.5 Options and accessories

A range of options and accessories is available for use with the ΣIGMA™ FESEM. Examples of the available options and accessories are as follows:

- Detectors – BSD, AsB, VPSE, CL, STEM, SCD
- Additional Chamberscope or Stubscope
- Sample holders and stage accessories, including Coolstage, Right-hand tilt, Faraday cup
- Software add-ins and enhancements
- Column maintenance kit, O-ring kit

For full details of the available options and accessories, please contact your local Carl Zeiss NTS Ltd service engineer or sales representative.

3.6 Customer service

For customer service please contact your local Carl Zeiss NTS Ltd service engineer.

A list of Carl Zeiss NTS Ltd locations and authorised service partners can be found at:

http://www.smt.zeiss.com/nts

IMPORTANT:
To maintain the best possible performance of the FESEM it is essential to perform regular preventive maintenance.

It is also recommended that you enter a service contract with your local Carl Zeiss service organisation or representative. This will help to ensure continuous trouble-free operation of the FESEM.

4 Detectors

This chapter describes the generation of secondary and backscattered electrons, and describes how the detector types that are available for use with the ΣIGMA™ use these electrons to provide imaging, topographical and other information. It also lists some characteristics of each detector type.

For more information about any of the detectors, contact Carl Zeiss NTS Ltd.

4.1 Principles of detection

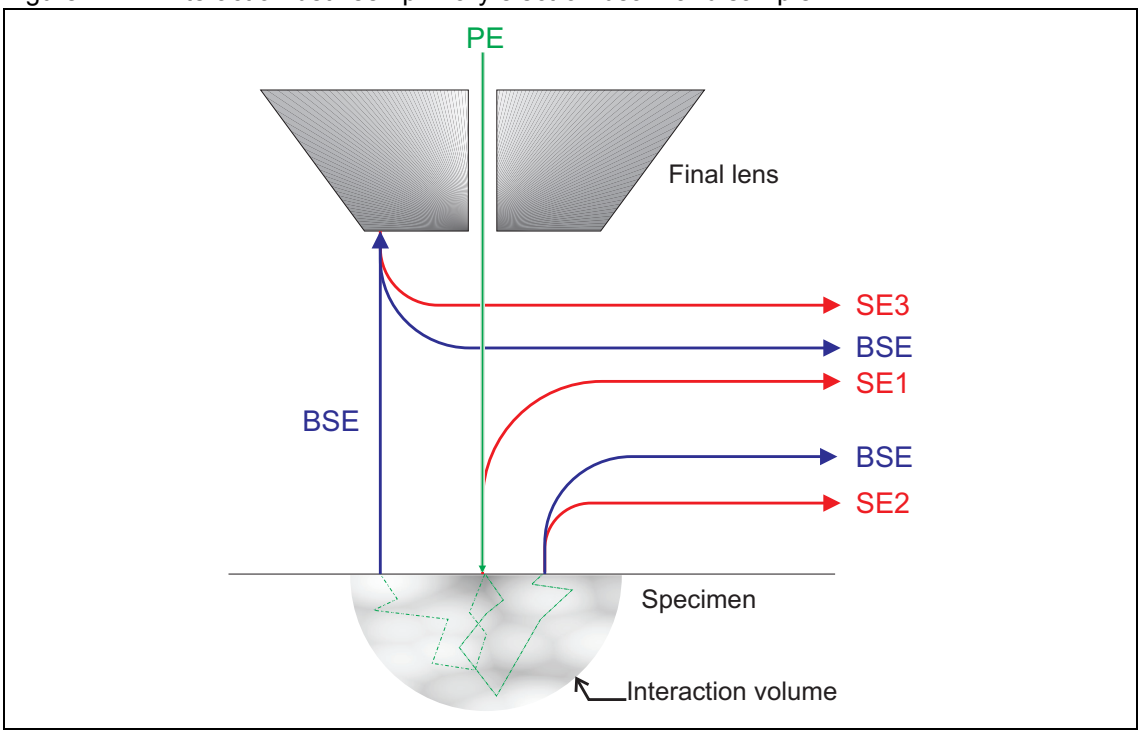
When a primary electron (PE) beam hits a sample, certain electron beam interaction processes occur. Secondary electrons (SEs) and backscattered electrons (BSEs) are then generated.

Specific types of detectors are able to detect the SEs and BSEs, and the detector signals can be used to create images and produce information about the properties of the sample.

Secondary electrons

Secondary electrons are ejected from the outer atomic shell of the sample material upon impact by the primary electron beam. Figure 4.7 shows a simplified example of the generation of secondary electrons.

Figure 4.7 Interaction between primary electron beam and sample



The three main categories of secondary electrons are shown in Figure 4.7. These categories are based on the origin of the secondary electrons and on the distance from the PE impact point, where they leave the sample.

- SE1 electrons are generated and leave the surface of the specimen directly at the spot where the primary electron beam impacts on the specimen surface.
- SE2 electrons are generated after multiple scattering inside the interaction volume, and leave the sample at a greater distance from the primary beam's impact point.
- SE3 electrons are generated by backscattered electrons colliding with the chamber walls or the lens system.

Secondary electrons have low energy (less than 50 eV).

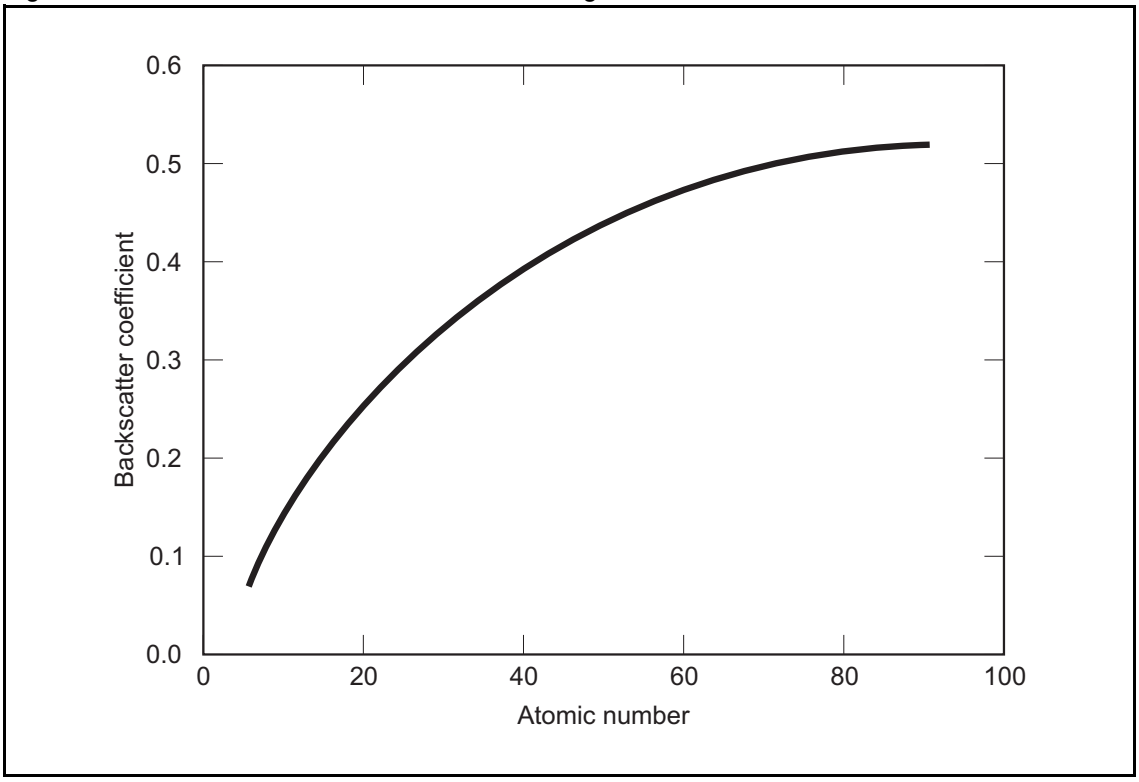
Backscatter electrons

All electrons with energy higher than 50 eV are known as backscattered electrons (BSEs).

BSEs are generated by elastic scattering in a much deeper range of the interaction volume and carry depth information.

As shown by Figure 4.8, the backscatter coefficient increases with increasing atomic number of the elements within the specimen. This allows the BSE detector to generate atomic number contrast, or compositional contrast images.

Figure 4.8 Backscattered electron coefficient against atomic number



4.2 In-lens detector

4.2.1 Application conditions

- Acceleration voltage 100 V to 20 kV
- Working distance Less than 10 mm
- Vacuum mode High vacuum

4.2.2 Description

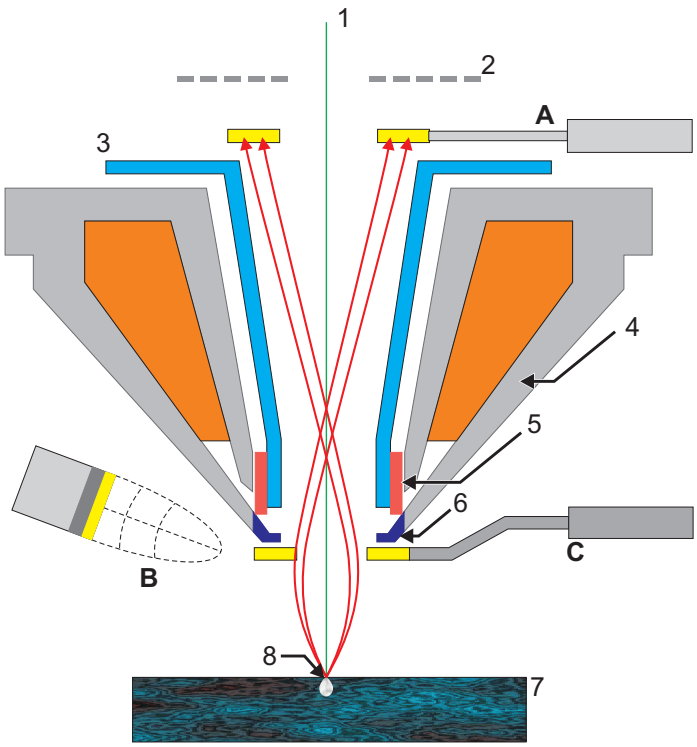
Interaction between the primary electron beam and the specimen generates a large number of SEs.

To map the actual surface of a sample, secondary electrons of type SE1 should be detected, because these are the only electrons generated at or near the primary beam's impact point. Also, only these secondary electrons are generated near the upper region of the interaction volume and therefore only they provide direct information on the sample's surface.

SE1 electrons can be detected very efficiently by the In-lens detector. This is because the In-lens detector is located in the beam path and is combined with the electrostatic/electromagnetic lens.

The detector is located above the objective lens and detects directly in the primary electron beam's path. Figure 4.9 shows the location of the In-lens and other detectors.

Figure 4.9 In-lens detector



1. Primary electron (PE) beam
2. Filtering grid
3. Beam booster
4. Magnetic lens
5. Scan coils
6. Electrostatic lens
7. Sample
8. Interaction volume

A. In-lens detector

B. ET-SE detector

C. CZBSD

Secondary electron paths

At an acceleration voltage of 20 kV, the electrons of the primary electron beam (**1**) are given additional acceleration by 8 kV applied to the beam booster (**3**).

To make sure the electrons arrive at the surface of the sample with the original energy set by the acceleration voltage, an electrostatic field is generated by the electrostatic lens (**6**), which decelerates the primary electrons by 8 kV.

This electrostatic field acts as an acceleration field on the secondary emission electrons generated on the surface of the sample. The SE electrons are absorbed, re-accelerated and focused through the electro-magnetic field to the In-lens detector, where they hit a scintillator and generate photons of light. These photons of light are guided out of the beam path through a light-guide, and are transferred to a photomultiplier.

The photomultiplier multiplies the photons and outputs a signal that the FESEM can use to generate an image.

4.2.2.1 Detector efficiency and working distance

Note:
The In-lens detector can be used as described with acceleration voltages up to 20 kV. At higher acceleration voltages, the beam booster and therefore the field of the electrostatic lens are switched off. This means that the low-energy secondary electrons are no longer deflected and re-accelerated, and the efficiency of the In-lens detector is reduced significantly.

The efficiency of the In-lens detector depends mainly on the electric field created by the electrostatic lens. The intensity of this electrostatic field decreases exponentially with distance. For this reason, the working distance is one of the most important factors that determine the signal-to-noise ratio and therefore the efficiency of the detector.

Depending on the geometry of the specimen and the acceleration voltage in use, reasonable working distances should be selected for different imaging applications.

- The working distance should be as low as possible when using acceleration voltages in the range 1 kV to 5 kV.
- When working at very low interaction energies (in the range of 100 V to 1 kV), the working distance should not be greater than 4 mm, and it is often reasonable to set the working distance to 2 mm. This will allow the SE1 electrons to be efficiently attracted by the 8 kV voltage from the beam booster towards the In-lens detector.

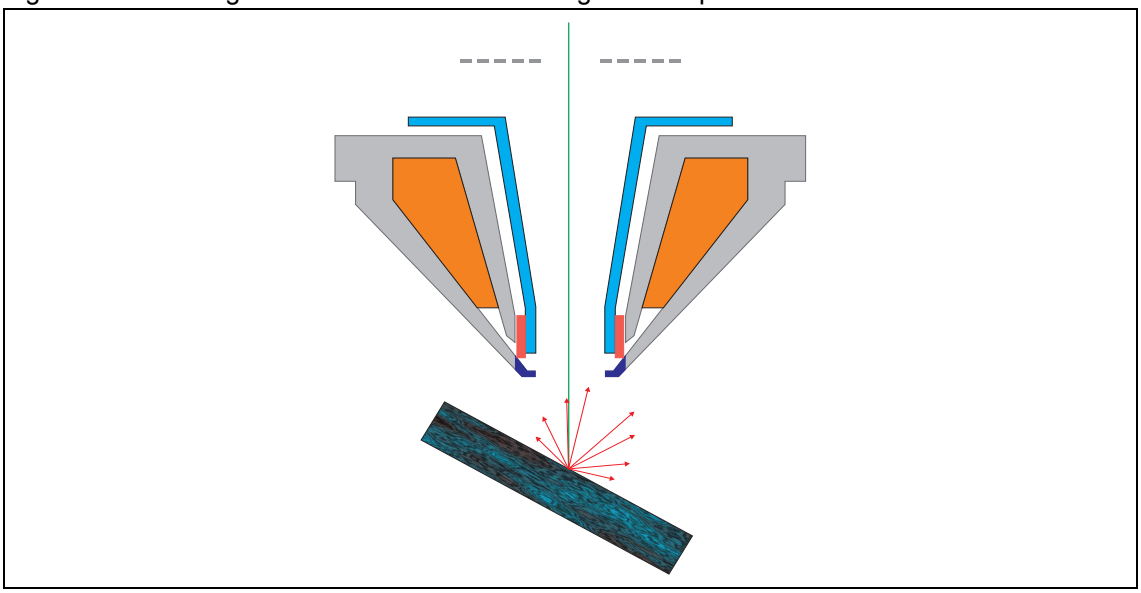
Tilted specimen

The signal from the In-lens detector can also be affected by the direction of the specimen's surface. Large angles of specimen tilt affect the emission angle of the secondary electrons, and fewer electrons are emitted in the direction of the final lens. This again reduces the detection efficiency. Refer to Figure 4.10.

Large angles of specimen tilt also prevent the use of very short working distances.

It is therefore recommended to avoid using large angles of tilt when using the In-lens detector.

Figure 4.10 Changed SE distribution when using a tilted specimen

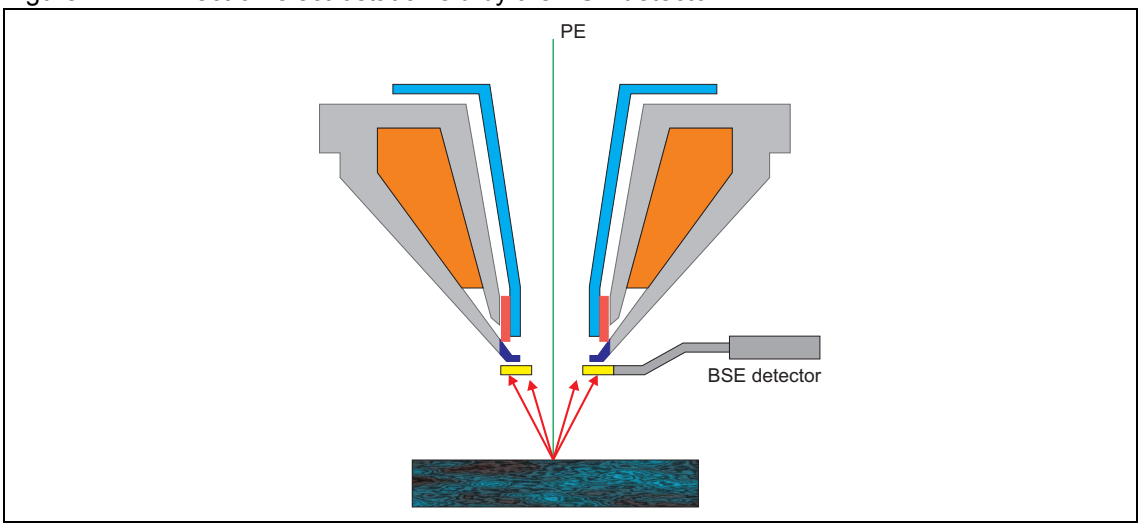


Effect of BSE detector

As shown in Figure 4.11, the location for the BSE detector is directly below the objective lens. The BSE detector may therefore influence the electrostatic field of the objective lens and affect the efficiency of the In-lens detector.

The presence of a BSE detector might also prevent imaging at very short working distances, which also reduces the efficiency of the In-lens detector (this applies only to CZBSD retractable detectors).

Figure 4.11 Effect on electrostatic field by the BSE detector



When using only the In-lens detector for imaging, it is recommended to move the CZBSD to its parking position in order to reduce the working distance and to increase the efficiency of the In-lens detector.

4.2.2.2 Benefits of the In-lens detector

The main benefit of using an In-lens detector is its high detection efficiency, particularly at very low acceleration voltages, and the almost pure detection of secondary emission electrons.

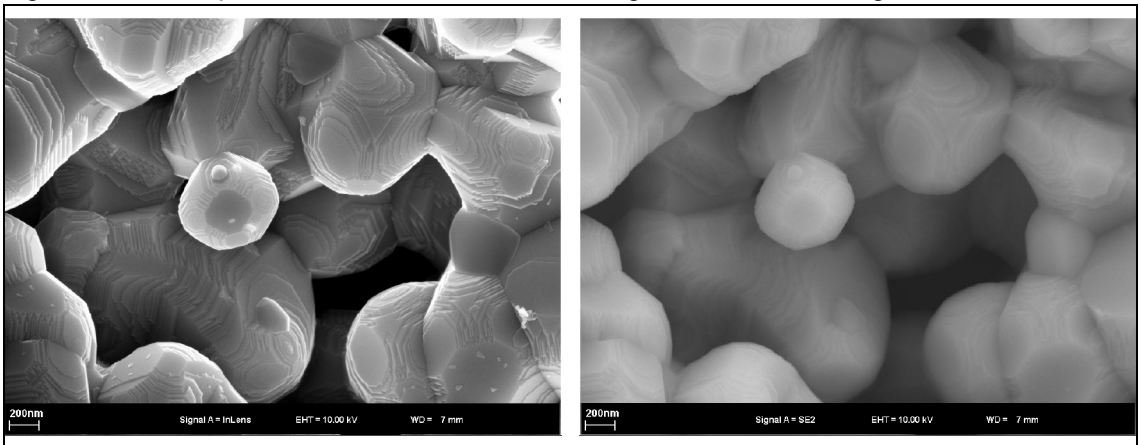
It provides an ideal tool to map the surface of a sample. Even at high acceleration voltages, images produced using the information from an In-lens detector include more surface information than would be possible to obtain using the ET-SE detector. This is because of the pure SE detection capability of the In-lens detector.

Surface detail

The signal from the In-lens detector is generated almost entirely through detection of the SE1 and SE2 electrons. The In-lens detector images do not include any signals generated by backscattered electrons or SE3 electrons. See the examples in Figure 4.12:

- At an acceleration voltage of 10 kV, the example image produced by the In-lens detector shows great surface detail.
- The image generated by the ET-SE detector shows less surface structure due to the contribution from SE3 electrons from the bulk of the specimen (lower layers of the specimen). BSE electrons also contribute to the whole signal.

Figure 4.12 Comparison of surface information at high acceleration voltages



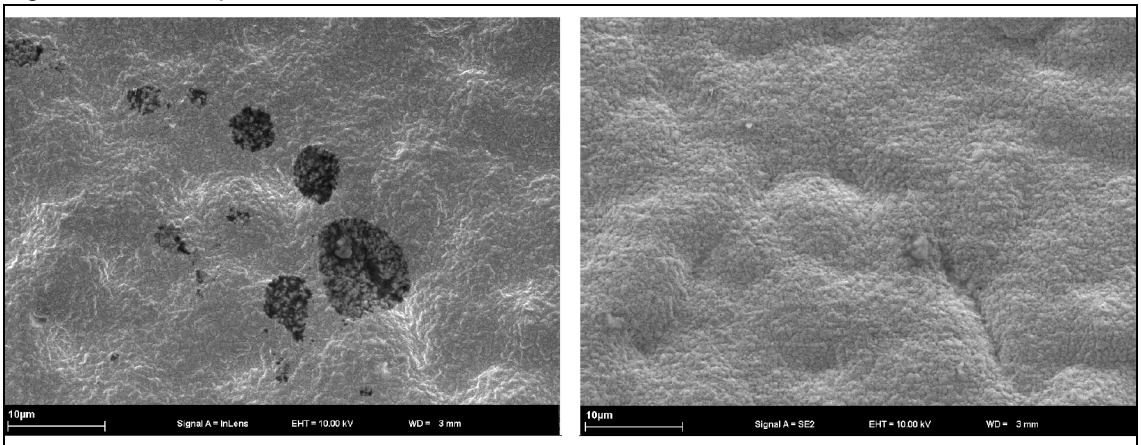
In-lens detector
Clear edge effect with good imaging of the surface structures

ET-SE detector
Little surface information

Thin layers on the specimen surface may not always be visible in an ET-SE detector image due to the larger electron beam-specimen interaction volume. See the examples in Figure 4.13:

- At an acceleration voltage of 10 kV, contamination on a metal-coated layer can clearly be seen in the image from the In-lens detector.
- The ET-SE detector image, taken from the same spot on the specimen surface, does not reveal any information with regards to the contamination.

Figure 4.13 Comparison of surface information with contamination



In-lens detector
Imaging of thin layers
on the specimen's surface

ET-SE detector
Layers are not imaged

Acceleration voltage effects

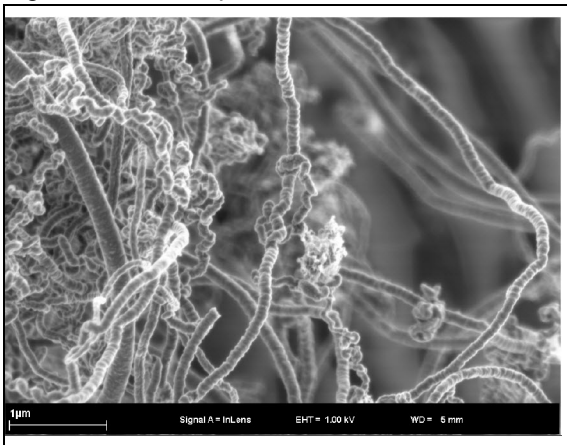
The In-lens detector is frequently used at lower acceleration voltages. When the primary electrons carry lower energy, their interaction volume is smaller and their depth of penetration is less. The SE1 electrons generated in the upper layers of the specimen reveal more specimen surface details.

Figure 4.14 shows images from specimens that have a very low atomic number, imaged at 1 kV and 5 kV:

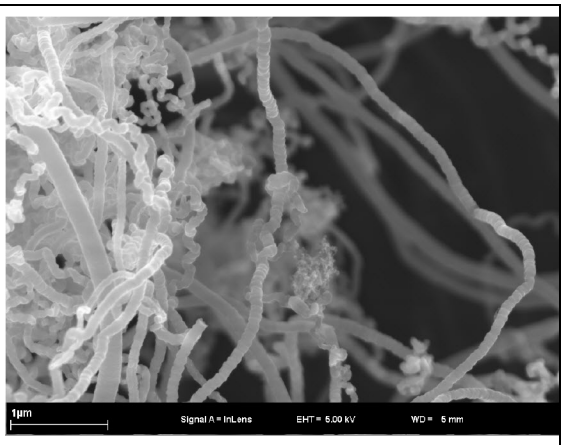
- The 1 kV image shows dark regions (contamination) on the surface due to the generation of electrons from the upper layers of the specimen.
- In contrast, the dark layers (shown in the In-lens detector image) appear transparent when increasing the acceleration voltage to 5 kV.

The depth penetration of the primary beam electrons increases by increasing the acceleration voltage and more information from the bulk of the material can be revealed. See the examples in Figure 4.15.

