

1 Introduction

The MIRA3 series is a family of high-quality; fully PC-controlled scanning electron microscopes equipped with a Schottky Field Emission electron gun designed for high vacuum or variable pressure operations.

The most important features of the microscope are:

- High brightness Schottky emitter for high-resolution/high-current/low-noise imaging.
- Unique three-lens Wide Field Optics™ design offering the variety of working and displaying modes embodying the Tescan proprietary Intermediate Lens for the beam aperture optimization.
- Real time In-Flight Beam Tracing™ for the performance and spot optimization integrating the well established software Electron Optical Design.
- A powerful In-Beam detector of secondary electrons located in the objective lens enabling work at very short working distances for high resolution.
- Fast imaging rate.
- High-throughput large-area automation, e.g., automated particle location and analysis.
- Fully automated microscope set-up including electron optics set-up and alignment.
- Sophisticated software for SEM control, image acquisition, archiving, processing and analysis.
- Network operations and built-in remote access/diagnostics.

This manual provides an overview of the components, the operational principles and the use of MIRA3 scanning electron microscopes. Not all parts of this manual may apply to a given installation nor should be taken laterally in all cases. Details of the MiraTC software may also vary according to the actual setting and thereby differ slightly from what is shown in the figures.

Since MIRA3 is installed and maintained by trained specialists, technical details and installation procedures are limited to a short overview. In case of necessary maintenance, reinstallation, hardware changes, etc. the appropriate service authorities or your local supplier must be contacted for further assistance and instructions.

4 Description of the Microscope

4.1 Electron Column

The scanning electron microscope displays the examined object by means of a thin electron probe. The column forms the electron probe (beam) and sweeps the beam over the examined specimen located in the microscope chamber. Most imaging qualities of the microscope depend on the parameters of this electron beam: *spot size*, *aperture angle* and *beam intensity*.

The spot size determines the resolution of the microscope as well as usable magnification at stable picture sharpness. It is mainly considered that the spot is circular and has a Gaussian intensity profile. We can specify its size for example with half the width of the intensity distribution. The spot size is determined by the demagnification of the primary electron source, optical aberrations of the final lens (objective) and the diffraction aberration on the final aperture. The spot size is smaller at shorter working distances.

The incident electron beam is cone-shaped. The vertex angle of the cone is determined by the **aperture angle**. The wider the cone, the lower the depth of focus.

The beam intensity (BI) is determined by the number of electrons passing through the probe in a defined time. The image noise of the electron microscope depends on the number of electrons used for the information collected from each picture element. It is necessary to use more time for image scanning at low beam intensity and vice versa.

It is evident that the incident beam parameters influence each other. The optical system of the microscope allows operation in different modes when some parameters of the beam can be preferred and the others can be kept down. Here are some typical examples:

- *Work at high magnification.* It is necessary to reach a high resolution; therefore a low beam intensity, short working distance and slow scanning speed should be used. We recommend using RESOLUTION mode, working distance not more than 7 mm and scanning speed 7 or slower. See chapter 4.1.1.
- *Work with high intensity.* Resolution is small and useful magnification is low but fast scanning can be used because the signal to noise ratio is better. In any mode, use the function BI. The higher the BI index, the higher the beam intensity (the current of electrons in the beam). The exact value of the intensity can be set by function BI continually.
- *Work with high depth of focus.* The aperture angle must be small. Use DEPTH mode.