Figure 4.14 Comparison of surface information at 1 kV and 5 kV – low atomic number



1 kV acceleration voltage
Good surface imaging



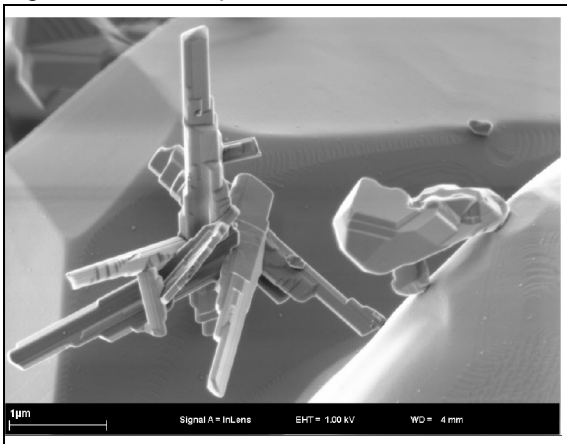
5 kV acceleration voltage
Transparent surface due to increased penetration depth

Figure 4.15 compares two images created at different acceleration voltages on a specimen that has a high atomic number.

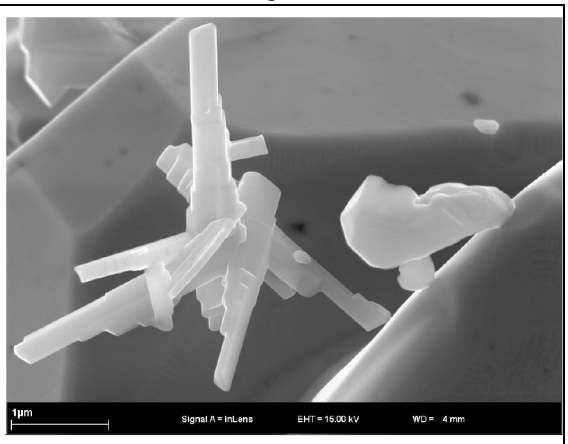
- The 1 kV image reveals fine surface structure of the specimen.
- The 15 kV image, however, seems to be transparent and the fine surface structures cannot easily be detected. Additional features appear in the background of the image that are not visible at 1 kV (signals arising from the lower layers of the specimen).

  Also, some structures appear in the background of the crystal that do not exist on the surface of the specimen. These structures come from inside the specimen.

Figure 4.15 Comparison of surface information at 1 kV and 15 kV – high atomic number



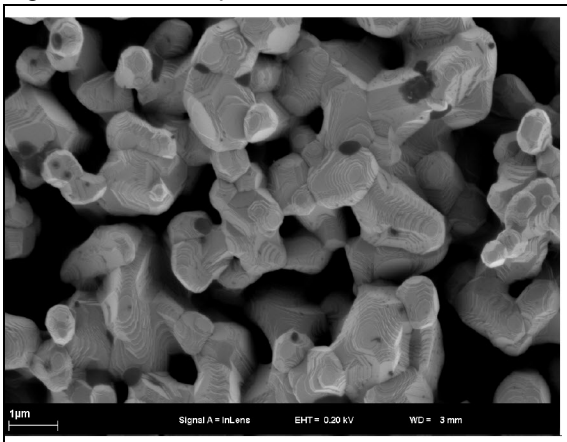
1 kV acceleration voltage
Good surface-sensitive imaging



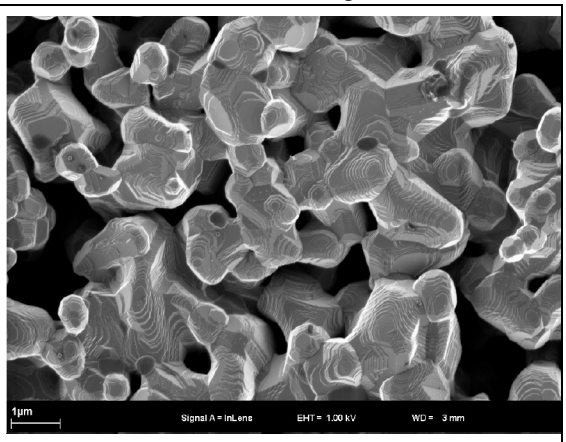
15 kV acceleration voltage
Transparent surface due to increased penetration depth

Figure 4.16 shows example images using an In-lens detector at a range of different acceleration voltages.

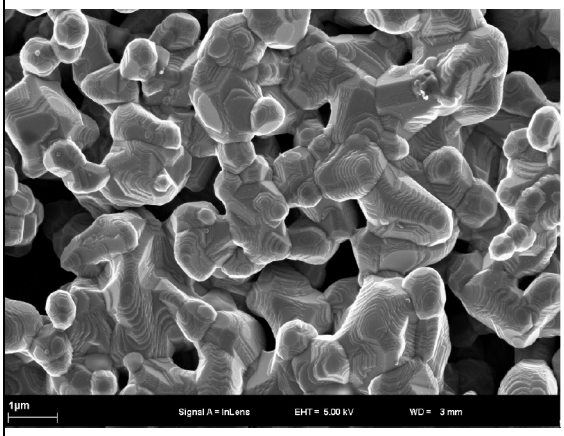
Figure 4.16 Comparison of surface information at different acceleration voltages



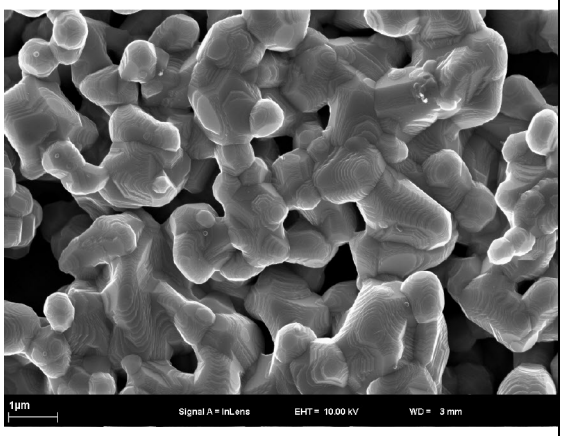
0.2 kV acceleration voltage
Homogenous illumination,
mapping of actual surface



1 kV acceleration voltage
Increasing edge effect



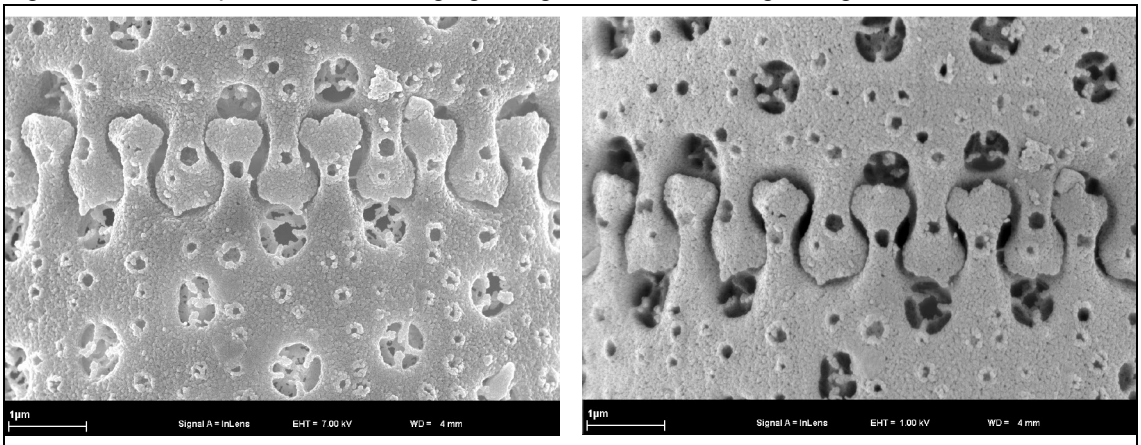
5 kV acceleration voltage
Increasing edge effect,
reversed contrast of some structures



10 kV acceleration voltage
Transparent surface due to
increased penetration depth

Another reason to use low acceleration voltages is to minimise and compensate the local charging on the surface of the specimen. If electrons hit a non-conducting or a partially-conducting specimen, they accumulate on the surfaces and cannot discharge. Generated local charges affect the electron beam and can significantly reduce the image quality. It is, however, possible to reduce or compensate for this effect by reducing the primary energy of the electrons and reducing the probe current (Aperture Size). Figure 4.17 shows this effect.

Figure 4.17 Compensation for charging using lower accelerating voltage



7 kV acceleration voltage
Poor image quality due to charging effects

1 kV acceleration voltage
No charging effects

Figure 4.17 shows the surface of a diatom imaged at 7 kV and at 1 kV.

- When imaging at 7 kV, extreme edge effects are visible, and charging of surface structures causes a significant loss of information.
- The charging effects are reduced when imaging at 1 kV and this allows homogeneous illumination of the surface structures.

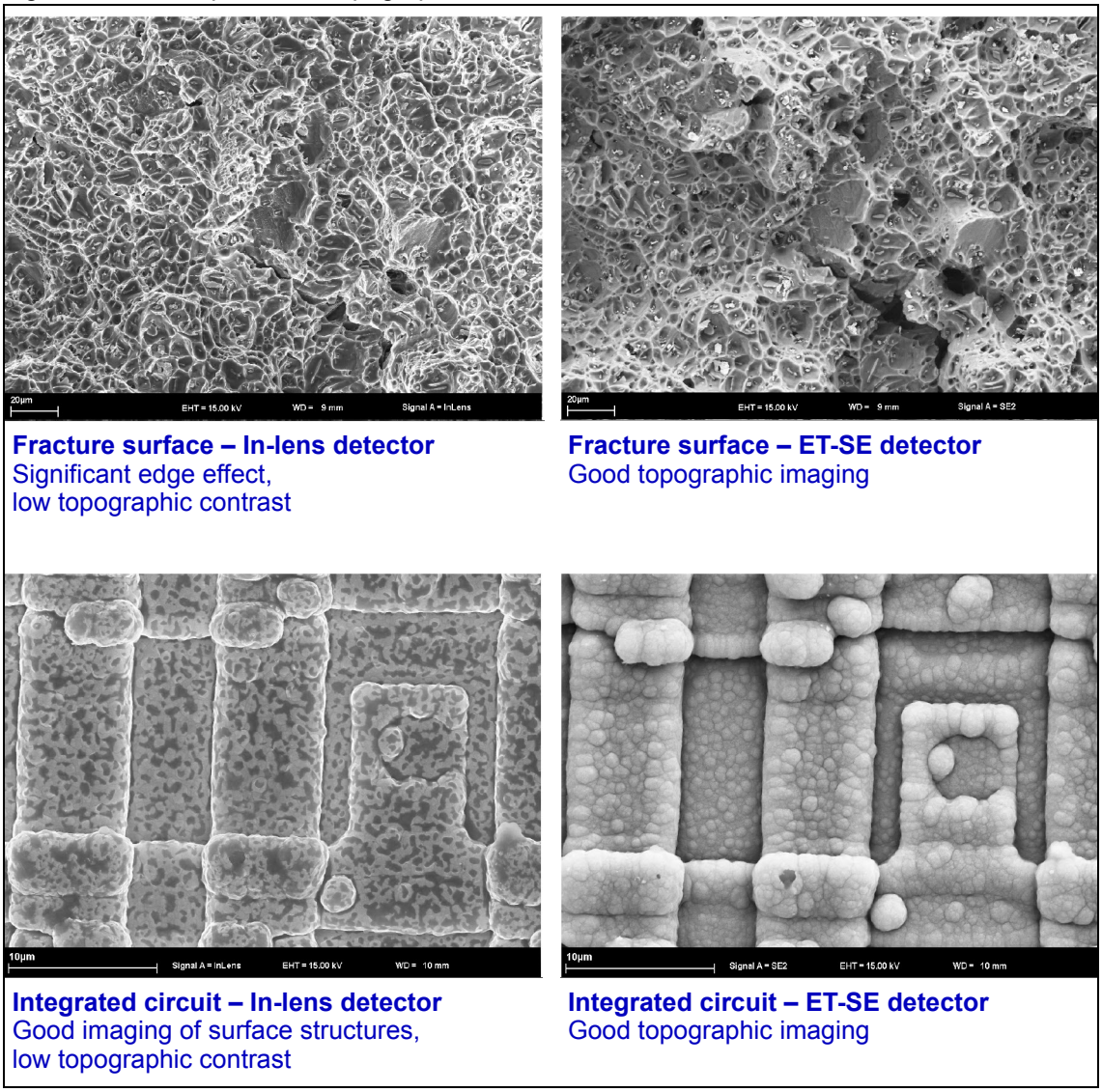
Topographic contrast

Because the In-lens detector views the specimen from directly above, images obtained by this detector seem to be ‘flat’. See the examples in Figure 4.18.

The image of the fracture surface taken with the In-lens detector shows a clear edge effect and provides good surface information. The topographic impression is, however, relatively poor. The image of the fracture surface taken with the ET-SE detector shows good topographic information. Generally, more signal can be obtained from surfaces that are tilted towards the detector.

The image of the integrated circuit (see Figure 4.18) taken at 15 kV with the In-lens detector seems to be relatively flat, but surface-specific information is detected. The ET-SE detector image, however, emphasizes the topography. The electrons penetrate deeper into the specimen material, and a large number of BSE electrons contribute to the image information.

Figure 4.18 Comparison of topographic contrast between In-lens and ET-SE detectors



Fracture surface – In-lens detector
Significant edge effect,
low topographic contrast

Fracture surface – ET-SE detector
Good topographic imaging

Integrated circuit – In-lens detector
Good imaging of surface structures,
low topographic contrast

Integrated circuit – ET-SE detector
Good topographic imaging

Applications

The In-lens detector is not always the appropriate detector for image navigation at low magnifications:

- It requires the use of a small working distance, which limits the smallest possible magnification.
- A small spot can appear in the centre of the image field at very low magnifications.

  Whether or not such a spot appears depends strongly on the geometry of the specimen; on the working distance; and on the selected acceleration voltage.

The ET-SE detector is most suitable for generating images with a large field-of-view for navigating on the specimen surface and for using long working distances.

Table 7 Summary of In-lens detector characteristics

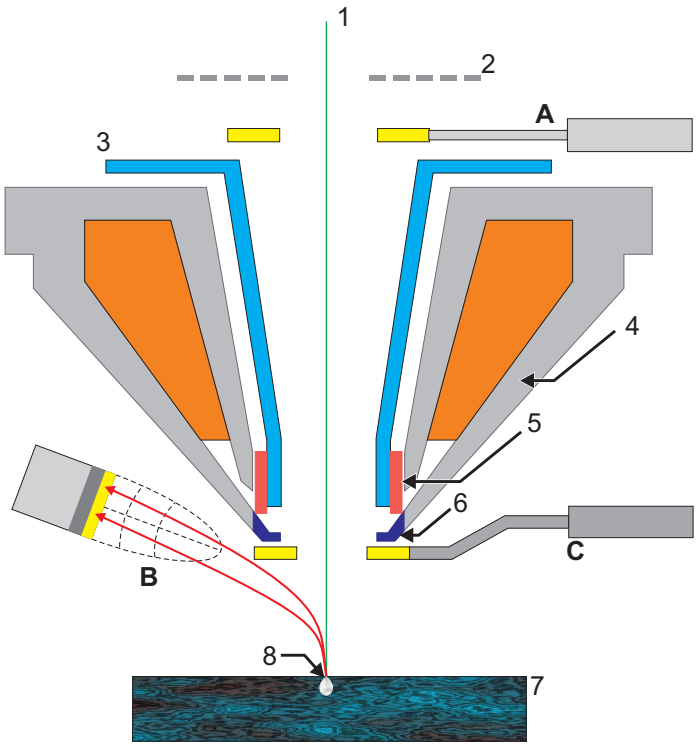
Parameter	Recommended conditions
Acceleration voltage 100 V to 20 kV 100 V to 3 kV 3 kV to 10 kV 10 kV to 20 kV	• Suitable up to 20 kV. At more than 20 kV the beam booster is switched off. • Low-voltage applications for the compensation of charges and for surface-sensitive imaging. • Average voltage range – suitable for many different applications. • Voltage range frequently used for analytical purposes.
Working distance Up to 10 mm 2 mm to 3 mm 3 mm to 6 mm	• Due to the dependence on the electrostatic field of the objective lens, the working distance should be as small as possible. • For low-voltage applications (100 V to 3 kV). • Useful for the average voltage range (3 kV to 10 kV)
Aperture 30 µm 7.5 µm to 20 µm 60 µm and 120 µm	• The standard aperture is recommended for many applications. • Limitation of the probe current for the compensation of charges, or for the analysis of beam-sensitive specimens. • Only recommended for analytical purposes.
Specimen tilt	• Avoid large angles of tilt, if possible.
Operation mode	• Only suitable in high vacuum, because the beam booster is switched off in the VP mode.

4.3 ET-SE detector

The ET-SE, or Everhart-Thornley, detector is mounted on the wall of the specimen chamber, and is therefore classed as a ‘chamber detector’. Due to its position in the chamber, the ET-SE detector views the specimen laterally.

The ET-SE detector allows detection of secondary electrons with a small backscattered component.

Figure 4.19 Secondary electron detector



1. Primary electron (PE) beam
2. Filtering grid
3. Beam booster
4. Magnetic lens
5. Scan coils
6. Electrostatic lens
7. Sample
8. Interaction volume

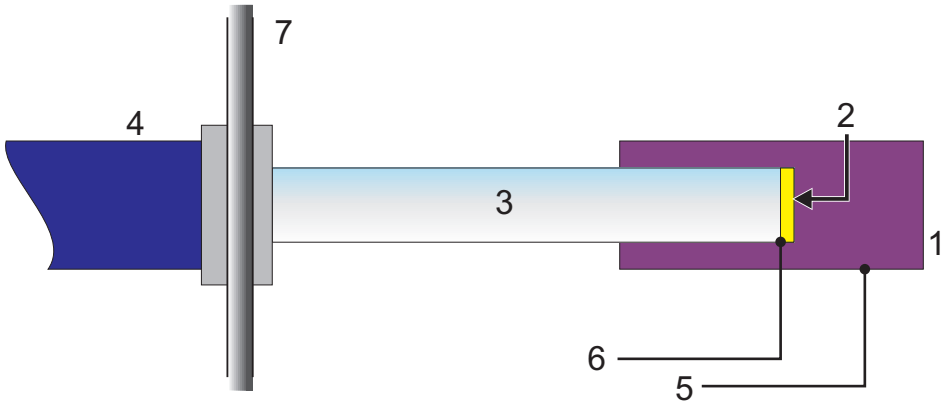
A. In-lens detector
B. ET-SE detector
C. CZBSD

Secondary electron paths

Figure 4.20 shows the basic structure of the ET-SE detector: Secondary electrons moving towards the detector are absorbed by the collector and are directed towards the scintillator (accelerated by the scintillator voltage).

When the high energy electrons hit the scintillator layer, photons are generated inside the scintillator. These photons are directed out of the vacuum system through a light pipe (**3**) and are transferred to the photomultiplier (**4**). The photomultiplier multiplies the flashes of light and outputs a signal that can be used for imaging.

Figure 4.20 Standard Everhart-Thornley secondary electron detector



1. Collector
2. Scintillator
3. Light pipe
4. Photomultiplier
5. Collector bias (–250 V to +400 V)
6. Scintillator voltage +8 kV
7. Inside of specimen chamber wall

Collector bias voltage

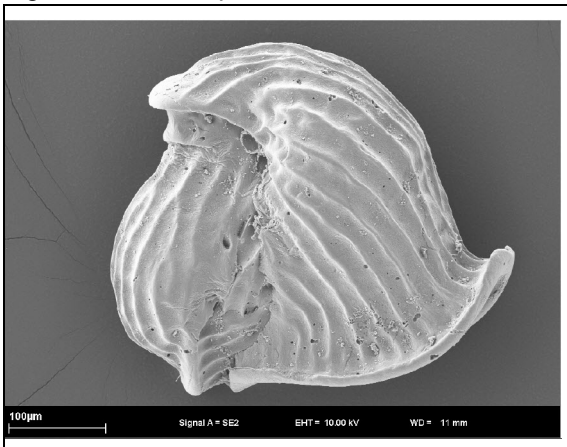
The **Detectors** tab of the **SEM Control** panel allows you to adjust the collector bias voltage (**5**) in the range –250V to +400V in steps of 1 V. This voltage generates an electric field in front of the detector. The electric field attracts the low energy SE electrons and accelerates them towards the detector. For all standard applications the collector bias voltage is usually set to 300 V.

It is also possible to set the collector bias voltage to a negative value. This generates a field that deflects the secondary electrons, preventing them from reaching the scintillator and contributing to the signal. Backscattered electrons are not affected significantly by the negative bias voltage and reach the scintillator to contribute to image information. This allows the generation of a ‘pseudo-backscattered image’, which shows enhanced topographical information.

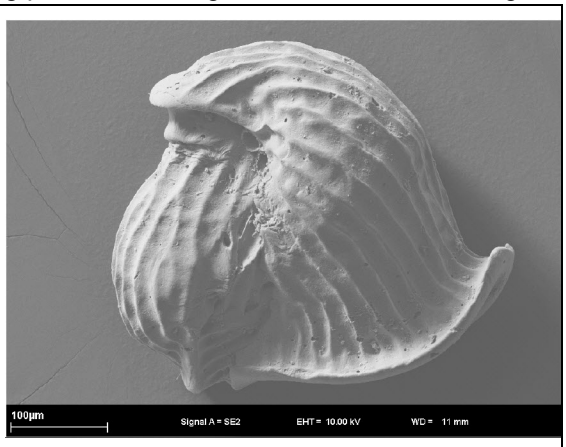
Surface images that show enhanced topographical information can also be generated using BSE detectors, but they do not show the shadows that can be created using the ET-SE detector. Figure 4.21 shows examples of this effect using a ET-SE detector with positive and negative collector bias voltages.

- When using a positive collector bias voltage, surfaces that are tilted in the direction of the detector are emphasized, but there are no shadowing effects.
- When using a negative collector bias voltage, the image shows enhanced topographical contrast, which arises mainly from the extreme shadowing effects. However, the fine surface details is less visible.

Figure 4.21 Comparison of ET-SE detector using positive and negative collector bias voltage



ET-SE detector using +300 V collector bias
Good display of surface structures and topography

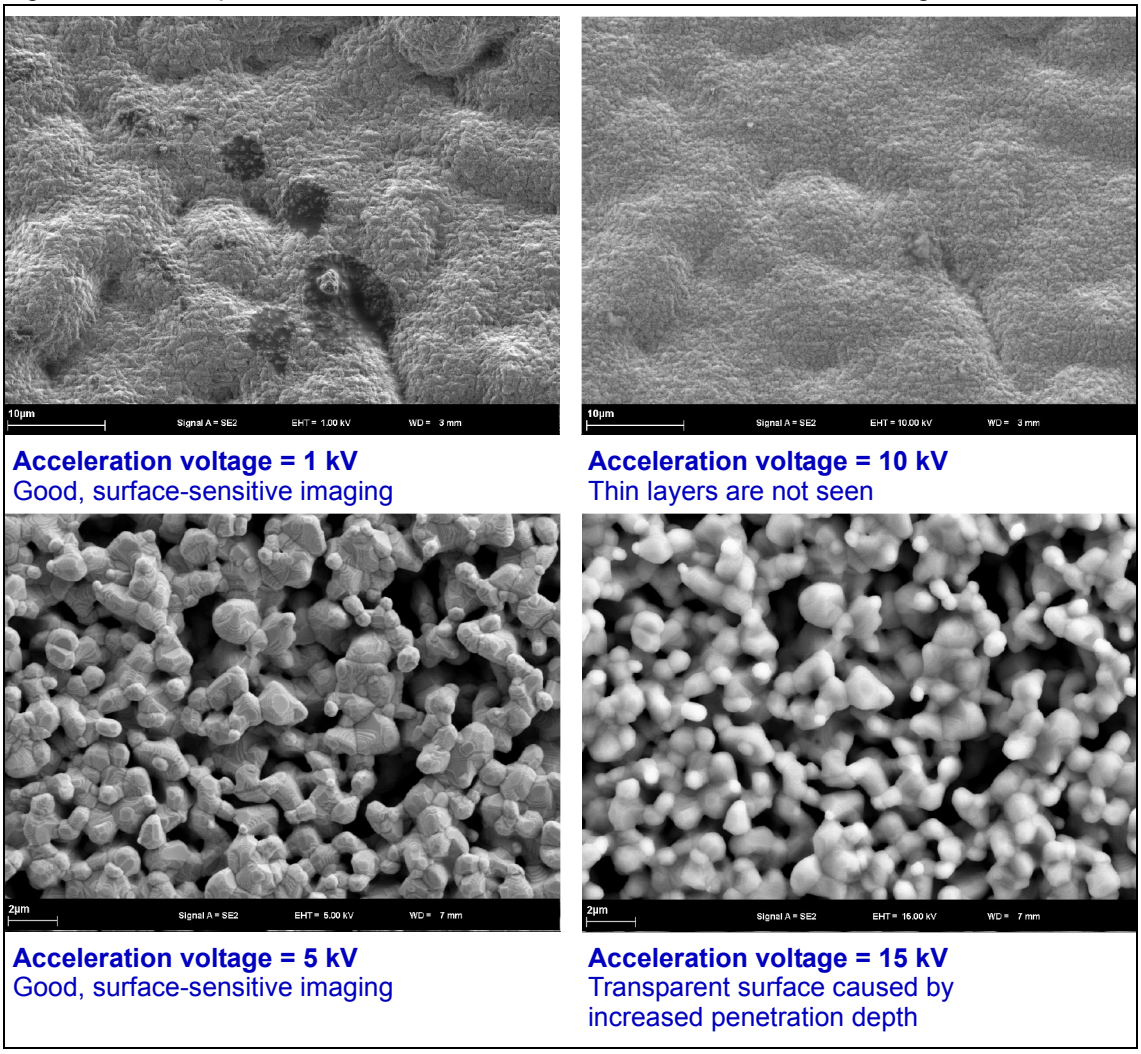


ET-SE detector using –150 V collector bias
Extremely strong topography, including shadow generation.

Applications

Unlike the In-lens detector, which can be used only with acceleration voltages up to 20 kV, the ET-SE detector can be used in the complete high-voltage range.

Figure 4.22 Comparison of surface information at different acceleration voltages



Acceleration voltage = 1 kV
Good, surface-sensitive imaging

Acceleration voltage = 10 kV
Thin layers are not seen

Acceleration voltage = 5 kV
Good, surface-sensitive imaging

Acceleration voltage = 15 kV
Transparent surface caused by increased penetration depth

As described on page 37 for the In-lens detector, working distance also has a significant effect on the efficiency of the ET-SE detector. Shadowing effects occur when the working distance is too short and, if the specimen is too close to the final lens, most of the electrons will be deflected by the field of the electrostatic lens or move to the final lens itself. This means they cannot be detected by the ET-SE detector.

Depending on the specimen material and on the specimen geometry, a minimum working distance of approximately 4 mm should be used. Extreme signal loss is likely to occur if shorter working distances than this are used.

Conversely, the ET-SE detector is very good when used for imaging at long working distances. This is particularly important for low magnification imaging that is necessary for adjusting the orientation of the specimen holder or locating a specific area on the specimen.

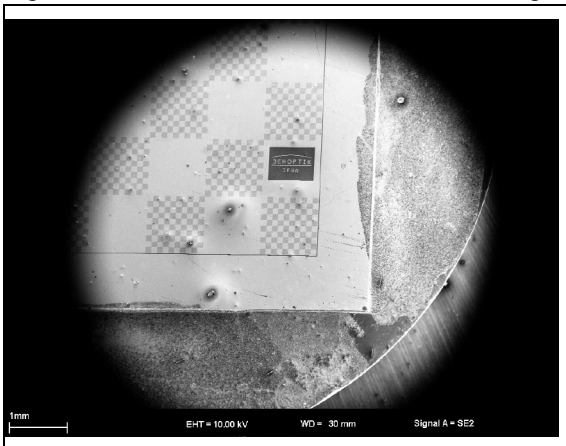
When introducing a new specimen into the specimen chamber:

- Set an initial working distance in the range 10 mm to 20 mm.
- Set the acceleration voltage to approximately 10 kV.
- Use the ET-SE detector as the signal source.

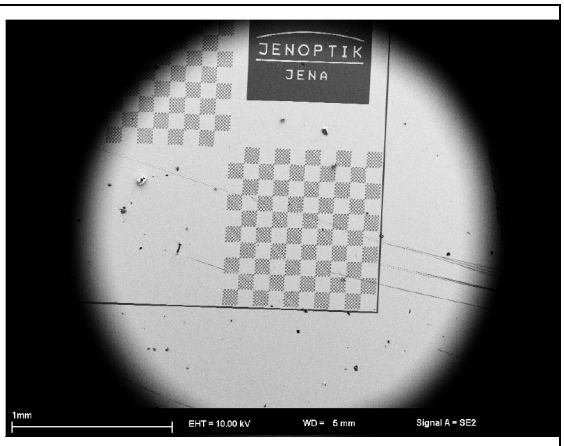
This configuration provides a good field of view for navigating on the specimen at low magnifications. The imaging conditions can be readjusted for a desired application after identifying the area of interest on the specimen.

Figure 4.23 shows that the smallest possible magnification depends on the working distance.

Figure 4.23 Field of view at different working distances



Field of View at 30 mm WD
Reasonably good signal-to-noise ratio.
Minimum magnification levels can be set.

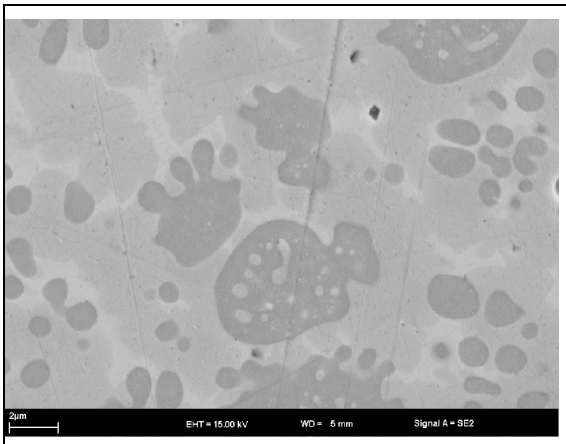


Field of View at 5 mm WD
Limits exist on the lowest magnification setting possible.

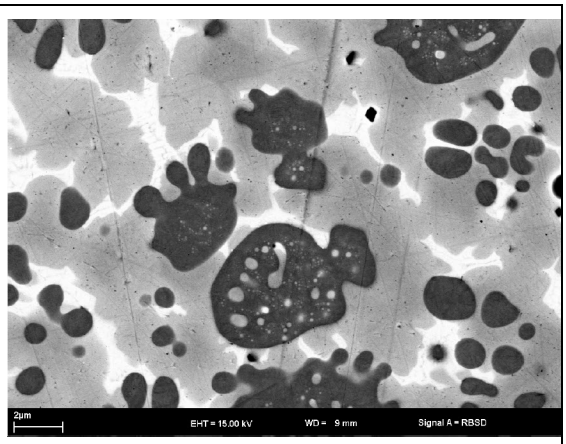
Although images produced by the ET-SE detector always include some backscattered electron components, most of the signal is generated by the secondary electrons and the fraction of backscattered signal is negligible. The images obtained by ET-SE are therefore primarily secondary electron images.

See the examples in Figure 4.24.

Figure 4.24 Comparison of material contrast using ET-SE/BSE detectors on a polished specimen



WD = 5 mm using ET-SE detector
Material contrast is very poor.



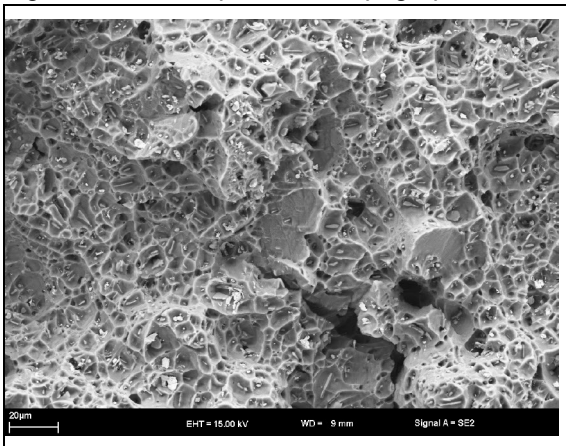
WD = 9 mm using BSE detector
Clear image showing good material contrast.

In Figure 4.24 the ET-SE image taken at 5 mm working distance shows relatively poor material contrast. In this example the reduced yield of secondary electrons is caused by the sample preparation technique of polishing the specimen surface. The ratio of SE to BSE electrons is therefore altered in favour of backscattered electrons.

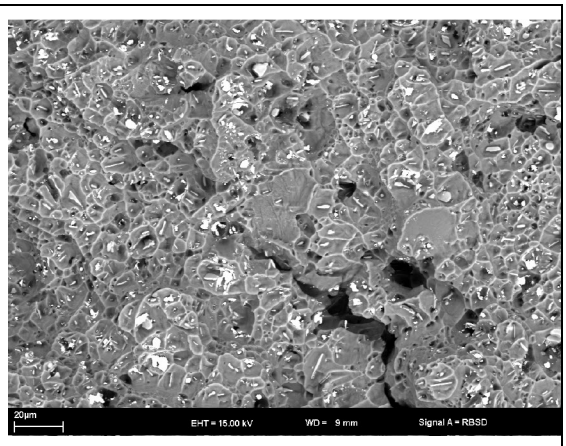
Because the ET-SE detector is mounted on the chamber at a certain angle to the specimen, the specimen is always viewed laterally. The ET-SE detector, therefore, provides good surface information. All other detectors (In-lens and BSE) view the sample from above, providing only limited information about the specimen's topography. Surfaces tilted towards the detector provide more surface detail with brighter edges; samples tilted away from the detector display shadowing effects and less surface detail.

See the examples in Figure 4.25.

Figure 4.25 Comparison of topographic contrast - ET-SE/BSE detectors on a fracture surface



ET-SE detector
Image with large depth of field.



BSE detector
Good material contrast but with limited topographical detail.

Some imaging applications require both compositional and topographical details. The generation of mixed ET-SE and BSE images is recommended for such applications. The signal mixing option is available on the **Detectors** tab on the **SEM Control** panel.

Tilting the specimen increases the signal in the ET-SE detector and sometimes improves the topographical information. Tilting the specimen towards the ET-SE detector also results in a change of the solid angle in which both the backscattered and secondary electrons are emitted from the specimen.

Applications

Table 8 below includes some standard values and notes on the operation of the ET-SE detector.

Table 8 Summary of ET-SE detector characteristics

Parameter	Recommended conditions
Acceleration voltage 100 V to 30 kV 1 kV to 5 kV 5 kV to 20 kV 20 kV to 30 kV	• In principle suitable for the entire high-voltage range. • Low-voltage applications for the compensation of charges and for surface-sensitive imaging. • Average voltage range – suitable for many different applications. • Voltage range frequently used for analytical purposes.
Working distance ≥4 mm 4 mm to 6 mm 6 mm to 12 mm 12 mm to 30 mm	• If the working distance is too short, shadowing effects will occur which diminish the efficiency of the detector. Below 20 kV, the SE electrons are absorbed by the field of the electrostatic lens. • For low-voltage applications (1 kV to 5 kV). • Useful for the average voltage range (5 kV to 20 kV) • Recommended only for low magnifications and to increase the depth of field.
Collector voltage 300 V 0 V to 400 V –150 V to 0 V	• Standard value of the collector voltage. • Variation of the collector voltage at high magnifications to obtain the mixed signal. • For pseudo- BSE images.
Aperture 30 µm 7.5 µm to 20 µm 60 µm and 120 µm	• The standard aperture is recommended for many applications. • Limitation of the probe current for the compensation of charges, or for the analysis of beam-sensitive specimens. • Only recommended for analytical purposes.
Specimen tilt	• Tilting the sample towards the detector increases collection efficiency.
Operation mode	• Only suitable in high vacuum.

4.4 Backscattered electron detector

A signal source commonly used in electron microscopy is the backscattered electron detector (BSE detector).The use of this type of detector makes it possible to effectively display compositional differences in the specimen.

One major reason for this ability is the position of the CZBSE detector: unlike the secondary electron detector (described in section 4.3) that views a specimen from the side, the CZBSE detector is located below the final lens and views the specimen from above. See Figure 4.27 on page 54. This position offers a very large solid angle that can be used for the detection of backscattered electrons.

Although the BSE detector can be used to image various types of specimen (crystal orientation contrast; magnetic contrast type II and so on), its main application is the display of material contrast (compositional differences). Its performance with respect to contrast is based on the backscattering coefficient, which increases with increasing atomic number. A higher backscattering coefficient results in an increase in the number of backscattered electrons generated by the primary electron beam, which are then made available for detection.

If different phases exist on the specimen, those with a higher average atomic number display higher brightness than those with a small atomic number. See Figure 4.26.

Figure 4.26 Display of material contrast with the BSE detector

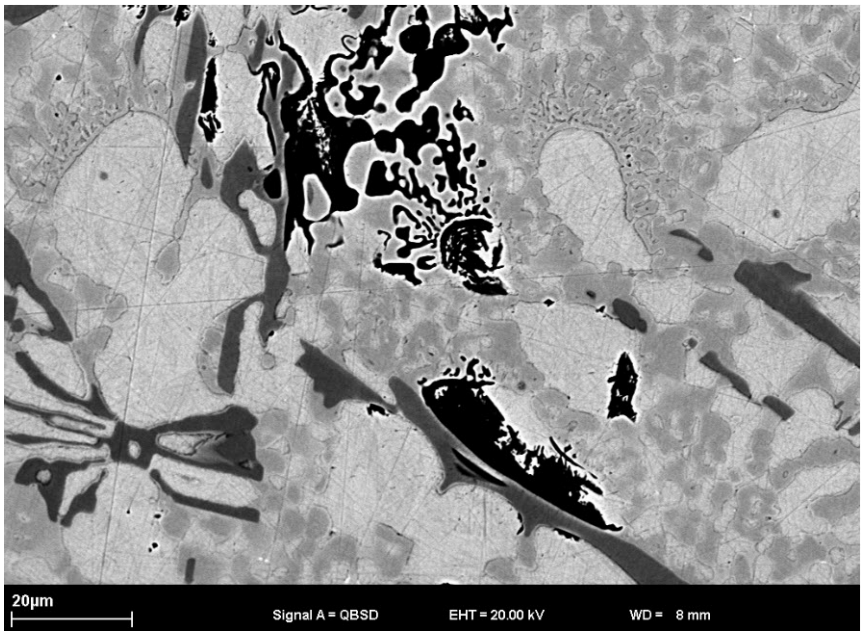
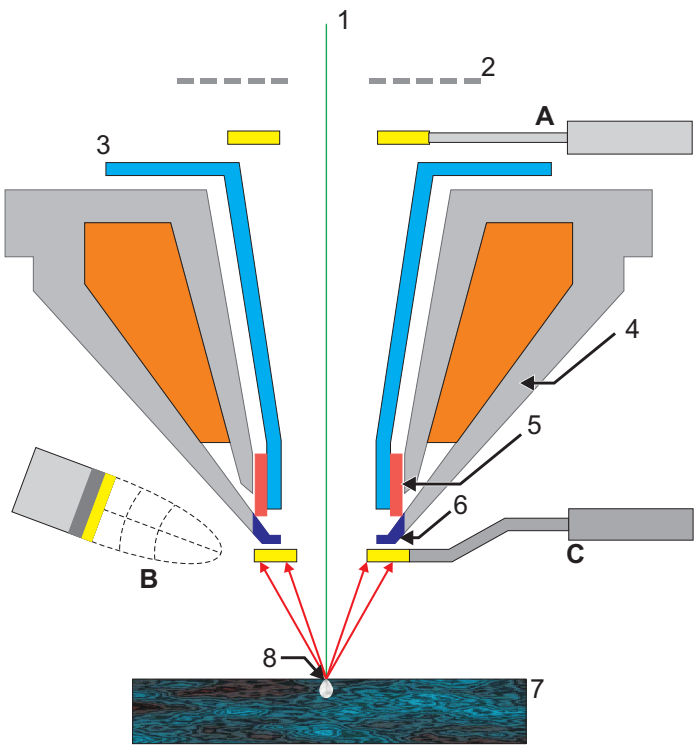


Figure 4.27 Location of the BSE detector (C)



1. Primary electron (PE) beam
2. Filtering grid
3. Beam booster
4. Magnetic lens
5. Scan coils
6. Electrostatic lens
7. Sample
8. Interaction volume

A. In-lens detector

B. ET-SE detector

C. Fixed AsB® or retractable CZBSD

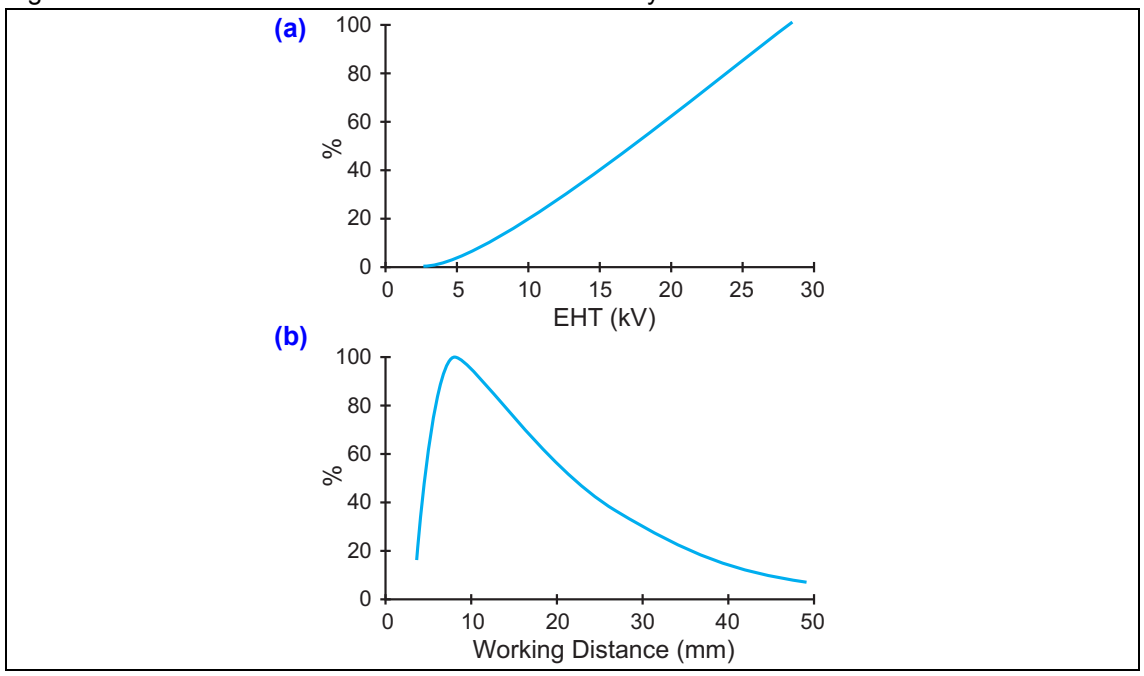
Backscattered electron paths

ΣIGMA™ BSE detector (fixed AsB® or retractable CZBSD) efficiency is determined mainly by three factors:

- the acceleration voltage
- the selected working distance, and
- the orientation of the specimen towards the detector.

See the examples in Figure 4.28.

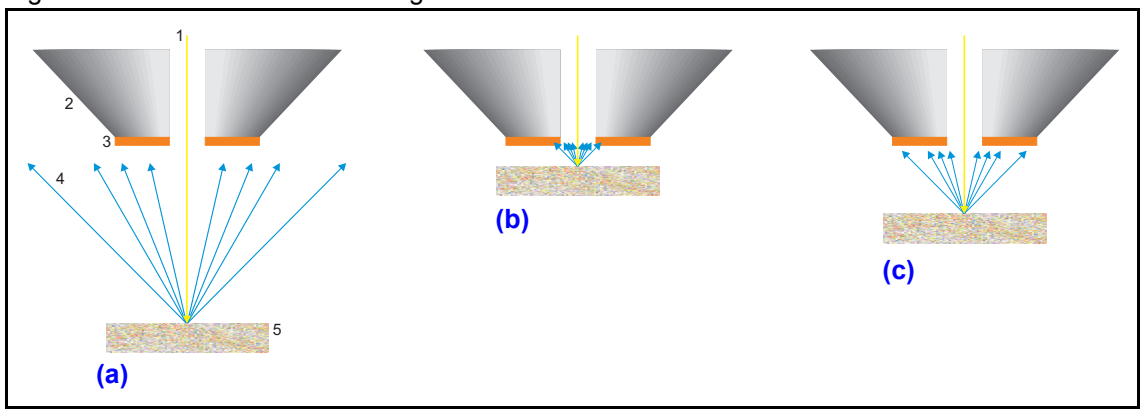
Figure 4.28 Factors that affect BSE detector efficiency



- Figure 4.28 (a): Since BSE detectors only use the energy of the generated backscattered electrons, the efficiency of the detector therefore increases with increasing acceleration voltage.

- Figure 4.28 (b): A further major parameter is the working distance. Because the BSE detectors are positioned directly below the final lens, a hole exists in the centre of the detector through which the electron beam scans the specimen. The active layer (top layers of the semiconductor diodes) is arranged around this hole. If the working distance is too long, many electrons will miss the detector, which will also reduce efficiency (Figure 4.29 (a)). If the selected working distance is too short (Figure 4.29 (b)), only few backscattered electrons will hit the detector and most electrons pass through the hole without contributing to the signal. The optimum solid angle for detection of the backscattered electrons exists only in a relatively small range of working distances centred at approximately 9 mm (Figure 4.29 (c)).

Figure 4.29 The effects of working distance



Location

CZBSE detectors are usually located in the chamber and are moved into a ‘parked’ position when they are not being used. When needed, the detectors are moved into their ‘active’ position in an arrangement called ‘push-pull’.

AsB® detectors are an integral part of the objective lens and cannot be moved.

Specimen tilt

Because of the viewing angle of the BSE detectors (directly from above), the specimen orientation towards the detector has an effect on detector efficiency.

Although the ET-SE detector responds very well when the specimen is tilted towards it, tilting degrades the detector response when using a BSE detector.

Tilting also distributes the generated backscattered electrons in different directions. Larger angles of tilt mean that more electrons are scattered in the forward direction and fewer are available to contribute to the BSE detector’s signal. Low angles of tilt should therefore be used with the BSE detector.

Table 9 below includes some recommended values and suggestions for use of the BSE detector.

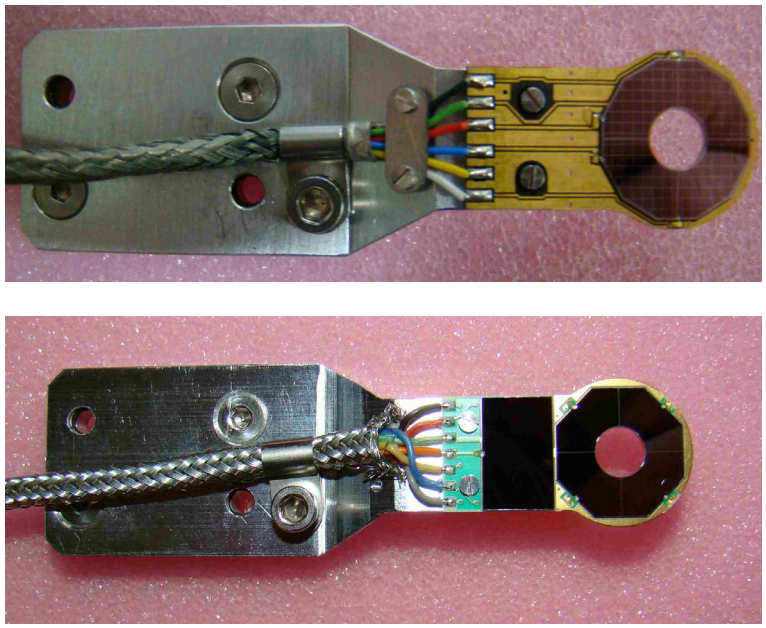
Table 9 Summary of BSE detector characteristics

Parameter	Recommended conditions
Acceleration voltage 1 kV to 30 kV	• Use of very low and very high acceleration voltages is possible.
Working distance 7 mm to 12 mm	• If the working distance is too short or too long, the solid angle available for detection deteriorates away from the optimum.
Aperture 30 µm 7.5 µm to 20 µm 60 µm 120 µm	• The standard aperture is recommended for many applications. • With these apertures, the probe current is frequently too low to obtain a sufficient signal-to-noise ratio and the required contrast. • Higher probe currents frequently improve the contrast. • Often only recommended for analytical applications.
Specimen tilt	• Avoid large angles of tilt, if possible.
Operation mode	• Use of the BSE detector is possible in high vacuum and VP mode.

4.5 Four-quadrant backscattered electron detector

Figure 4.30 shows examples of a four-quadrant CZBSD and 5-segment CZBSD.

Figure 4.30 CZBSD detector types



The CZBSD is a semiconductor detector that has four or five silicon diode segments. When high-energy electrons hit the different segments, electron-hole pairs are generated in these segments. The separation of charges and the current in each segment can be measured and used to generate an image.

There is a thin layer on the surface of each diode segment, which the backscattered electrons must pass through before they reach the diode. Due to the presence of this layer, both CZBSD and AsB® detectors can only produce images above a certain electron energy threshold.

These semiconductor detectors have a relatively small bandwidth and a high capacitance (relatively long discharge time), and therefore a reduced scan rate is recommended when using them. The ET-SE detector can primarily be used to adjust the electron-optical parameters (focus, stigmation), and the signal source can then be switched to the CZBSD to generate the image.

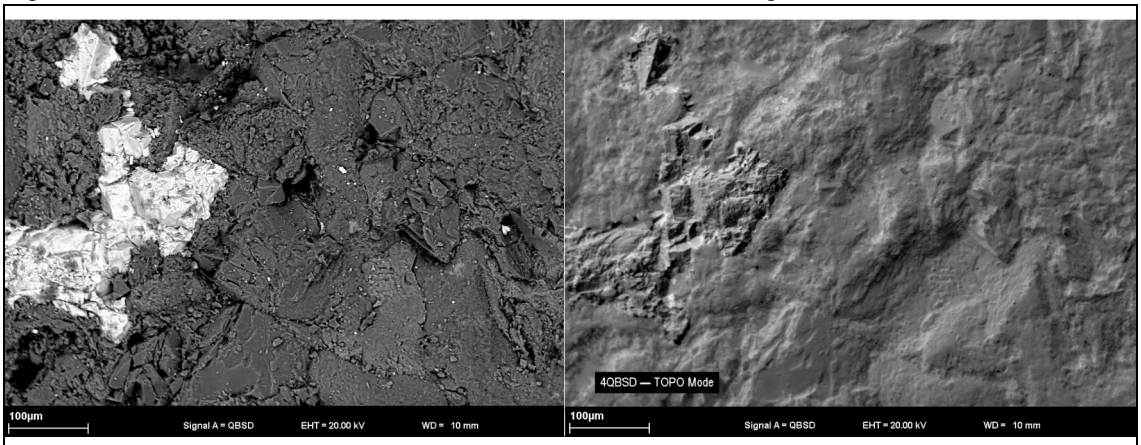
CAUTION
When you move the CZBSD below the final lens, make sure the specimen stage cannot hit the semiconductors. The diodes can be damaged easily by contact with sharp surfaces. If you need to change the working distance, use the TV camera mode to view the specimen and help avoid a collision between the specimen and the detector.

IMPORTANT:
The diode segments of the CZBSD are sensitive to the infra-red (IR) light that is used in TV mode. When you use this detector, always make sure the IR LEDs are switched off.

By selecting and combining different diode segments, it is possible to generate images with both topographical and compositional information.

Figure 4.31 shows an example comparing the compositional contrast (COMPO) and topographic contrast (TOPO) modes when using a CZBSD. More examples of compositional and topographical contrast (shadow mode) modes are shown in Figure 4.32.

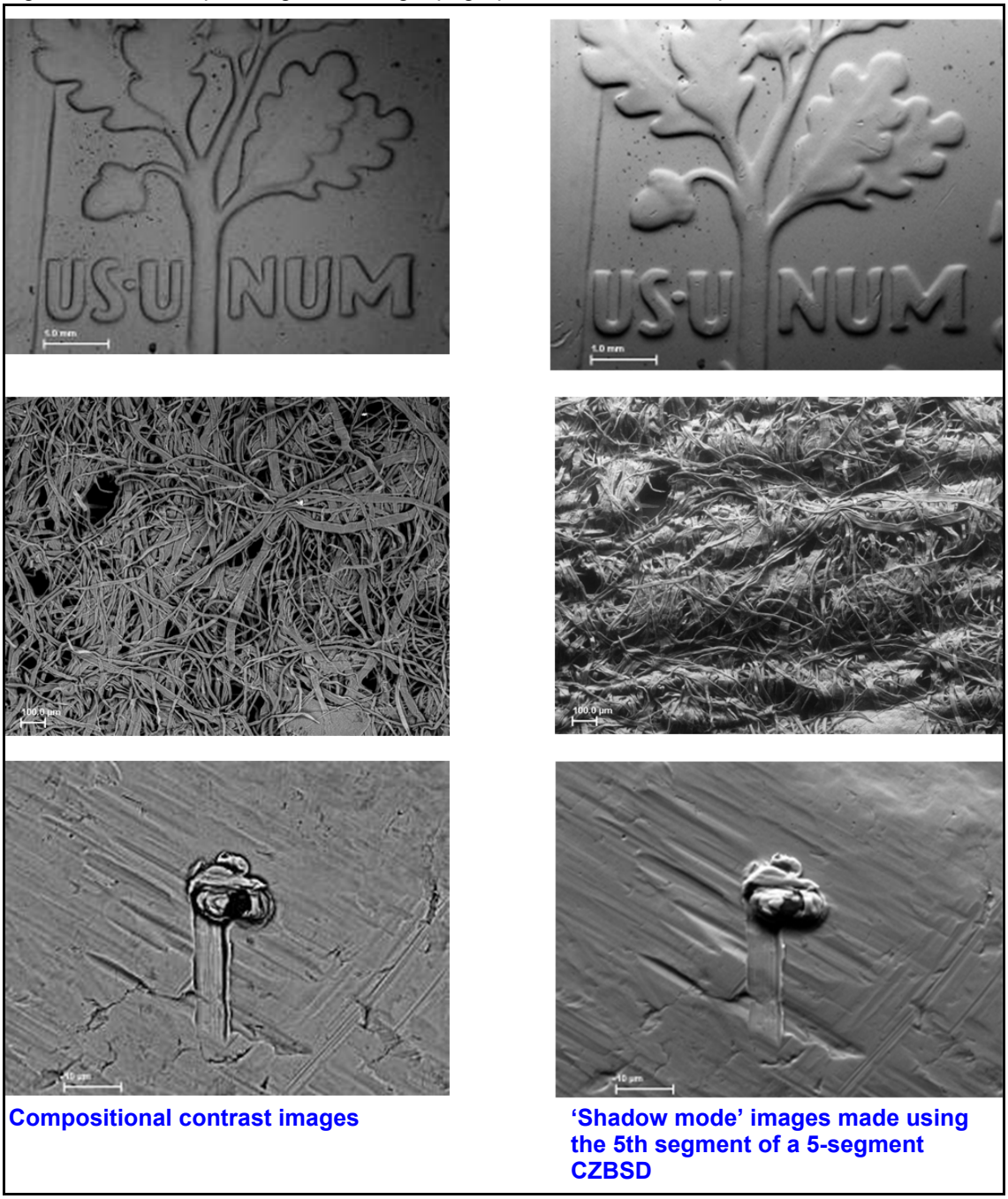
Figure 4.31 Difference between COMPO and TOPO mode using a CZBSD



Material compositional contrast **Topographic contrast**

The images show more examples of shadow mode images created using compositional contrast and topographic contrast modes with a 5-segment CZBSD.

Figure 4.32 Example images showing topographical detail and compositional contrast



Compositional contrast images

'Shadow mode' images made using the 5th segment of a 5-segment CZBSD

4.6 VPSE G3 detector

The variable-pressure secondary electron (VPSE G3) detector is a detector designed to generate images that are similar to those produced by SE detectors, but in the variable pressure (VP) mode.

The secondary electrons generated on the specimen are attracted to the VPSE G3 detector (voltage applied by the VPSE G3 collector bias). Secondary electrons that are emitted from the spec-

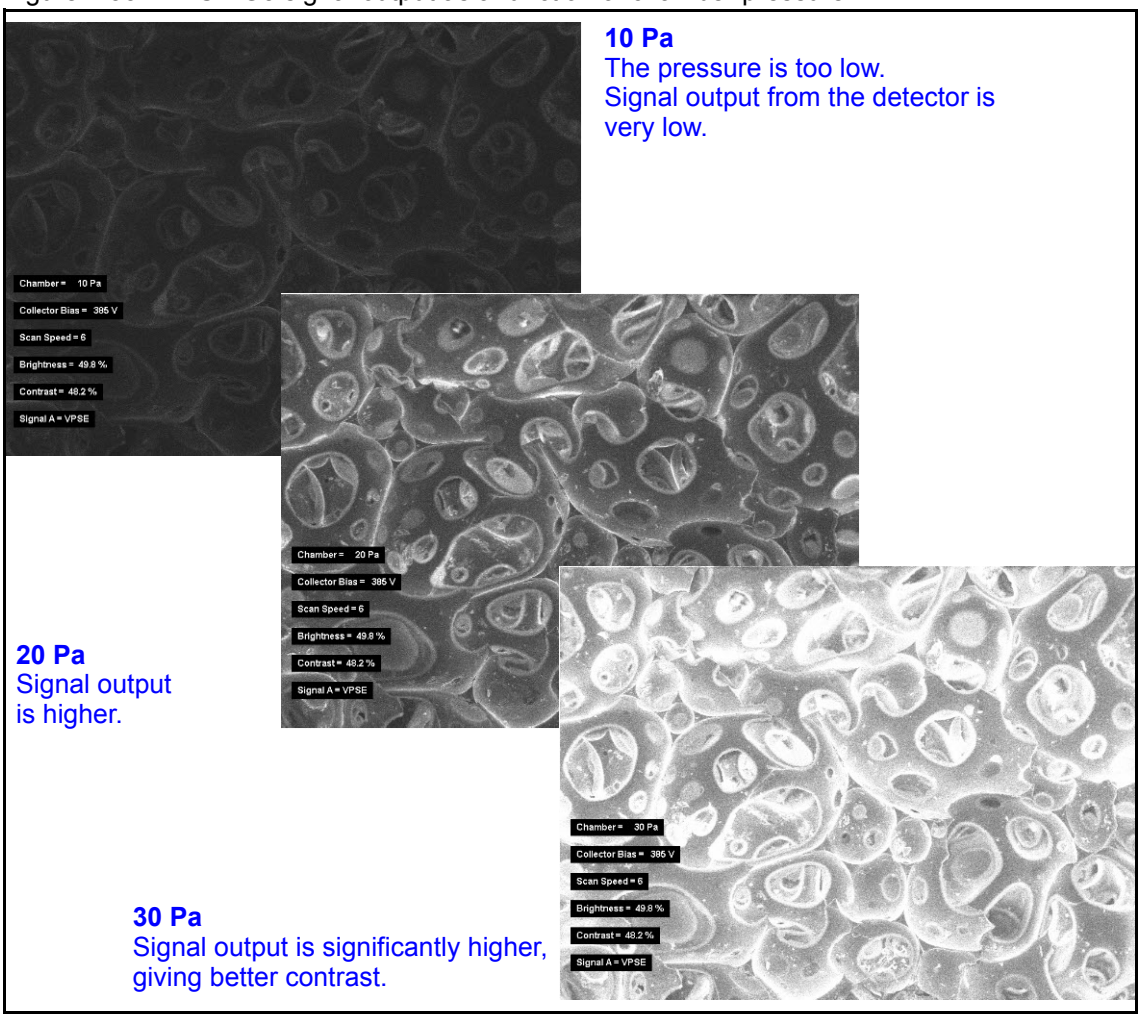
imen collide with the residual gas molecules (nitrogen, air or water). Collisions between SEs and gas molecules can ionize the molecules, releasing further electrons and resulting in further collisions (an 'ion cascade'). This process amplifies the SE signal, and also results in the generation of photons. The signal source for the VPSE G3 is not the SEs themselves, but the photons (secondary products) that are produced during this process.

Chamber pressure

When using a VPSE G3 detector, it is important to remember that a certain pressure is required in the specimen chamber to generate enough photons to be detected. If the number of residual gas molecules is too low, the collision probability and therefore the efficiency of the detector reduces. Depending on the specimen used and the operating parameters, optimum detection occurs in the pressure range 20 Pa to 60 Pa.

The examples in Figure 4.33 show how the chamber pressure affects imaging. In each of the examples, the same scan rate, brightness and contrast values were used. Only the pressure inside the specimen chamber changed between the images.

Figure 4.33 VPSE G3 signal output as a function of chamber pressure



Note that increasing the chamber pressure also increases the scattering process, and reduces the resolution of the SEM. It is therefore essential to find optimum conditions for each particular application.

Dwell time

Another key parameter is the length of time that the primary electron beam dwells on the specimen.

If this dwell time is too short (that is, at a fast scan rate), there is not sufficient time for an ion cascade to develop or for the residual gas molecules to generate the imaging photons. This reduces the detector efficiency.

If the dwell time is too long (that is, at a slow scan rate), very high energy is applied to the specimen per unit time. This can result in charging artefacts on the obtained images.

Optimum scan rate for different specimens might vary and can only be determined by experiment. The Frame Averaging function in the user interface software might be helpful for reducing the charging effects, by using fast scan speeds and increasing the number of frames (N).

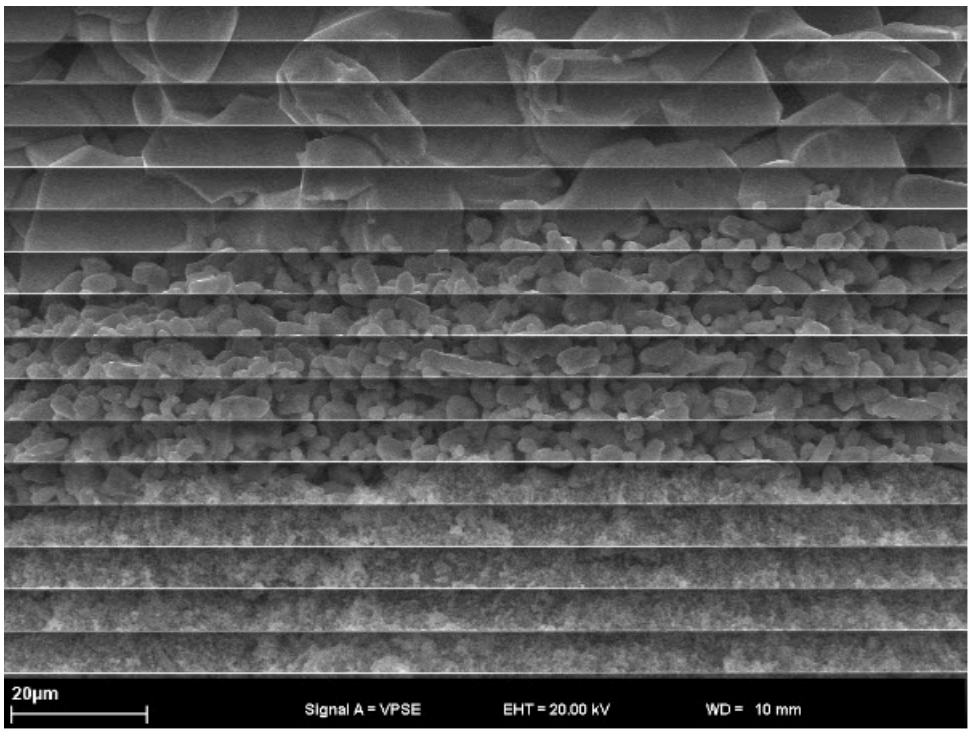
Collector voltage

The third key parameter is the collector bias, because it sets the electric field between the specimen and the VPSE G3 detector.

If the collector bias is too low, the VPSE G3 detector efficiency is significantly reduced.

Too high collector bias values result in saturation of the VPSE G3 detector (depending on the specimen, the set acceleration, the probe current and the pressure in the specimen chamber). This in turn results in very bright periodic lines on the image that prevent proper specimen imaging, as shown in the example of Figure 4.34.

Figure 4.34 Example of the saturation of a VPSE G3 detector

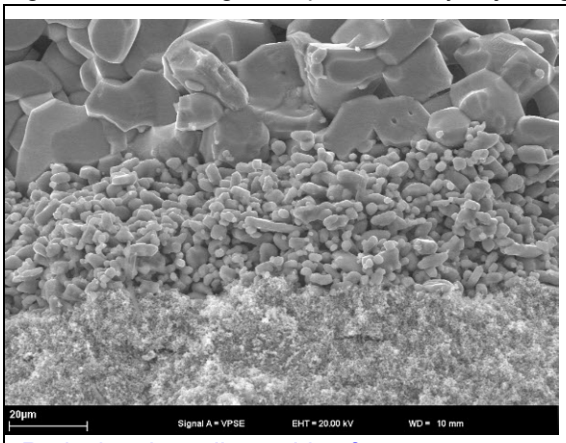


Extreme banding effects are visible when using a high collector bias and a chamber pressure of 40 Pa.

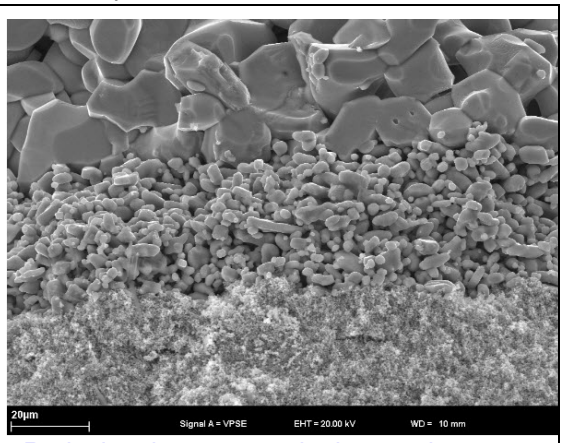
The examples in Figure 4.35 show how the banding effects can be eliminated either by reducing the collector bias or by reducing the pressure in the specimen chamber.

However, the detector efficiency reduces by making either of the above mentioned adjustments. The user therefore needs to find the optimum parameters for imaging different specimens. It is generally better to reduce the collector bias, because reducing the chamber pressure can cause new charging effects.

Figure 4.35 Charge compensation by adjusting chamber pressure and collector bias



Reducing the collector bias from 82 % to 78 % results in the elimination of banding effects at 40 Pa.



Reducing the pressure in the specimen chamber from 40 Pa to 20 Pa results in the elimination of banding effects at a collector bias of 79 %.

Table 10 below includes some recommended values and suggestions for use of the VPSE G3 detector.

Table 10 Summary of VPSE G3 detector characteristics

Parameter	Recommended conditions
Acceleration voltage	
3 kV to 30 kV	• Possible application range for VPSE G3 detector. However, sufficient contrast can be obtained only at higher voltages.
3 kV to 7 kV	• Low voltage application with VPSE G3 detector.
7 kV to 25 kV	• Standard application for VPSE G3 detector.
Working distance	
6 mm to 8 mm	• For low voltage applications (3 kV to 7 kV)
8 mm to 15 mm	• For standard applications (7 kV to 25 kV).
Aperture	
30 µm	• The standard aperture is recommended for many applications.
7.5 µm to 20 µm	• With these apertures, the probe current is frequently too low to obtain a sufficient signal-to-noise ratio and the required contrast.
60 µm	• Higher probe currents frequently improve the contrast.
120 µm	• Only recommended for analytical applications.

Table 10 Summary of VPSE G3 detector characteristics (Continued)

Parameter	Recommended conditions
Specimen tilt	• Avoid large angles of tilt, if possible. Slight tilting can improve efficiency.
Operation mode	• The VPSE G3 detector is used mainly in the VP mode. Note: Because the VPSE G3 detector detects light, it can be used as a simple cathodoluminescence (CL) detector in high-vacuum mode.

4.7 Cathodoluminescence (CL) detector

The cathodoluminescence detector is an inclined detector that allows efficient visible light collection.

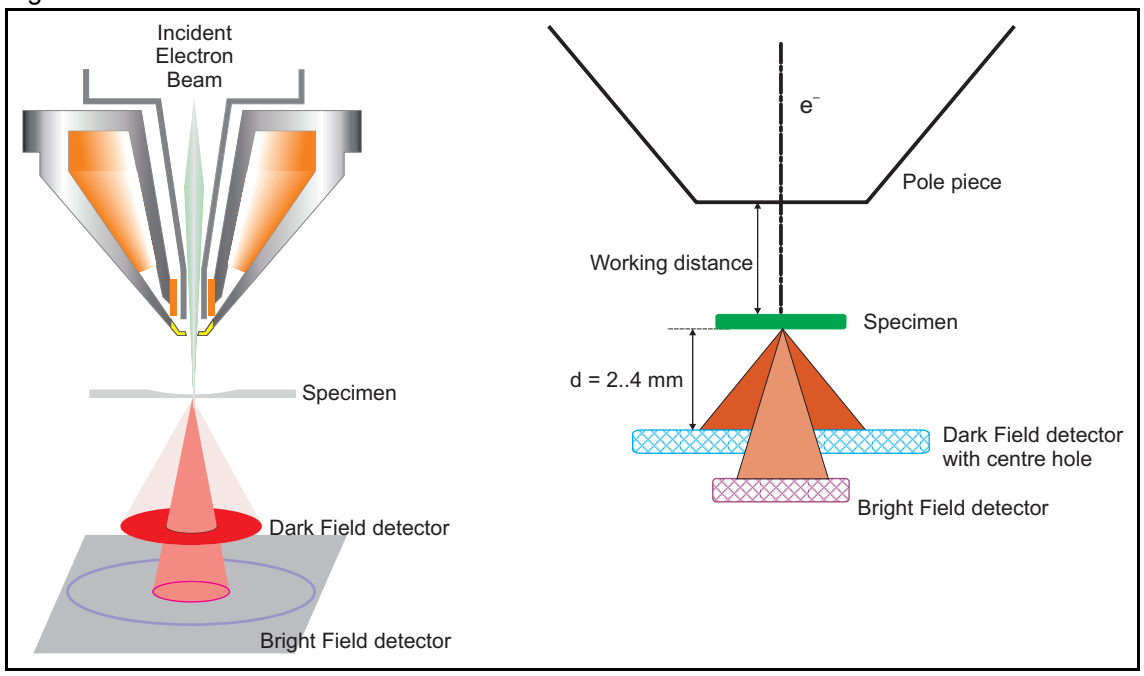
The CL detector is ideal for use in geology, mineralogy and materials science applications where it can help in internal structural examination of rocks, ceramics and semiconductors. The specimens, however, need to emit light when interacting with the primary electron beam. Differences in crystal structure or the presence of impurities in a cathodoluminescent material result in variations in the energy gap between the filled valence bands and the empty conduction bands, and consequently a change in the CL emission. The light (photons) emitted from the specimen is collected by the CL detector and converted to signal for imaging.

The CL detector is fully integrated into the SEM's automatic brightness and contrast control and can be used simultaneously with any of the detectors without degrading their performance. The detector can be used during EDS and wavelength-dispersive spectrometer (WDS) measurements, at any valid magnification.

4.8 Scanning Transmission Electron Microscopy (STEM) detector

The STEM (Scanning transmission electron microscopy) detector is a pneumatic retractable multimode detector with a 12-stub sample holder for Bright Field and Dark Field detection. The detector is equipped with a semiconductor diode that is positioned under the sample. The diode area consists of four quadrants for the Dark Field (DF) and one diode for the Bright Field (BF) imaging.

Figure 4.36 ΣIGMA™ STEM detector schematics



The ‘cone angles’ of the BF and DF signals depend on the specimen as well as the illumination aperture. The centre hole separates the DF and the BF signals, and the arrangement of the diodes allows simultaneous detection of the Bright Field and Dark Field signals without the need for realignment.

Moving the detector in the Z axis and changing the working distance allows obtaining optimum separation of the signal. A detector-to-specimen distance (d) in the range 2 mm to 4 mm is recommended for optimum imaging results.

The STEM detector is used in cases where the thickness of a specimen is similar to or less than the dimensions of the interaction volume. The specimen must be mounted on a TEM grid with a thin carbon-film support (approximately 10 nm thick).

Electrons that pass through the target can then be collected by the detector and used to form an image. The SmartSEM® user interface allows selecting different imaging modes (DF or BF). It is also possible to mix the DF and BF signals.

5 Transport and storage

5.1 Transport

WARNING

Crushing hazard while load is being lowered.

Stay a safe distance from the equipment until it has been safely lowered to ground level. Do not walk or place your hands or feet under the load while it is being lowered. Wear safety shoes and gloves.

CAUTION

Risk of damage to the FESEM.

Use only vehicles that use air suspension to transport the FESEM. Moving parts must be secured during transport to prevent them from slipping or tipping over.

Do not rock the crates back and forth.

Devices for transporting the FESEM must be rated to handle its full weight and dimensions. Note the weight information on the package and on the shipping document.

In order to avoid damage of the FESEM by shock, the FESEM must be transported only in vehicles that use air-suspension.

The ambient temperature around the FESEM during transport must be maintained in the range between –10 °C and +70 °C.

The FESEM is delivered in two wooden crates:

Microscope plinth	Wrapped with recyclable polyethylene foil. Dimensions and weight of crate: 1350 mm × 1100 mm × 2000 mm (W × D × H); approx. 750 kg
Microscope console and accessories	Console, valve, damper, monitors, cables, pipes and so on are wrapped with recyclable polyethylene foil or packed in separate cartons. Dimensions and weight of crate: 1400 mm × 1350 mm × 1122 mm (W × D × H); approx. 350 kg

Make a check on the shipment and report any damage to Carl Zeiss NTS Ltd and to the shipping agent.

5.2 Storage

You must arrange to store the packed FESEM in a dry place while you wait for it to be installed.

The ambient temperature around the FESEM during storage must be maintained in the range between –10 °C and +70 °C.

6 Installation

Unpacking, installation and first start-up are carried out by authorised Carl Zeiss service staff.

7 Operation

At a glance

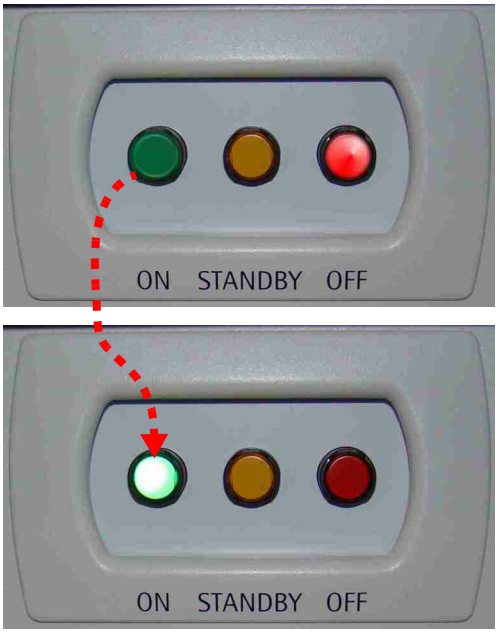
This chapter contains information about the following topics:

- Switching on the FESEM
- Starting the SmartSEM® user interface
- Using the SmartSEM® user interface
- Obtaining a first image
- Setting SEM conditions
- Using the help functions
- Finishing the work session
- Closing the SmartSEM® user interface
- Switching off the FESEM as a matter of routine
- Switching off the FESEM completely

7.1 Switching on the FESEM

1. Press the green **ON** push button that is located at the front of the plinth.

   The green **ON** button comes ON.



7.2 Starting the SmartSEM® user interface

Before you start

Before you start to use the SmartSEM® user interface, make sure of the following conditions:

- The FESEM must be switched on.
- The Windows® operating system has started.

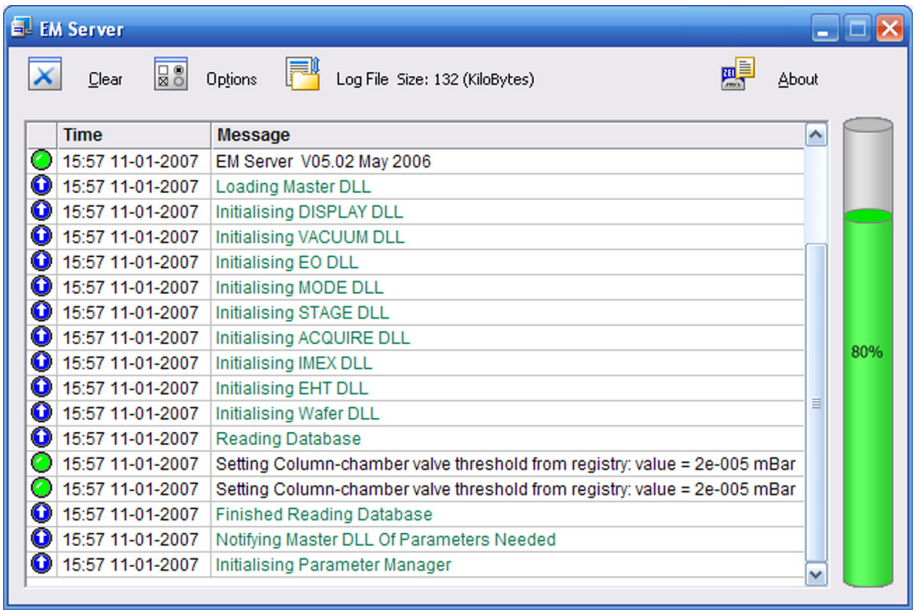
Starting SmartSEM®

1. Double-click on Zeiss SmartSEM icon, or select **Start > Programs > SmartSEM > SmartSEM User Interface**.

The **EM Server** starts and begins to load a series of drivers. The purpose of the EM Server is to allow and support internal communications between the FESEM's software and its hardware.

The **EM Server** window and the **EM Server Log On** dialog are displayed.

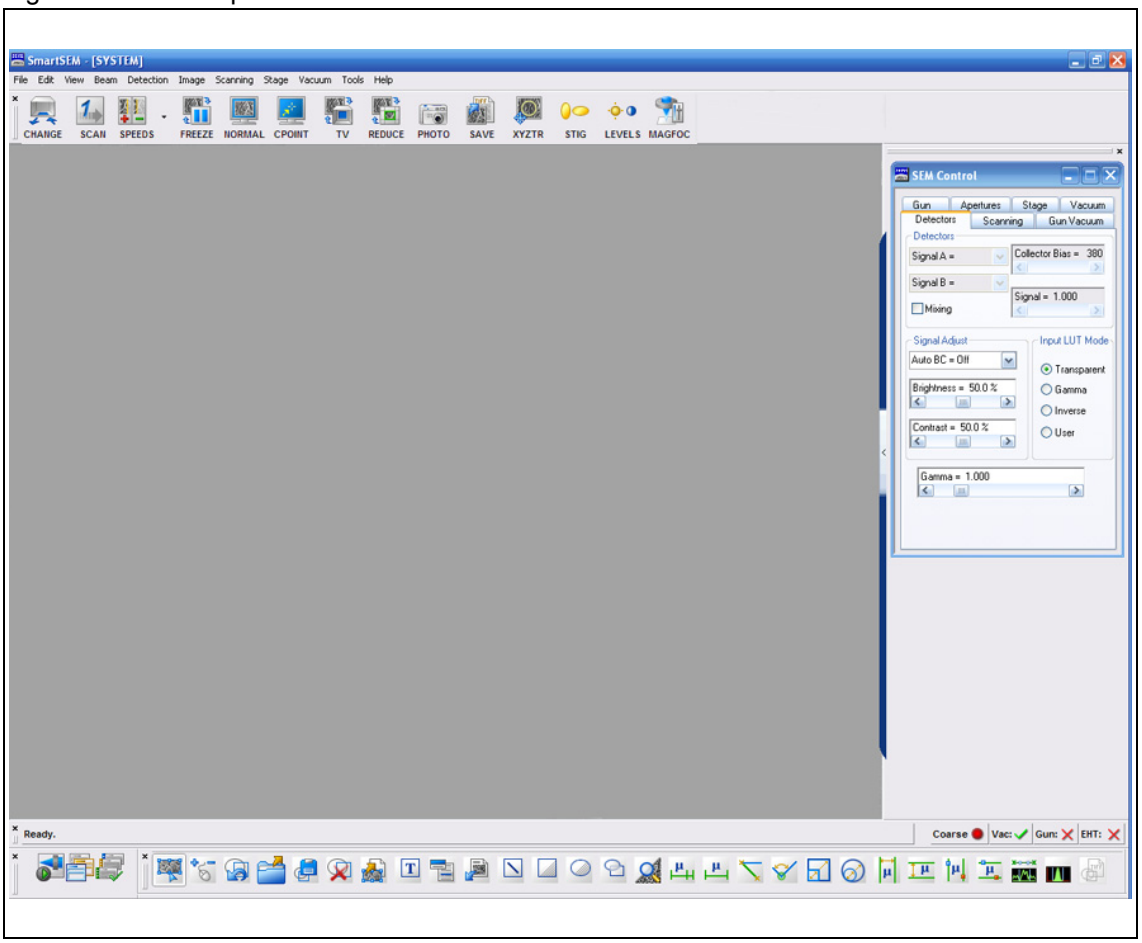
Figure 7.37 Examples of the EM Server window and EM Server Log On dialog



2. Type your **User Name** and your **Password** in the **EM Server Log On** dialog, and click **OK**.

The SmartSEM® user interface window is displayed, and the EM Server window is minimised to a small icon on the Windows® taskbar.

Figure 7.38 Example of the SmartSEM® user interface window



The SmartSEM® user interface is now ready to operate the FESEM.

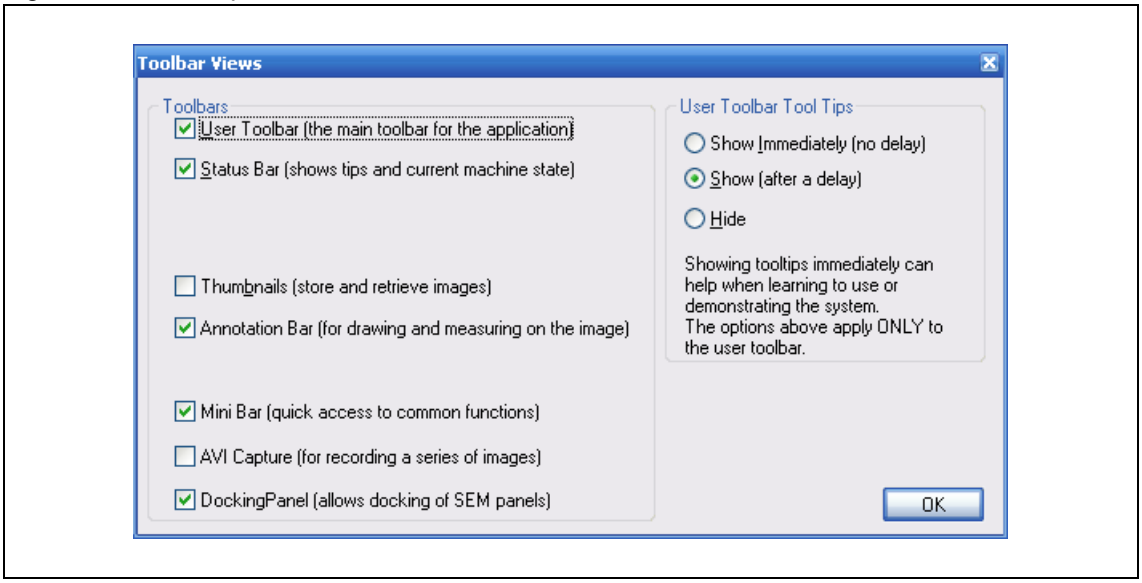
7.3 Using the SmartSEM® user interface

7.3.1 Showing or hiding toolbars

Several features allow easy access to SmartSEM® functions, such as the user toolbar, the status bar, and the annotation bar.

1. Select **View > Toolbars** from the menu, or type **<Ctrl+B>** to display the **Toolbar Views** window.

Figure 7.39 Example of the Toolbar Views window



2. Select the check box for each toolbar that you want to show.

3. If you want to change the tool tip features of the user toolbar, select the respective radio button on the right hand side of the panel.

4. Click **OK** to confirm.

7.3.2 Showing or hiding the data zone

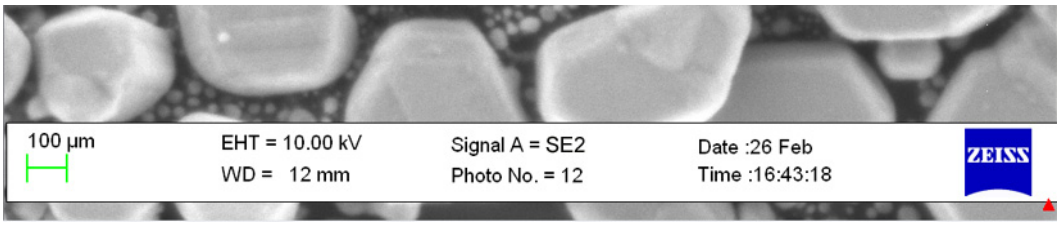
The data zone is a special group of annotation objects that are used to display the current parameters. You can also include a micron marker to show the base magnification.

1. Select **View > Data Zone > Show Data Zone** from the menu.

   The option shows a check mark when the function is activated.

   Alternatively, type **<Ctrl+D>** to toggle the data zone.

Figure 7.40 Example of the SmartSEM® data zone



7.3.3 Showing a full-screen image

There is an option to show a full-screen image on the monitor. This option takes advantage of the full monitor size to display the microscopic image.

1. Select **View > Toggle Full Screen Image** from the menu, or type **<Shift + F3>** to toggle the full-screen display function on and off.

7.3.4 Using docking panels

It is possible to dock various control panels onto the main window. The purpose of docking a panel is to keep the area of the image completely clear, because the docked panel is outside the border of the main window.

Show the docking panel

1. To show the docking panel select **View > Toolbars** from the menu.

2. Select the **Docking Panel** check box.

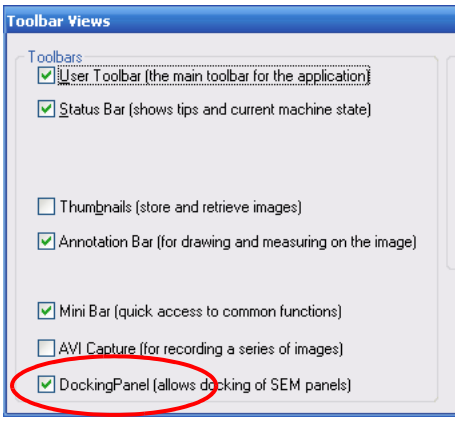


Figure 7.38 on page 71 shows the docking panel to the right of the image area.

Docking panel options

You can click and drag the docking panel's title bar to move the docking panel to the left or to the right of the image area, whichever position is more convenient.

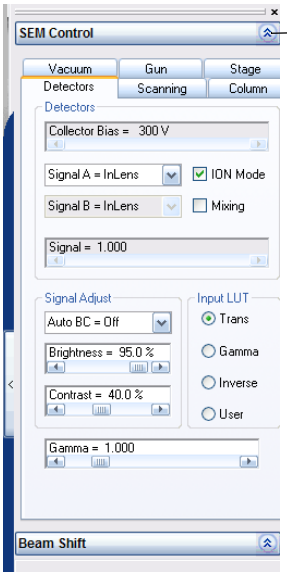
After you display the docking panel you can dock individual control panels to it. Click and drag the title bar of a control panel to the docking panel to dock it there.

Click and drag a control panel away from the docking panel to undock it.

You can dock more than one control panel.

After you have docked a control panel you can minimise it by clicking the arrow button (**1**) in the control panel's title bar.

You can use more of the screen area for the image display if you hide the docking panel. To do this, select **View > Toolbars** from the menu and then de-select the **Docking Panel** check box.



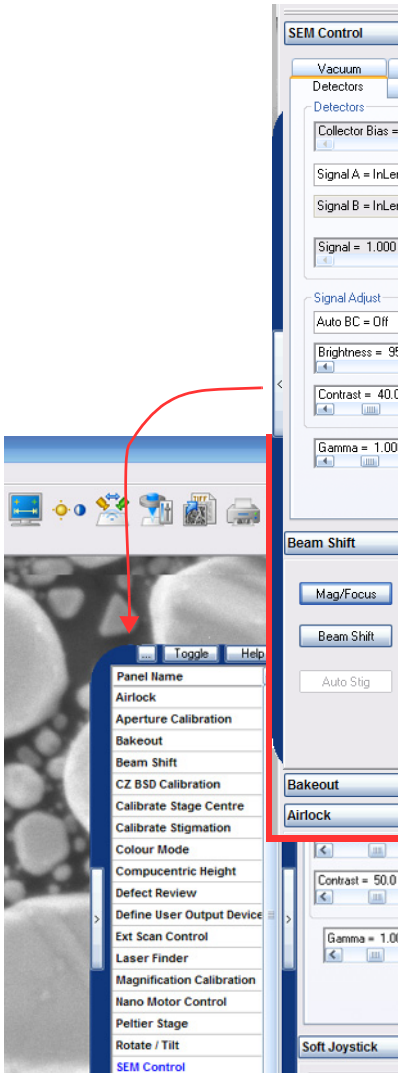
7.3.5 Using the panel configuration bar

The panel configuration bar allows you to customise the SmartSEM® user interface by displaying or hiding any of the available functions.

1. Select **Tools > Goto Panel** from the menu to open the panel configuration bar and display an alphabetical list of functions, as shown in the example here.

   Alternatively, click the arrow button at the side of the image area.

2. Double-click a function in the panel configuration bar to select it.



7.4 Obtaining a first image

This section describes basic procedures to help you obtain an image quickly using the SE2 detector. To simplify the procedure, the description uses the **SEM Control** panel and status bar functions in the SmartSEM® software.

Before you begin this procedure, make sure the SmartSEM® software is running and is ready to control the FESEM.

Parts required:

- Hexagonal key, 1.5 mm
- Stub
- Tweezers for specimen handling
- Specimen holder
- If necessary, carbon tape, conductive carbon, adhesive metal tape or similar
- Appropriate specimen (with conducting properties, for example gold on carbon)
- Lint-free gloves

At a glance

The complete process includes the following procedures:

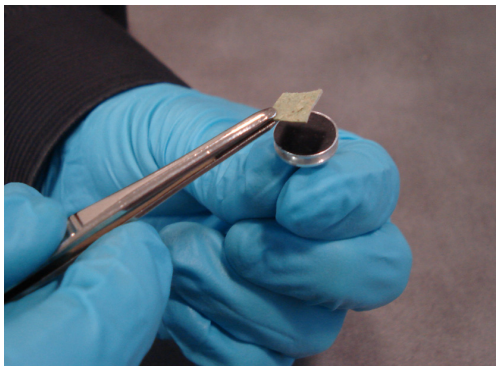
- Preparing the sample holder
- Loading the specimen chamber
- Locating the specimen
- Switching on the gun
- Switching on the EHT
- Generating an image
- Optimising the image
- Saving the image

7.4.1 Preparing the sample holder

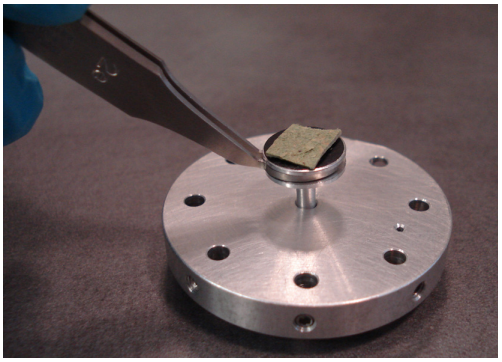
Note:
IMPORTANT: Contamination caused by fingerprints can cause deterioration of the vacuum and can increase pumping times. Always wear lint-free gloves when you touch the specimen, the sample holder or the stage.

1. Attach the specimen to the stub by using conductive carbon, adhesive metal or carbon tape.

   Make sure the specimen area to be analysed is in proper contact with the stub.

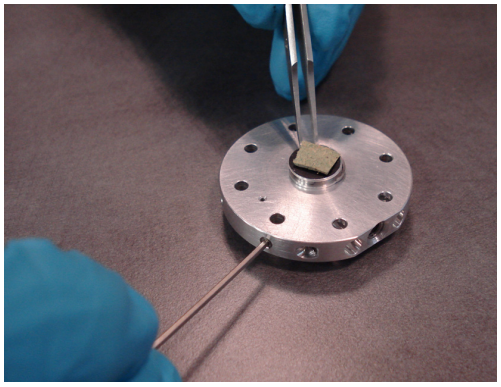


2. Use tweezers to insert the stub into the sample holder.



3. Fix the stub properly to the sample holder.

   Use the 1.5 mm hexagonal key to tighten the location screw.



7.4.2 Loading the specimen chamber

1. Click on the **ChamberScope** icon in the toolbar to display a TV view of the specimen chamber.

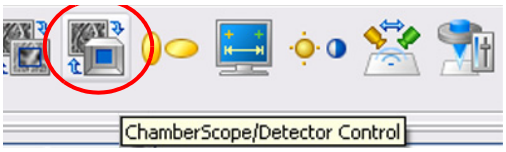
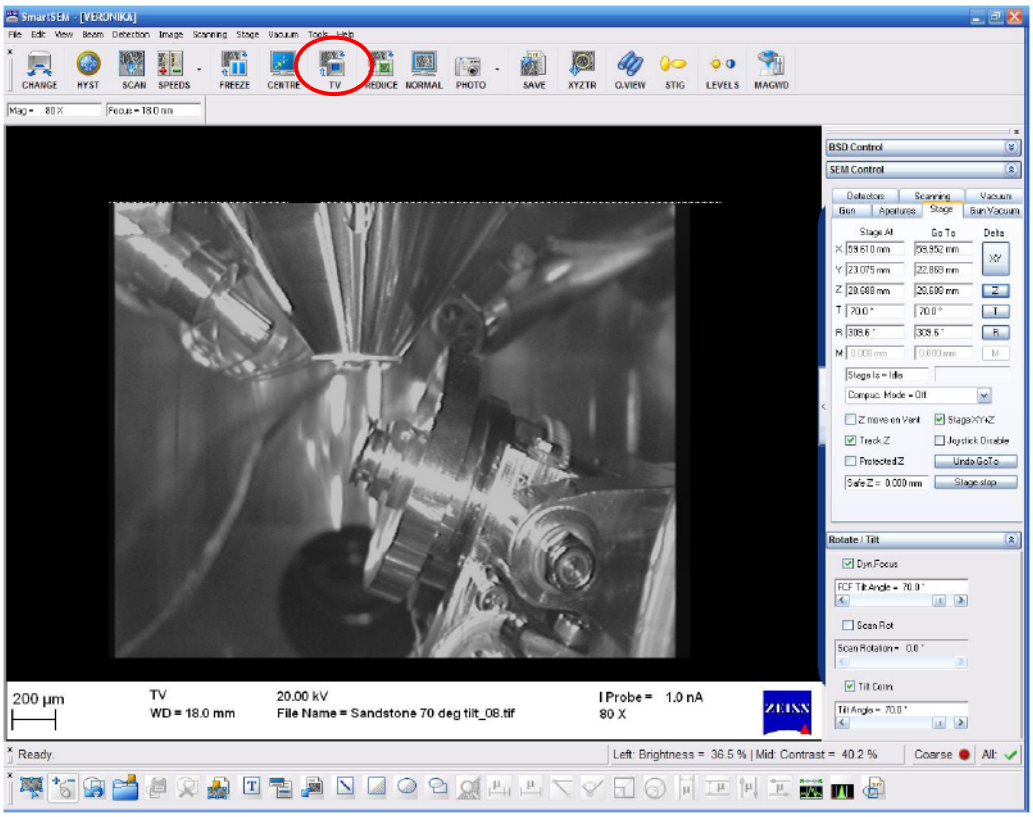


Figure 7.41 Example TV view of the specimen chamber



CAUTION

There is a risk of damage to the objective lens and to your specimen.

Be very careful to avoid hitting the objective lens with the specimen when you move the specimen stage. Use the TV mode to observe the moving specimen stage.

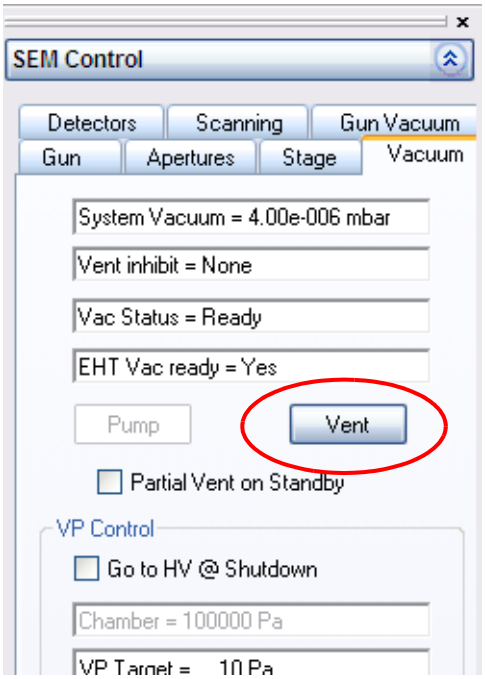
2. Select **Tools > Goto Control Panel** from the menu to display the **SEM Control** panel.

3. Select the **Vacuum** tab on the **SEM Control** panel.

4. Click **Vent** to ventilate the specimen chamber.

   A message is displayed asking you to confirm that you want to vent the chamber.

5. Click **Yes** to confirm the Vent command and to fill the chamber with nitrogen gas.



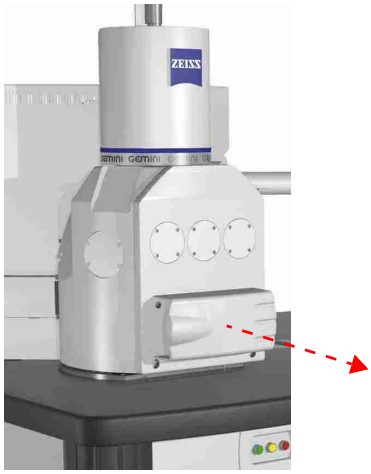
WARNING

Because FESEM uses nitrogen to vent the chamber, there is a risk of suffocation caused by lack of oxygen.

After you change the specimen, shut the chamber door as soon as possible. DO NOT breathe the gas from inside the chamber.

Make certain the area around the FESEM is ventilated properly.

6. Pull the chamber door open carefully.



IMPORTANT:

Contamination caused by fingerprints can cause deterioration of the vacuum and longer pumping times.

Always wear lint-free gloves when you touch the specimen, the sample holder or the specimen stage. Keep the chamber door open for as short a period as possible.

All sample holders have a dovetail in their mounting so that the position of the sample holder is defined precisely.

7. Mount the sample holder:

   (a) Make sure you use the correct orientation when you fit the dovetail onto the holding device on the specimen stage.

   (b) Make sure the flat side of the dovetail is flush with the milled edge of the stage.

8. Make a visual check inside the specimen chamber to confirm the specimen cannot hit any components when it is introduced.

WARNING

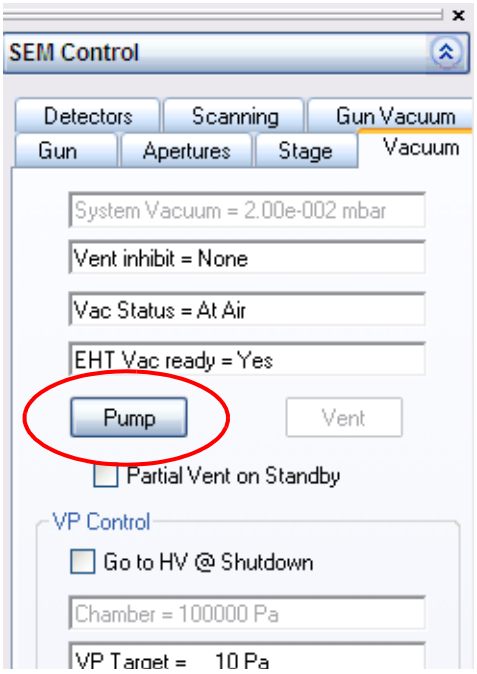
There is a pinch hazard when you close the chamber door.

Use care when you close the chamber door. DO NOT trap your fingers between the chamber door and the chamber.

9. Carefully close the chamber door.

10. Click **Pump** in the **SEM Control** panel.

    The vacuum status messages show the current vacuum levels achieved.



7.4.3 Locating the specimen

1. Use the SmartSEM® software's TV mode (the ChamberScope – see the example in Figure 7.41 on page 78) to view the specimen chamber.

CAUTION

There is a risk of damage to the objective lens and to your specimen.

Be very careful to avoid hitting the objective lens with the specimen when you move the specimen stage. Use the TV mode to observe the moving specimen stage.

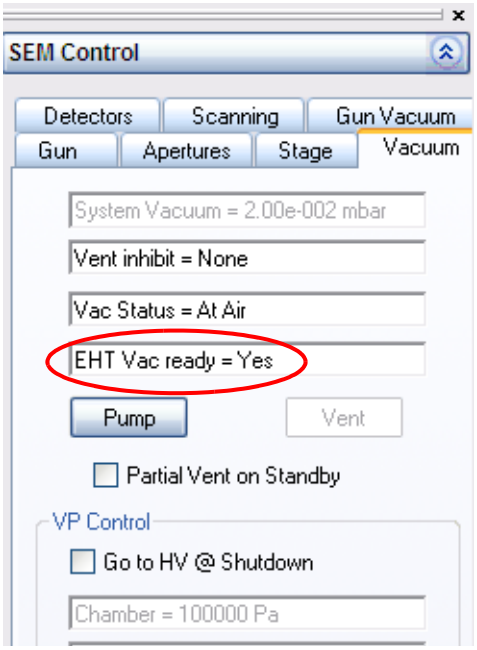
2. Use the optional dual joystick to move the specimen.

   Alternatively, use the soft joystick by choosing **Tools > Goto Panel > Soft Joystick**.

3. Move the specimen carefully so that it is no more than approximately 10 mm from the objective lens.

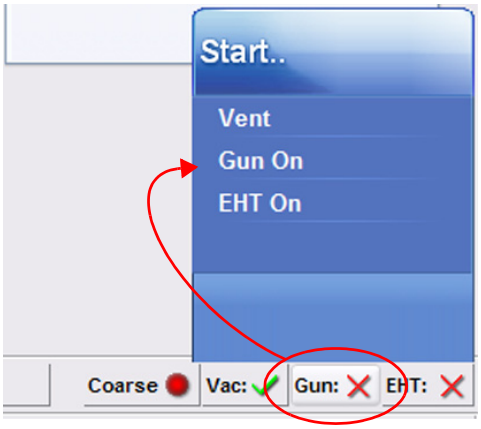
7.4.4 Switching on the gun

1. Confirm that **EHT Vac ready = Yes** is displayed on the **Vacuum** tab of the SEM Control panel.



2. Click **Gun** in the status bar.

3. Select **Gun On** from the pop-up menu to start the gun.

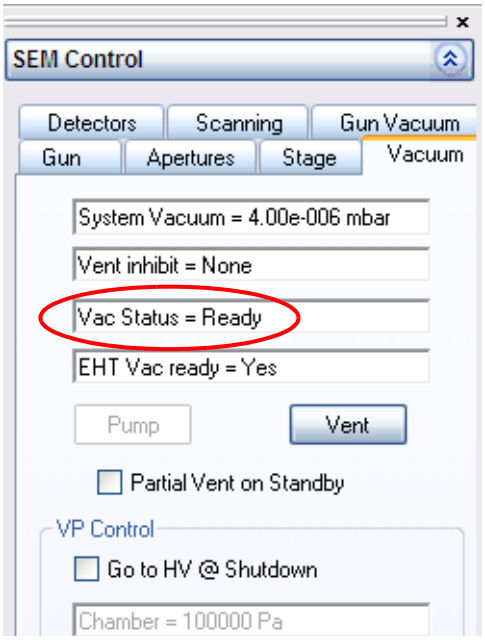


7.4.5 Switching on the EHT

'EHT' means the extra-high tension acceleration voltage. This voltage must be applied to the gun to make the gun emit electrons.

1. Watch the vacuum status messages on the **Vacuum** tab of the **SEM Control** panel.

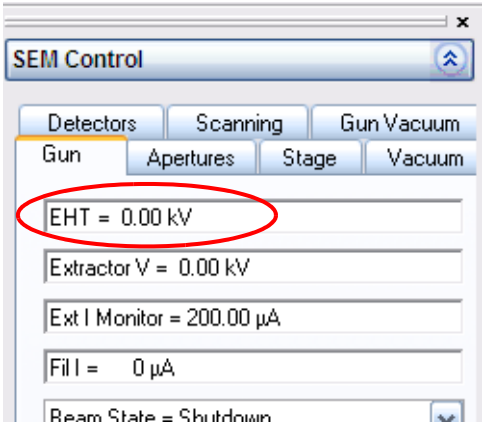
   The message **Vac Status = Ready** is displayed when the required level of vacuum has been reached.



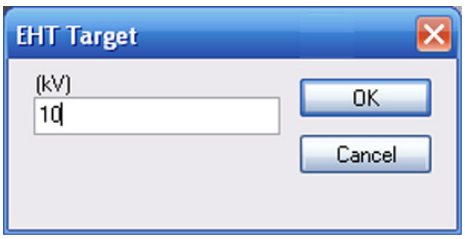
2. Select the **Gun** tab on the **SEM Control** panel.

3. Set the acceleration voltage:

   (a) Double-click in the **EHT=** field.



   (b) Enter the required acceleration voltage in the **EHT Target** field, for example *10 kV*, and click **OK**.

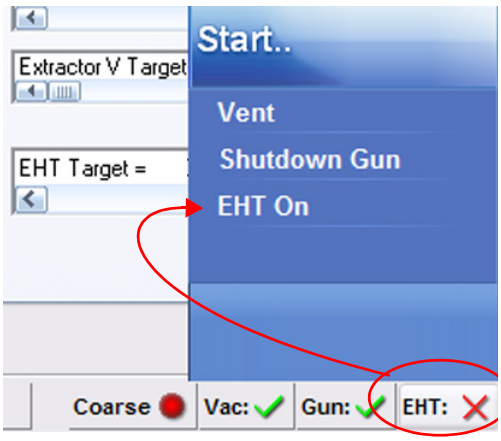


4. Switch on the EHT:

   (a) Click **EHT** in the status bar.

   (b) Select **EHT On** from the pop-up menu.

   The EHT switches on and increases to 10 kV.



   The status bar buttons are merged and the **All:** button is displayed.

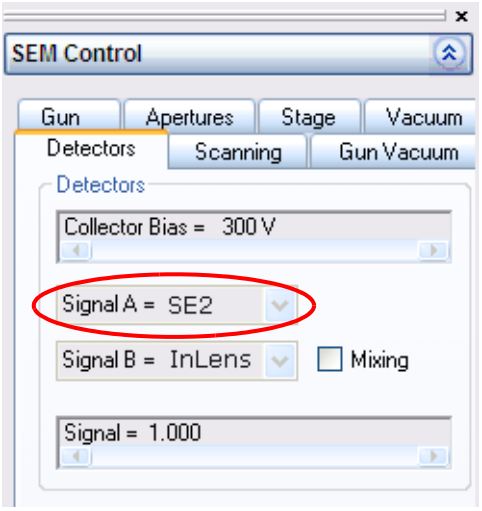
The electron beam is now ON.

7.4.6 Generating an image

1. Select the **Detectors** tab on the **SEM Control** panel.

2. Select **Signal A = SE2** from the drop-down list.

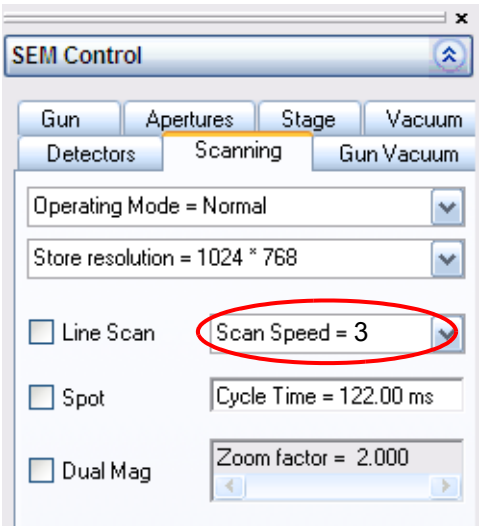
   ZEISS recommends that you select the SE2 detector to obtain the first image. This is because the SE2 detector provides a good signal-to-noise ratio even at long working distances.



3. Select the **Scanning** tab on the **SEM Control** panel.

4. Select a fast scan speed, for example select **Scan Speed = 3** from the drop-down list.

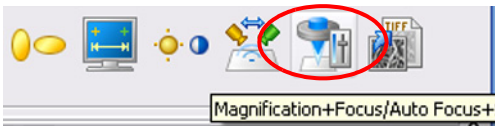
   Lower scan speed numbers cause the electron beam to scan across the specimen at a faster rate. Setting the scan speed to 3 allows you to obtain an image quickly.



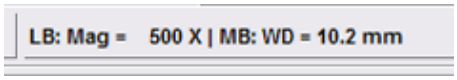
5. Set a low magnification, for example set a magnification of × 500:

   (a) Click the **Magnification/Focus** icon in the toolbar.

   (b) Press the left mouse button and drag the mouse to adjust the magnification to *500* ×.



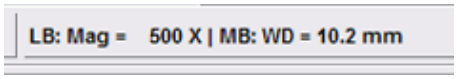
   The current magnification is indicated in the status bar.



6. Set the focus:

   (a) Press the middle mouse button and drag the mouse to focus.

   The current working distance (WD) is indicated in the status bar.



7. Adjust the image contrast and brightness.

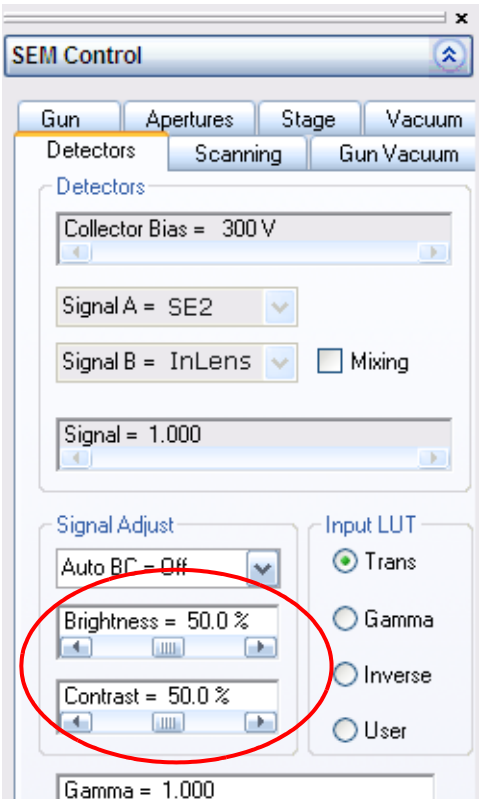
   (a) Select the **Detectors** tab on the **SEM Control** panel.

   (b) Use the mouse to drag and adjust the **Brightness** and **Contrast** slider controls.

8. Select a detail on the specimen surface.

9. Focus the detail.

10. Adjust the contrast and brightness again, if necessary.



7.4.7 Optimising the image

1. Toggle the **Coarse/Fine** button in the status bar to the *Coarse* setting.

2. Increase the magnification in steps to a higher setting, for example × 50000.

   Adjust the focus correctly at each step.

Beam shift function

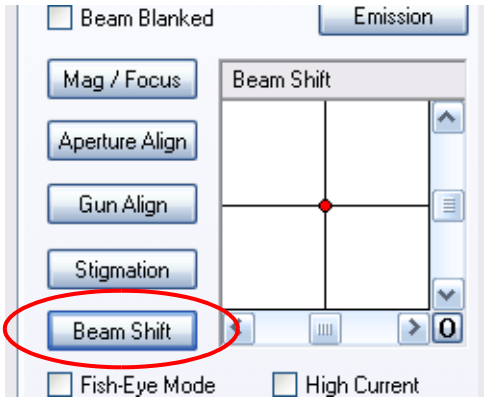
When you select high magnifications, ZEISS recommends that you move the image of the specimen by using the Beam Shift function instead of driving the stage.

3. Use the Beam Shift function:

   (a) Select the **Apertures** tab of the **SEM Control** panel.

   (b) Click **Beam Shift**.

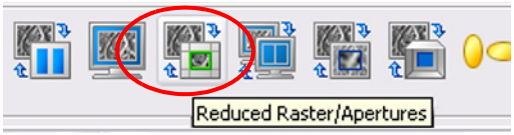
   (c) Use the vertical and horizontal slider controls, or click and drag the red dot to shift the beam.



Reduced raster

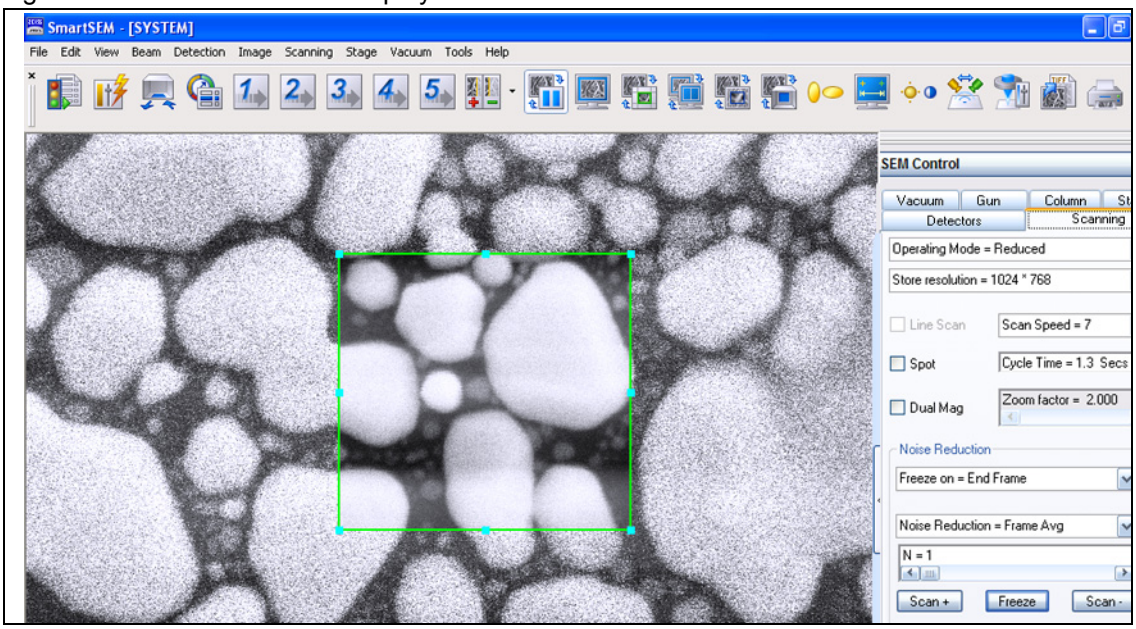
4. Click the **Reduced Raster** icon to display a scan frame.

   The image inside the scan frame continues to update, but the image outside the scan frame does not.



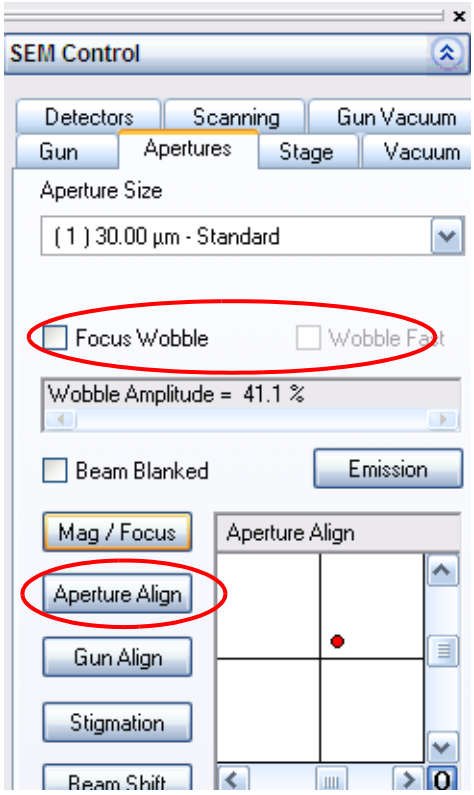
   You can change the size and position of the scan frame by dragging the frame with the mouse. Refer to Figure 7.42 on page 88 for an example of the reduced raster display.

Figure 7.42 Reduced raster display



5. Focus the image in the scan frame.

6. Align the aperture:



(a) Select the **Apertures** tab of the **SEM Control** panel.

(b) Select the **Focus Wobble** check box.

Focus Wobble is a function that sweeps the focus of the objective lens backwards and forwards through the point of focus on the specimen plane. Any misalignment in the aperture appears as lateral shift during focus wobble.

You can use the **Wobble Amplitude** slider to adjust the intensity of wobble. You can select the **Wobble Fast** check box to increase the wobble speed.

(c) Click the **Aperture Align** button.

(d) Adjust the horizontal and vertical slider controls of the **Aperture Align** grid to remove any movement of image detail in the X and Y axes.

When the adjustment is correct, the image of the specimen should pulsate around the focus point, but there should be no X and Y shift in its position.

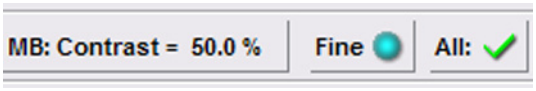
(e) Deselect the **Focus Wobble** check box.

7. Select the **Scanning** tab of the **SEM Control** panel.

8. Select **Scan Speed = 7** in the drop-down list.

9. Adjust the image focus.

10. Toggle to **Fine** in the status bar.



Use the coarse and fine modes of adjustment where appropriate.

Stigmation control

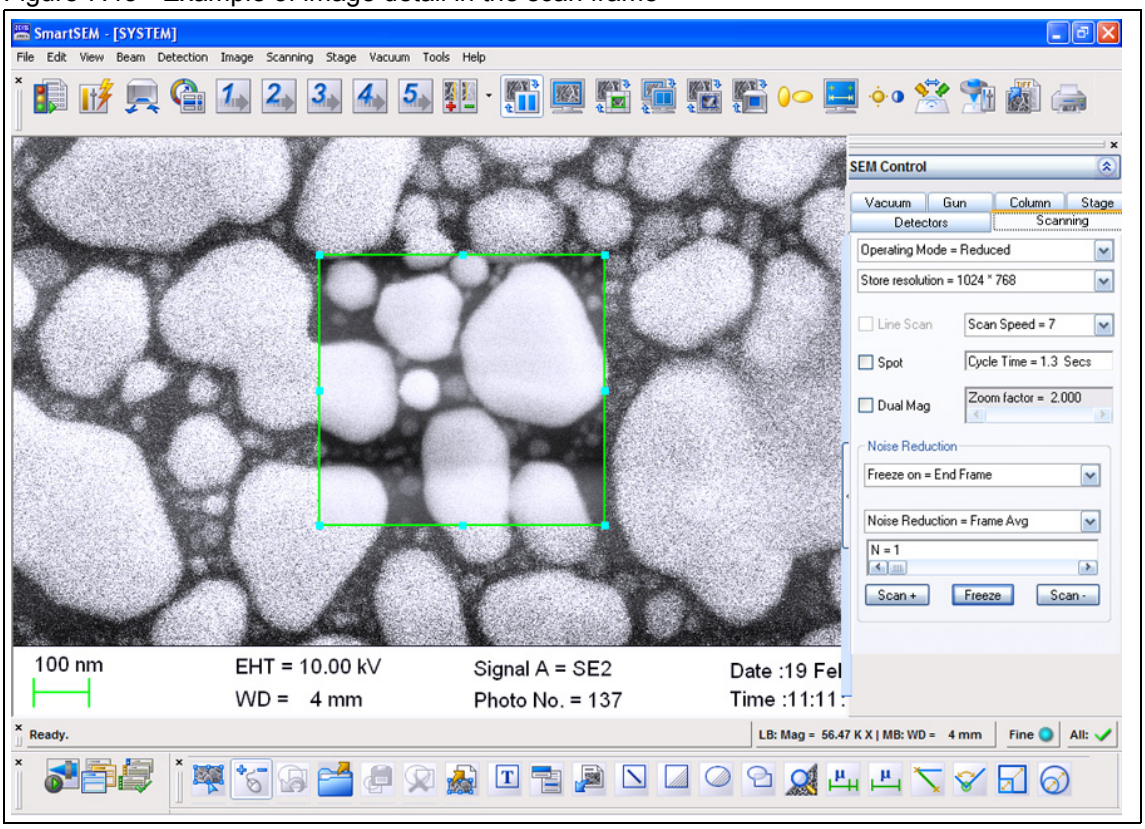
11. Correct astigmatism:

(a) Select a detail on the image (for example, a mark or an edge on the specimen's surface).

(b) Click the **Reduced Raster** icon and adjust the image so that the detail you have selected is inside the scan frame.

You can move the stage, or you can shift the beam for this purpose.

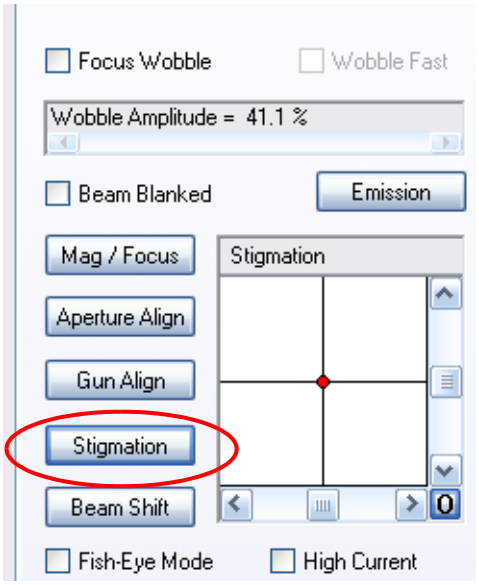
Figure 7.43 Example of image detail in the scan frame



(c) Select the **Apertures** tab of the **SEM Control** panel.

(d) Click the **Stigmation** button.

(e) Adjust the horizontal and vertical slider controls of the Stigmation grid to obtain the sharpest image possible.



12. Deselect the reduced raster icon.

13. Select the **Scanning** tab of the **SEM Control** panel.

14. Select a low scan speed, for example set **Scan Speed = 6** or **Scan Speed = 8**.

7.4.8 Saving the image

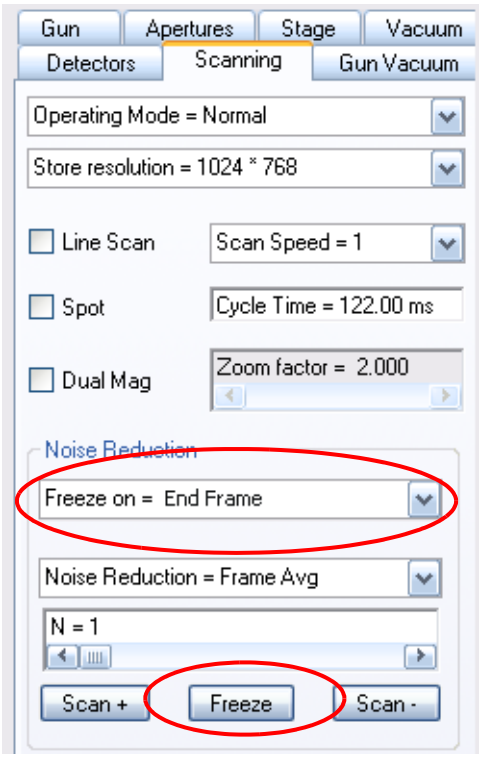
1. Stop the scan:

(a) Select the **Scanning** tab on the **SEM Control** panel.

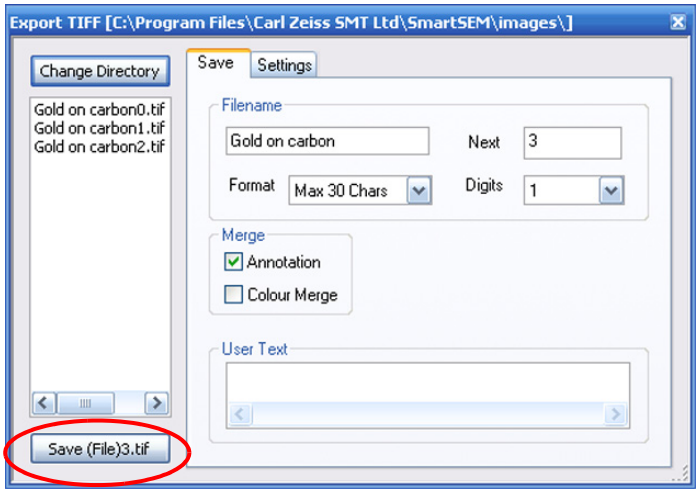
(b) Select **Freeze on = End Frame** in the drop-down list.

(c) Click **Freeze**.

A red dot near the lower right corner of the image area indicates that the image is frozen.



2. Select **File > Save Image** from the SmartSEM® menu.
3. Enter a path and a file name.
4. Click **Save....tif** to save the image file.
5. To continue imaging, select **Image > Unfreeze** from the SmartSEM® menu, or click **Unfreeze** on the Scanning tab.



7.5 Setting SEM conditions

Note:
Refer to Table 1 on page 27 for information about anode aperture diameters, column configurations and probe currents.

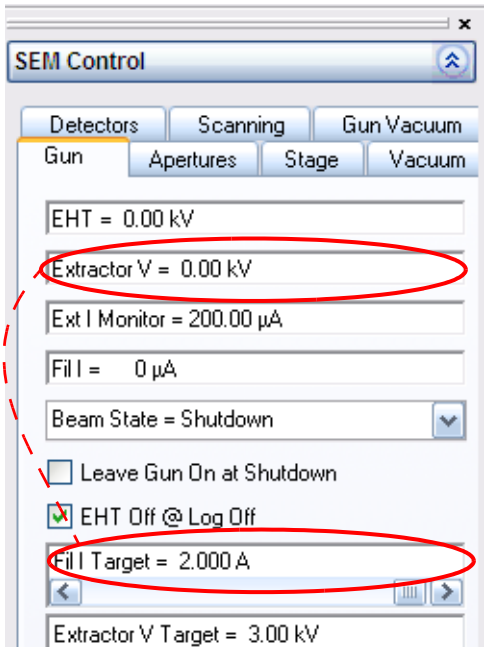
7.5.1 Changing the extractor voltage

The extractor voltage is preset before shipment from the factory, and can be adjusted by the Carl Zeiss service engineer.

You can adjust the extractor voltage within certain limits to optimise the probe current for particular applications. Use care if you attempt this adjustment.

1. Select the **Gun** tab of the **SEM Control** panel.
2. Adjust the **Extractor V Target** slider to increase the extractor voltage.

   Adjusting the extractor voltage can affect the probe current.



CAUTION
Performance and resolution of the FESEM can be impaired by this adjustment.

Avoid reducing the extractor voltage. If it is really necessary to reduce the extractor voltage, do this for only a short time (for no longer than 1 to 2 hours) and by no more than 500 V.

After you change the extractor voltage, calibrate the probe current.

7.5.1.1 Measuring the specimen current

The specimen current is the current flowing through the specimen. It corresponds to the total number of electrons that hit the specimen.

You can use a Faraday cup to detect and measure the specimen current. A Faraday cup consists of a strongly absorbing material with a cavity covered by an electron-microscopic aperture. If there is no risk that secondary electrons or backscattered electrons leave the Faraday cup, the displayed current is the same as the incident beam current.

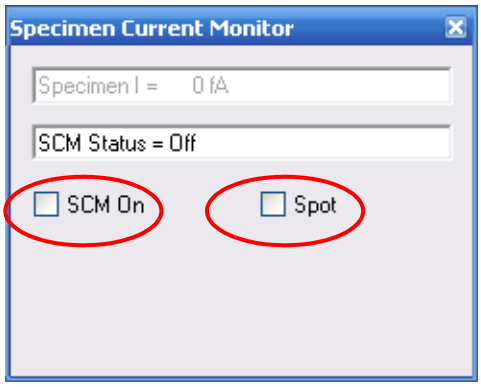
Table 11 Part number – Faraday cup

Parts required	Part no.
Faraday cup	348342-8055-000

Procedure:

1. Load the Faraday cup into the specimen chamber.
2. Pump the specimen chamber to the normal operating vacuum.
3. Turn the electron beam ON.
4. Set a magnification that allows transmission of the complete electron beam into the cavity of the Faraday cup through the Faraday cup's aperture.
5. Open the **Panel Configuration Bar.**
6. Double-click on **Specimen Current Monitor** to display the Specimen Current Monitor panel.
7. Select the **SCM On** check box.
8. Select the **Spot** check box.
9. Use the mouse to move the cross-hairs so that they are in the centre of the Faraday cup.

   The specimen current is measured permanently. The measured value is displayed in the field **Specimen I =** ….

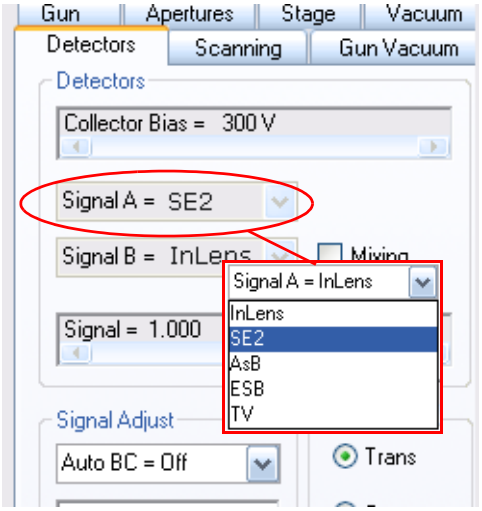


7.5.2 Setting detection parameters

7.5.2.1 Selecting a detector

1. Select the **Detectors** tab on the **SEM Control** panel.

2. Select the required detector from the **Detectors** drop-down list.



7.6 Working in VP mode

The variable pressure (VP) mode makes it possible to use the scanning electron microscope to image specimens that are non-conducting, strongly gassing, or humid, without the need for vapour deposition or other preparation procedures. This is made possible by using a differential pumping system, which allows partial pressures above 1 Pa to be set in the specimen chamber while maintaining a high vacuum or ultra-high vacuum in the gun area and in the beam path.

7.6.1 Principles of VP

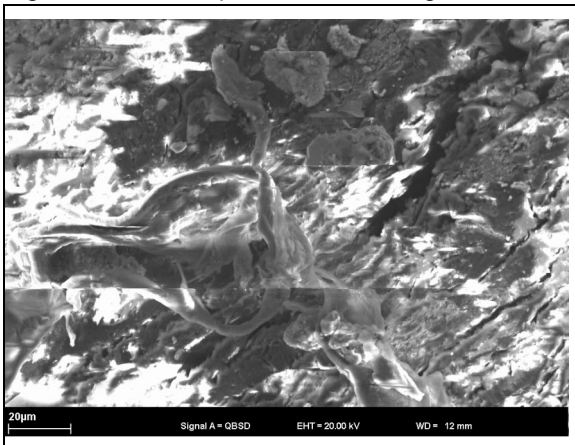
The residual gas atmosphere in the specimen chamber creates an interaction region of electrons and residual gas molecules between the final lens and the specimen. In this region, high-energy electrons in the primary electron beam hit the residual gas molecules and ionise them. The ions generated in these collisions contribute to the compensation of negative charge on the specimen.

However, another effect of these collisions is to scatter the electron beam. This is called the ‘skirt effect’. The electrons that are lost from the primary beam by this effect provide only a resolution-limited background signal for imaging purposes. Although it is possible to tolerate these leakage losses at chamber pressures up to a few hundred Pa, it is necessary to carefully select and control the important factors such as acceleration voltage, chamber pressure and beam path.

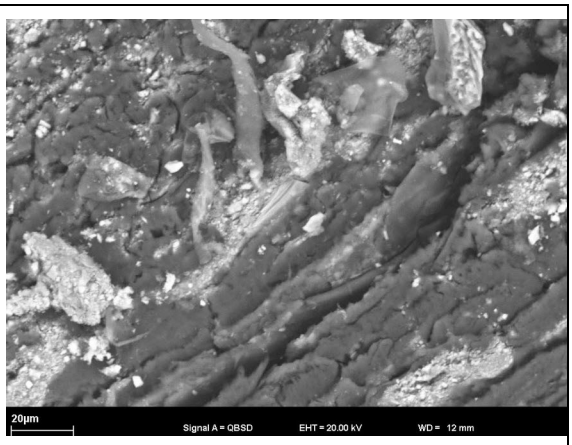
Figure 7.44 compares the charge compensation of a non-conducting target in high-vacuum mode and in VP mode. Both images used an acceleration voltage of 20 kV and a 30 µm aperture.

Although operation in VP mode compensates for the charging effects, the increased chamber pressure reduces the signal-to-noise ratio. This can be compensated by using the noise suppression features of the user interface software.

Figure 7.44 Compensation of charges in VP mode



Non-conducting sample in HV mode, showing strong charging effects. The electron beam is distorted, and high-quality imaging is not possible.



Non-conducting sample in VP mode at 21 Pa. Charges can be completely compensated, allowing easy imaging of the sample.

7.7 Using the help functions

The SmartSEM® user interface provides help on a range of subjects, including operation of the FESEM, optimization of the images, and the handling of accessory options.

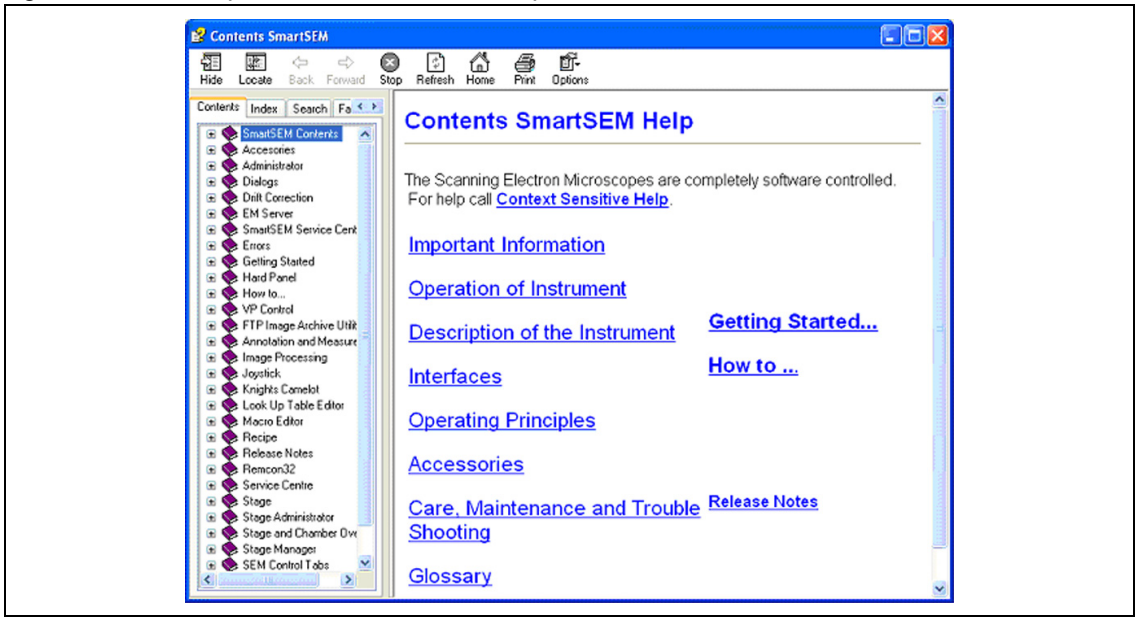
7.7.1 Starting the SmartSEM® help

1. Press the <**F1**> key, or select **Help > SmartSEM help** from the menu to display the SmartSEM® help window.

Context sensitivity

The SmartSEM® help system is context sensitive. If you have windows open in the SmartSEM® user interface, press <**F1**> to open the help text for the respective menu. This feature helps you to find help that is relevant to the task you are currently performing.

Figure 7.45 Example of the SmartSEM® help



7.7.1.1 Printing help texts

1. Click on the printer icon in the help window.

   If a printer is installed, the help text is printed.

7.7.1.2 Displaying help on top of all open windows

1. Select **Help > Help Always On Top** from the SmartSEM® menu.

   The displayed help windows remain visible on top of other open windows.

7.7.2 Showing context-sensitive help

1. Press <**SHIFT+F1**>, or select **Help > What's This** from the SmartSEM® menu.

   The mouse cursor changes to a question mark.

2. Click the cursor on an item on the screen.

   Help is displayed for the item you clicked.

3. Press the <**ESC**> key to disable the context-sensitive help.

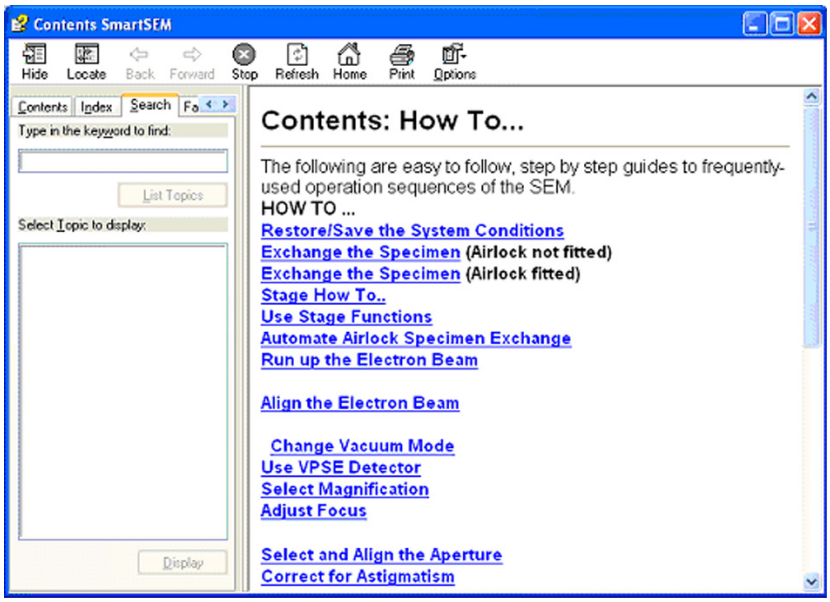
7.7.3 Searching for a topic

1. Select **Help > Search** from the menu.

2. Select the **Search** tab.

3. Type details of the topic to find and click List Topics to display a list of topics that include the details you want to find.

Figure 7.46 Searching for a topic



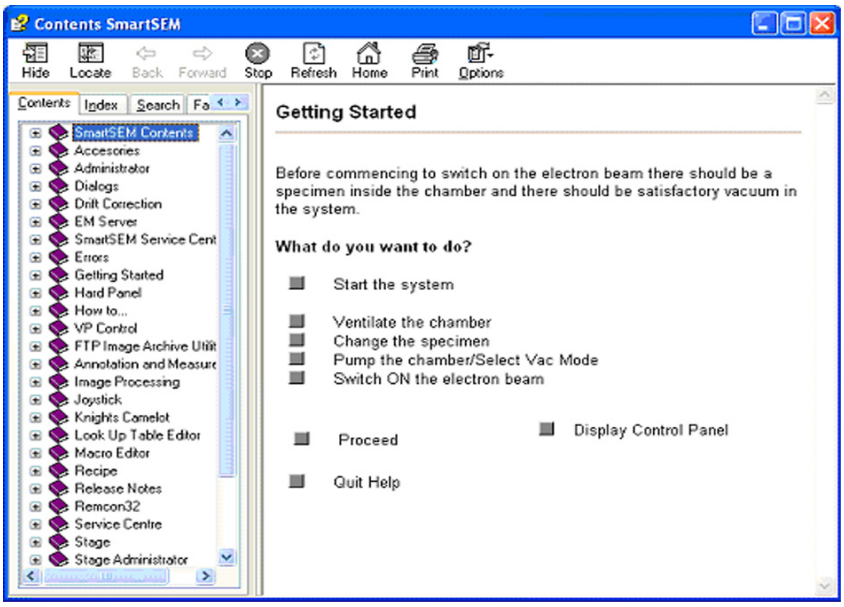
7.7.4 Using the step-by-step guides

The step-by-step guides provide quick information on important operation sequences.

7.7.4.1 Getting started

1. Select **Help/Getting started** from the menu.

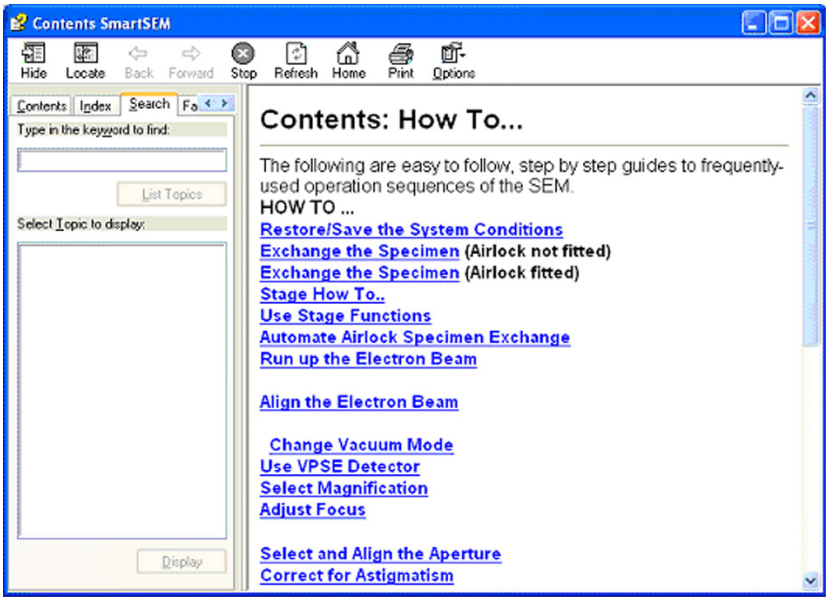
2. Click on the topic of interest.



7.7.4.2 Frequently used operation sequences

1. Select **Help > How To** from the SmartSEM®menu.

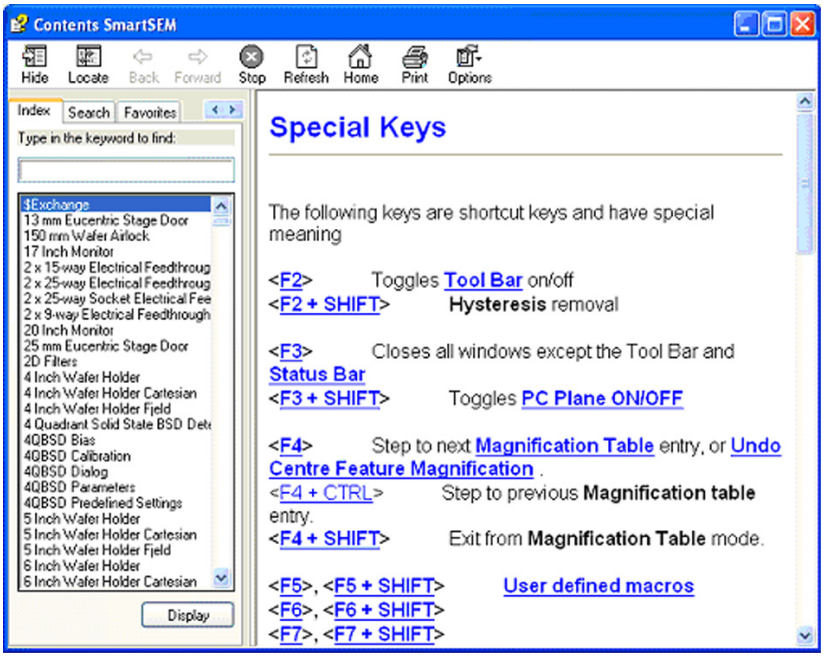
2. Click on the topic of interest.



7.7.5 Using the shortcuts help

You can enter shortcut commands at the keyboard to use many of the functions available in the SmartSEM® user interface. You can see a list of the keyboard commands that are available.

1. Press < **F9**>, or select **Help > Keys help** from the SmartSEM® menu.

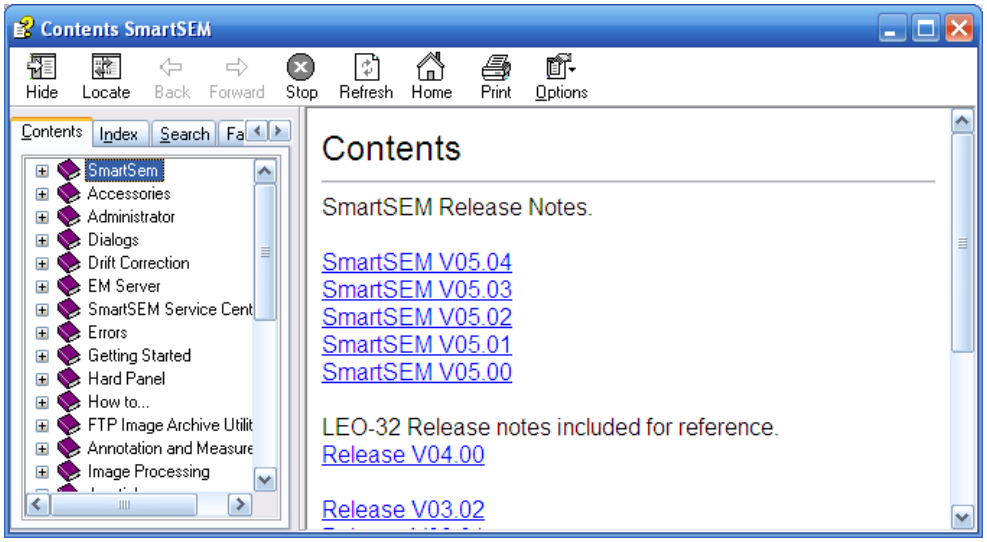


7.7.6 Viewing information about SmartSEM®

7.7.6.1 Version history

The Release Notes summarise important information about the software version history. New functions, bug fixes and special features of the different versions are explained.

1. Select **Help > Release Notes** from the SmartSEM® menu.



7.7.6.2 About SmartSEM®

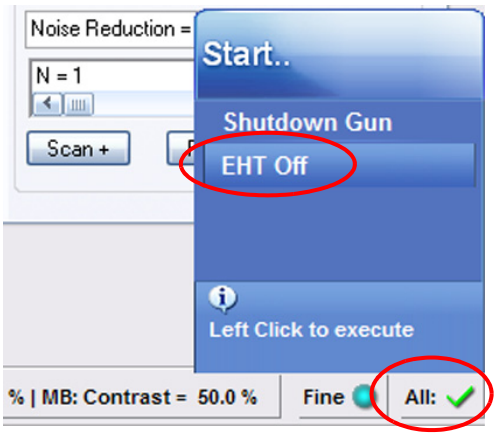
1. Select **Help > About SmartSEM** from the SmartSEM® menu.

7.8 Finishing the work session

1. Switch off the EHT:

   (a) Click on the **All:** button in the status bar.

   (b) Select **EHT Off** from the pop-up menu.



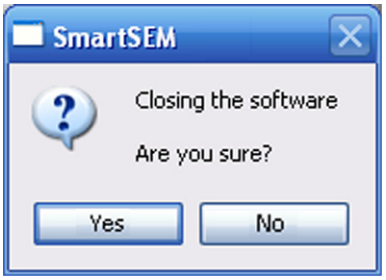
Note:
ZEISS recommends that you leave the gun ON during the working week. This can help to optimise the lifetime of the emitter.

7.9 Closing the SmartSEM® user interface

7.9.1 Logging off

1. Select **File > Log Off** from the SmartSEM® menu.

   A message box is displayed asking for confirmation to close the session.



2. Click **Yes** to confirm.

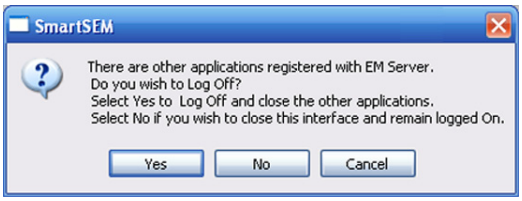
The electron-optical parameters are filed in a macro in the individual user directory.

The EM Server remains active.

7.9.2 Exiting SmartSEM®

1. Select **File > Exit** from the SmartSEM® menu.

   A message box is displayed asking for confirmation to close the session.



2. Click **Yes** to confirm.

The electron-optical parameters are filed in a macro in the individual user directory.

7.10 Switching off the FESEM as a matter of routine

7.10.1 Changing to STANDBY mode

When to use STANDBY

Change to **STANDBY** mode when the FESEM is not operated, even for longer periods.

When the FESEM is in STANDBY mode, the filament continues to be heated, and the vacuum in electron optical column and specimen chamber is maintained.

STANDBY mode is also the recommended mode to store the FESEM. If you need to store the FESEM, select the **Partial Vent on Standby** check box in the **Vacuum** tab of the **SEM Control** panel. This can help to prevent oil vapours from penetrating into the specimen chamber during the period of storage.

Procedure

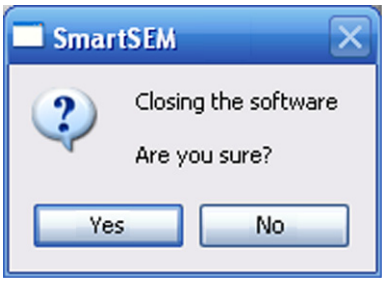
1. Switch off the EHT.

2. Close SmartSEM®:

   (a) Select **File > Exit** from the SmartSEM® menu.

   A message box is displayed asking for confirmation to close the session.

   (b) Click **Yes** to confirm.

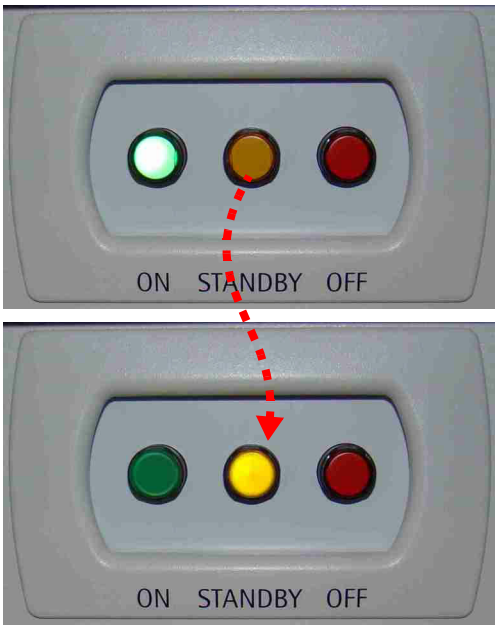


The electron-optical parameters are filed in a macro in the individual user directory.

3. Shut down the PC.

4. Press the yellow **STANDBY** push button.

   The **STANDBY** button comes ON.



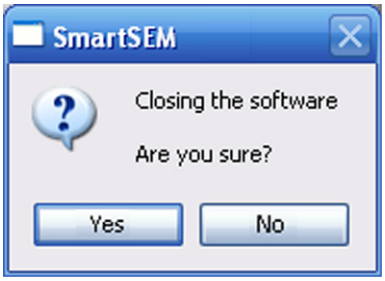
7.10.2 Changing to OFF mode

Change to **OFF** mode if the FESEM needs to be reset.

1. Switch off the EHT.

2. Close SmartSEM®:

   (a) Select **File > Exit** from the SmartSEM® menu.



   A message box is displayed asking for confirmation to close the session.

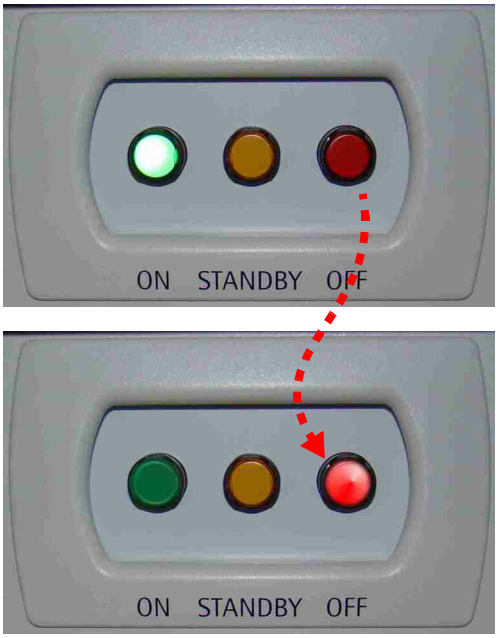
   (b) Click **Yes** to confirm.

The electron-optical parameters are filed in a macro in the individual user directory.

3. Shut down the PC.

4. Press the red **OFF** push button.

   The **OFF** button comes ON.



In this mode, the PC, the electronic components and the vacuum system are all switched off. The electron optical column is partially ventilated. A 24 V auxiliary voltage is available to restart the FESEM.

7.11 Switching off the FESEM completely

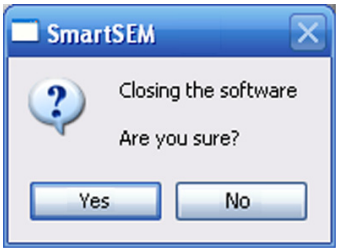
This procedure completely switches off the FESEM from the electrical main electrical supply.

1. Switch off the EHT.

2. Close SmartSEM®:

   (a) Select **File > Exit** from the SmartSEM® menu.

   A message box is displayed asking for confirmation to close the session

   (b) Click **Yes** to confirm.

The electron-optical parameters are filed in a macro in the individual user directory.

3. Shut down the PC.

4. Press the red **OFF** button.

   The red **OFF** button comes ON.

5. Close and lock the main shut-off valves at the installation site.

8 Maintenance and repair

WARNING

Risk of injury. Risk of property damage.

Perform only such tasks described in this instruction manual.

Those maintenance and service tasks that are NOT described full in this instruction manual must be performed ONLY by authorised Carl Zeiss service engineers who have received the proper training from Carl Zeiss NTS Ltd.

IMPORTANT:

To maintain the best possible performance of the FESEM it is essential to perform regular preventive maintenance.

It is also recommended that you enter a service contract with your local Carl Zeiss service organisation or representative. This will help to ensure continuous trouble-free operation of the FESEM.

Scheduled downtime is the time when the FESEM is not available to perform its intended function because of planned downtime events. The schedule downtime include the following reasons:

- Change of consumables and chemicals
- Basic preventive maintenance performed by the operator
- Preventive maintenance performed by authorised Carl Zeiss service staff

8.1 Change of consumables and chemicals

The change of consumables and chemicals is a scheduled interruption of operation to replenish process consumables and chemicals. The times scheduled are designed for the maximum equipment performance level (that is, 24 hours of continuous operation).

Table 12 Recommended schedule – Change of consumables and chemicals

Interval	Component/Part	Action
Every 6000 hours[a] (filament on)	Field emission gun[a]	Contact the local Carl Zeiss service engineer to have the field emission gun replaced.
As required or yearly (and after exchange of field emission gun)	• Standard aperture • Anode aperture • Extractor aperture • Anode aluminium seal • Copper seal at gun head	Contact the local Carl Zeiss service engineer to have the apertures replaced.
Yearly or as required	Pre-vacuum pump	Replace the tip seal. Refer to pump manufacturer's documentation.
Yearly	• SE2 detector • In-lens detector • AsB® or CZBSD detectors • VPSE G3 • STEM • CL	Contact the local Carl Zeiss service engineer to have the detectors checked and scintillators replaced if required.

a. There is no warranty on field emission guns; manufacturers do not guarantee any lifetime.

8.1.1 Fitting a new field emission gun

Emitter lifetime depends on several operating parameters, but depends mainly on filament temperature. An emitter can be destroyed by a catastrophic arc between the filament and the extractor electrode.

Field emission gun and apertures may be removed and fitted only by an authorised Carl Zeiss service engineer.

8.1.2 Fitting a new tip seal in the pre-vacuum pump

This operation should be performed only by a Carl Zeiss engineer.

Refer to the instruction manual provided by the manufacturer of the pre-vacuum pump for instructions.

8.2 Basic preventive maintenance performed by the operator

8.2.1 Checking for safe operation

1. Check that all protective covers are in position and are in good condition.

2. Inspect and clean the product safety labels to maintain good legibility.

8.2.2 Disk maintenance on the PC

As with any PC it is important to periodically perform disk maintenance. If necessary, refer to standard Windows® manuals for instructions to do this. You should backup the database to the server or to other storage before you perform any disk maintenance.

1. Empty the temporary files folder.

2. Defragment the hard drive.

3. Check for adequate free space on the hard drive.

8.2.3 Initialising the stage

It is necessary to initialise the stage if a stored stage position cannot be approached or if absolute stage movement is required.

Before you can perform a stage initialisation, you must have *Stage Initialise* privileges in your user profile.

Note that the specimen chamber must be evacuated before you can perform a stage initialisation.

Note that this procedure assumes there is no Coolstage fitted.

Procedure

1. Select **Stage > Stage initialise** from the SmartSEM®menu.

   A message box is displayed asking you to confirm the action.

2. Click **Yes** to confirm.

IMPORTANT:
If initialisation of the stage does not solve the stage problem, contact your local Carl Zeiss service engineer.

8.2.4 Baking out the gun head

The gun vacuum will deteriorate with time. It is possible to perform a bake-out operation as a regular maintenance procedure to restore the vacuum.

Note:
Only advanced operators with Admin rights on the controlling PC are allowed to perform the bake-out procedure.

The bake-out procedure requires you to have Supervisor privileges and the user access level Service.

Note that you cannot continue working with the FESEM while the bake-out procedure continues.

Procedure:

1. Select **All > Shutdown Gun** from the status bar in SmartSEM® to switch off the EHT and the Gun.
2. Wait until the Gun has completely switched off.
3. Remove the gun cable from the gun head.
4. Select **Tools/Goto panel** the SmartSEM® user interface to display the **Panel Configuration Bar**.
5. Double-click on **Bakeout** to display the **Bakeout** dialog.

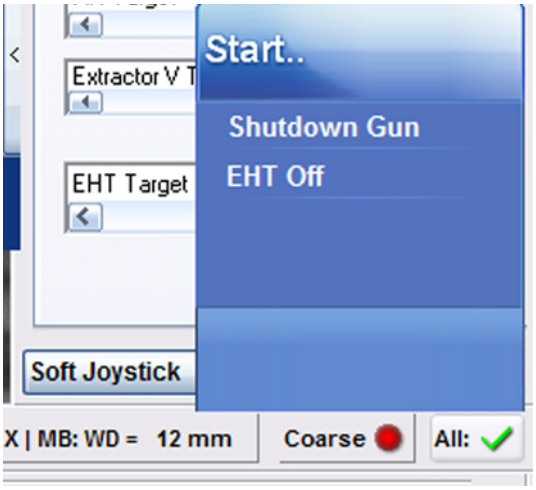
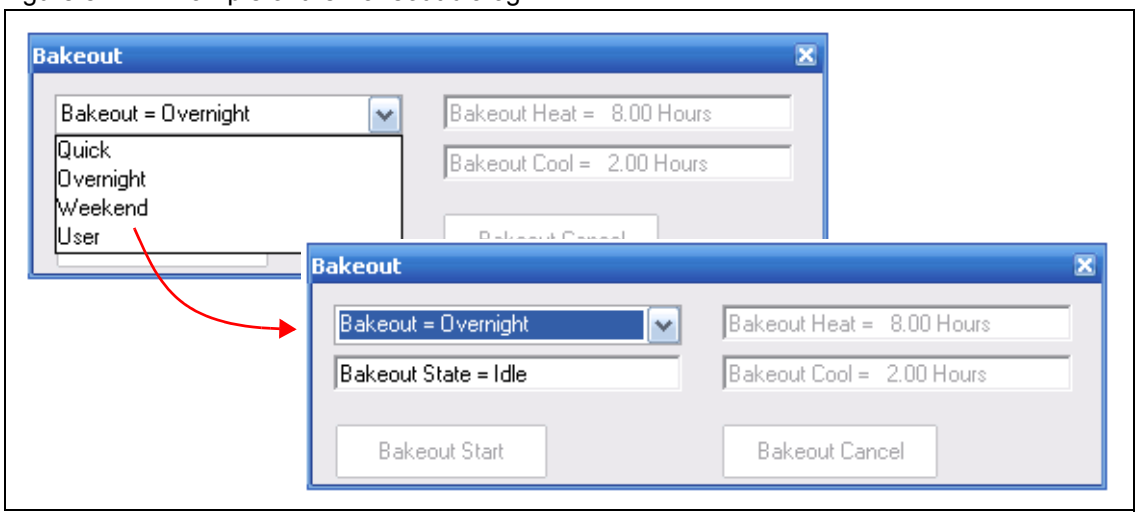


Figure 8.47 Example of the Bakeout dialog



6. Select one of the following bake-out cycles from the drop-down list:

   - *Quick*: 2 hours heating / 1 hour cooling
   - *Overnight*: 8 hours heating / 2 hours cooling
   - *Weekend*: 40 hours heating / 3 hours cooling
   - *User*: To be defined by the operator.

WARNING

Risk of injury from hot surfaces during bakeout.

Parts of the enclosure in the upper part of the column might become hot during the bake-out procedure, particularly after a long bake-out cycle.

Do not touch any parts of the cover panel. Do not place any combustible objects on the electron optical column.

Note:

You can switch to STANDBY mode while the bake-out procedure is running.

Before you switch to STANDBY mode, make certain the PARTIAL VENT ON STANDY check box is DESELECTED in the SEM Control panel.

7. Click **Bakeout Start** to start the bakeout procedure.

8. Switch on the gun to continue working with the FESEM.

8.2.5 Servicing the pre-vacuum pump

For maintenance of the pre-vacuum pump refer to the instruction manual supplied by the pump manufacturer.

8.3 Preventive maintenance performed by Carl Zeiss service staff

Preventive maintenance is a scheduled downtime that is essential to achieve the best equipment performance level (that is, 24 hours of continuous operation).

Annual preventive maintenance is performed by the local Carl Zeiss service engineer. It includes the following services:

- Inspection
- Preventive actions
- Equipment test
- Verification run

8.4 Repair

The repair tasks described in the following section can be performed by the operator.

Note:
Those maintenance and service tasks that are NOT described fully in this instruction manual must be performed ONLY by authorised Carl Zeiss service engineers who have received the proper training from Carl Zeiss NTS Ltd.

8.4.1 Fitting a new chamber door seal

It may be necessary to fit a new O-ring to seal the chamber door if the chamber door does not close tightly. This can cause a poor chamber vacuum.

WARNING
Suffocation hazard due to lack of oxygen.

The specimen chamber is ventilated with nitrogen.

Make certain the area around the FESEM is properly ventilated.

Note:
Contamination caused by fingerprints can lead to vacuum deterioration or prolonged pumping times.

Always wear lint-free gloves when touching specimen, sample holder or stage. Keep the chamber door open for as short a time as possible.

Procedure:

1. Ventilate the specimen chamber.

2. Open the chamber door.

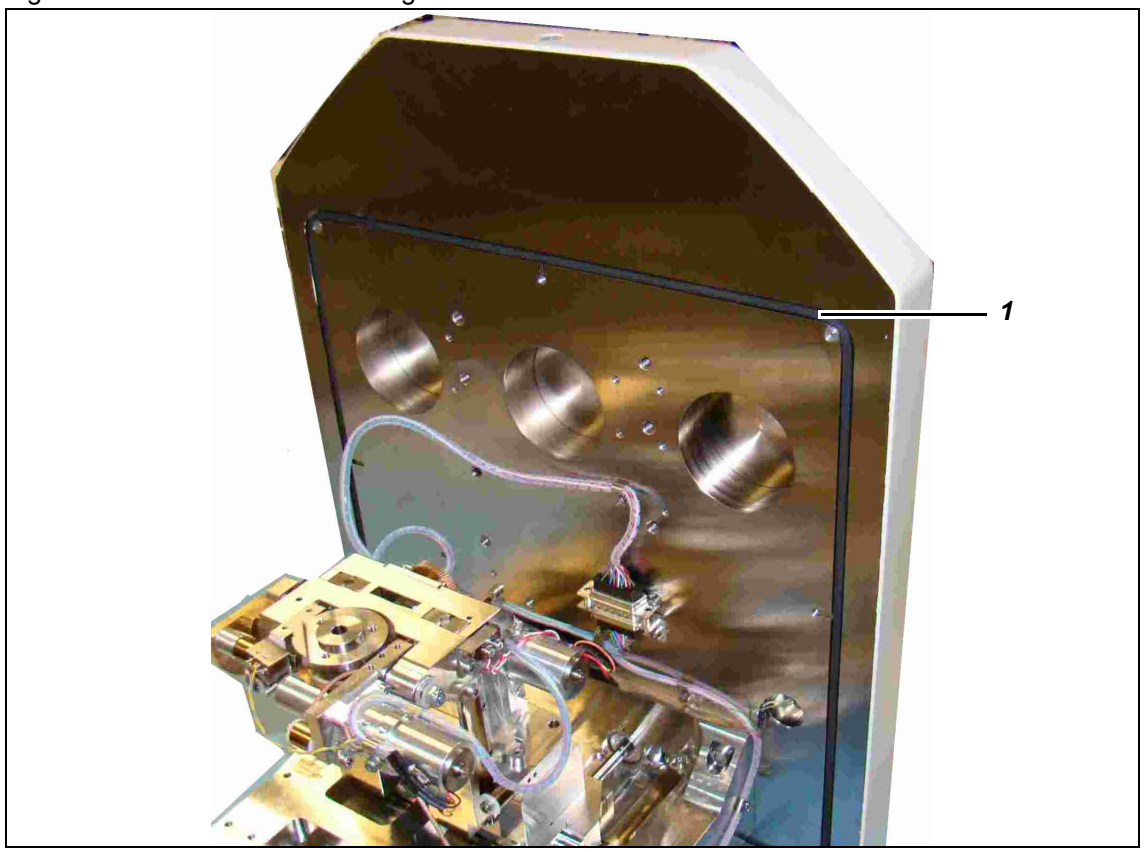
CAUTION

There is a danger of damaging the sealing surface when using metal tools.

If necessary, use a plastic or wooden tool to remove the O-ring that seals the chamber door.

3. Remove the O-ring (**1**) that seals the chamber door.

Figure 8.48 Chamber door O-ring



4. Inspect the groove that holds the O-ring and remove any contamination.

5. Fit the new O-ring into the groove in the chamber door.

6. Close the chamber door.

7. Pump the specimen chamber to the normal vacuum level.

8. Check that the vacuum level is maintained.

8.4.2 Checking the circuit breakers

You must check the circuit breakers if one or more of them trips. A tripped circuit breaker is in the down position.

Procedure:

1. Check the circuit breakers at the back of the plinth.

Figure 8.49 Circuit breakers shown in their closed position

2. If one of the circuit breakers is tripped, reset it by pressing the operating lever upwards.

   If this does not solve the problem, contact your local Carl Zeiss service engineer for assistance.

Note:
Tripped circuit breakers might indicate an electrical problem in the FESEM.

If a circuit breaker trips again after you reset it, or if it trips often, switch off the FESEM completely and contact the Carl Zeiss service engineer for assistance.

9 Troubleshooting

The following table gives some clues to solve problems.

If you cannot solve the problem or if you are feeling unsure do not hesitate to get in contact with your local Carl Zeiss service engineer.

WARNING

Danger to life: There are hazardous voltages inside the FESEM.

Only service engineers who have been trained and authorised by Carl Zeiss NTS Ltd are allowed to service the FESEM.

Table 13 Troubleshooting

Keyword	Symptom	Possible reason	Recommended action/s
FESEM	FESEM shows no lights and does not appear to function	Circuit breaker is tripped (lower position).	Check the circuit breakers. Refer to section 8.4.2
Vacuum	“Vac ready = OK” is not shown after specimen exchange.	System vacuum is bad due to a vacuum leak at the chamber door.	Check the chamber door seal for cleanliness. If necessary, fit a new chamber door seal. Refer to section 8.4.1
	“Vac ready = OK” is shown very late after specimen exchange.	Gas ballast is activated at the pre-vacuum pump.	Deactivate the gas ballast at the pre-vacuum pump.
	FESEM does not vent.	No nitrogen. No compressed air.	Check the nitrogen supply. Check the compressed air supply.
System vacuum	“Vac ready = OK” is indicated abnormally fast.	Penning gauge has not been identified correctly.	Re-start the FESEM. If this does not solve the problem, call your local Carl Zeiss service engineer.
	Bad system vacuum.	Chamber door seal does not seal tightly.	Fit a new chamber door seal. Refer to section 8.4.1
Gun vacuum	Gun vacuum is worse than 8 to 9 × 10^{-9} mbar.	Gun has been switched off for safety reasons because the gun vacuum is too bad.	Bakeout the gun head. Refer to section 8.2.4

Table 13 Troubleshooting (Continued)

Keyword	Symptom	Possible reason	Recommended action/s
Specimen stage	Stage does not move.	Stage needs to be initialised.	Initialise the stage. Refer to section 8.2.3 If this does not solve the problem, call your local Carl Zeiss service engineer.
	Stored position cannot be approached correctly.	Stage needs to be driven to a well-defined position.	Initialise the stage. Refer to section 8.2.3
Specimen stage / PC	Stored position cannot be approached correctly.	PC has crashed. Stage needs to be driven to a well-defined position.	Re-boot the PC. Initialise the stage. Refer to section 8.2.3
Drift	Specimen seems to be moving.	Charging effects. Non-conducting specimen.	Ensure proper conduction of the specimen. Optimise specimen preparation. Apply a charge compensation method.
Gun	Gun is switched off automatically. Gun vacuum worse than 2×10^{-8} mbar	Gun has been switched off for safety reasons because the gun vacuum is too bad.	Bakeout the gun head. Refer to section 8.2.4
Image quality	Image quality degrades, but there is no change in total emission current.	Field emission gun has been damaged due to arcing.	Call the local Carl Zeiss service engineer to fit a new field emission gun.
	Image is noisy. Noise reduction methods do not remedy.	Field emission gun is used up.	Call the local Carl Zeiss service engineer to fit a new field emission gun.
	Image is bad at low EHT (for example, 1 kV)	Working distance is too long.	Reduce the working distance to a maximum of 7 mm.
In-lens image	In-lens image is noisy.	Working distance is too long.	Reduce the working distance to a maximum of 7 mm.
	No In-lens image	EHT exceeds 20 kV.	Reduce the EHT to a maximum of 20 kV.
SE2 image	SE2 image is noisy	Scintillator is worn out.	Call the local Carl Zeiss service engineer to fit a new scintillator.

Table 13 Troubleshooting (Continued)

Keyword	Symptom	Possible reason	Recommended action/s
Specimen current meter	Specimen current is low.	Field emission gun is used up.	Call the local Carl Zeiss service engineer to fit a new field emission gun.
After power failure	Stored stage position cannot be approached correctly.	Stage needs to be initialised.	Initialise the stage. Refer to section 8.2.3

10 Shutdown and disposal

10.1 Putting the FESEM out of operation

You should arrange to put the FESEM out of operation if you do not intend to use it for an extended period of time, for example several months.

Contact your local Carl Zeiss service engineer to have the FESEM put out of operation. The service engineer make certain the cooling water is completely removed from the interior of the FESEM.

10.2 Disposal

10.2.1 Disposing of solid waste (consumables)

The operator must make certain that solid waste (consumables) is disposed of and recycled in a responsible manner.

Table 14 Waste disposal

Description	Material	Disposal
Schottky field emitter	Tungsten, ceramics	Used-up emitters may be returned to the emitter manufacturer.
Apertures	Platinum, iridium, gold	Very small amounts. May be disposed of in accordance with local/regional regulations.

10.2.2 Disposing of the FESEM

The operator must ensure that waste products are disposed of and recycled in a responsible manner.

Refer to EC directive 2002/96/EC on waste electrical and electronic equipment (WEEE).

The FESEM consists of several modules. Be careful to separate the materials properly when you dispose of the FESEM. Separate the materials as follows:

- Materials: for example metals, non-metals, composite materials, process materials
- Electronic scrap material: for example transformers, circuit boards, cables

Comply with national and regional waste disposal regulations.

11 Parts and tools

WARNING

Risk of injury or property damage when using inappropriate parts or tools.

Use only genuine ZEISS parts.

Order parts and tools at your local Carl Zeiss service organization.

For customer service please contact your local Carl Zeiss service engineer.

A list of Carl Zeiss locations and authorised service partners can be found at:

http://www.smt.zeiss.com/nts

12 Abbreviations

AIC	Ampere interrupting capacity
AsB®	Angle selective backscattered
BSE	Backscattered electron
CC	Charge compensator
CCD	Charge coupled device
CZBSD	Carl Zeiss backscattered electron detector
EC	European Community
EHT	Extra high tension
EIGA	European Industrial Gases Association
EMC	Electromagnetic compatibility
FESEM	Field emission scanning electron microscope
GUI	Graphical user interface
H	Height
IGP	Ion getter pump
M	M-axis
MSDS	Material safety data sheet
PC	Personal computer
PE	Protective earth (ground)
R	R-axis
SE	Secondary electron
SMT	Semiconductor Manufacturing Technologies
T	T-axis
U	Voltage
UIF	User interface
W	Width
WD	Working distance
WEEE	Waste electrical and electronic equipment
X	X-axis
Y	Y-axis
Z	Z-axis

Abbreviations

13 Glossary

Aperture	Small opening in the beam path that forms and limits the electron or ion beam.
Astigmatism	Lens aberration that distorts the shape of the electron beam, compensated by the stigmator.
Backscattered electrons	High-energy electrons that are liberated from the specimen surface when the specimen is hit by the primary electron beam.
Bakeout	Degassing of surfaces of a vacuum system by heating during the pumping process.
Beam booster	Anode and liner tube of the Gemini® column are connected mechanically and electrically forming the beam booster. A booster voltage (U_B, liner voltage) of +8 kV is applied to the beam booster, so that a high beam energy is maintained throughout the entire column. The beam booster technique has two main advantages: • It minimises beam widening, that may occur due to stochastic electron-electron interactions. Consequently there is almost no loss in beam brightness, even at low acceleration voltages. • It enhances protection against external stray fields.
Condenser	Device that collects and focuses the electron beam onto the specimen. The ΣIGMA™ is equipped with a double condenser that includes an upper and a lower part.
Depth of field	Distance along the optical axis that an object in the specimen can be moved while remaining in focus
Extractor	Positive electrode that attracts electrons from the filament.
Faraday cup	Small insulated metal container, equipped with an aperture where electrons can enter but not escape. Used to measure the specimen current in the FESEM.
Focus wobble	Function that sweeps the focus of the objective lens backwards and forward through the focus on the specimen plane. When the aperture is misaligned a lateral shift is observed.
Penning gauge	Device for measuring high vacuum in the vacuum system.
Pre-vacuum pump	A pump for generating a pre-vacuum.
Scintillator	Phosphor-treated surface that emits small flashes of light when it is hit by electrons.

Secondary electrons	Low energy electrons that are liberated from the specimen surface when the specimen is hit by the primary electron beam. Secondary electrons are generated by inelastic scattering.
Suppressor	Electrode (anode) that suppresses unwanted thermionic emission from the shank of the Schottky field emitter.
Stigmator	Compensates astigmatism (lens aberration), so that the electron beam becomes rotationally symmetrical.
Schottky field emitter	Type of electron source in which emission occurs at or near the work function barrier.
Scintillator	Substance that absorbs electrons and, in response, fluoresces photons while releasing the previously absorbed energy.
Primary electrons	Narrowly bundled beam of accelerated electrons that hit the specimen surface.
X-ray	Type of ionising radiation that is generated during the operation of electron microscopes

14 Declaration of conformity

Denomination:	Field emission scanning electron microscope (FESEM)
Model:	ΣIGMA™
Manufacturer	Carl Zeiss NTS Ltd 511 Coldhams Lane Cambridge CB1 3JS UK

This is to declare that the machinery mentioned above fulfils all the relevant provisions of the

- Directive 2006/42/EC.

Moreover, the machinery fulfils the following directives and standards:

- Directive 2004/108/EC
- Standard EN 60204-1
- Standard EN 61000-6-4
- Standard EN 61000-6-2
- Standard EN 61010-1
- Standard EN ISO 12100-1/2

Unauthorised modifications of the machinery will cancel this declaration.

CE marking

The CE conformity marking is located on the type plate of the machinery.

Declaration of conformity

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Due to a policy of continous development, we reserve the right to change specifications without notice.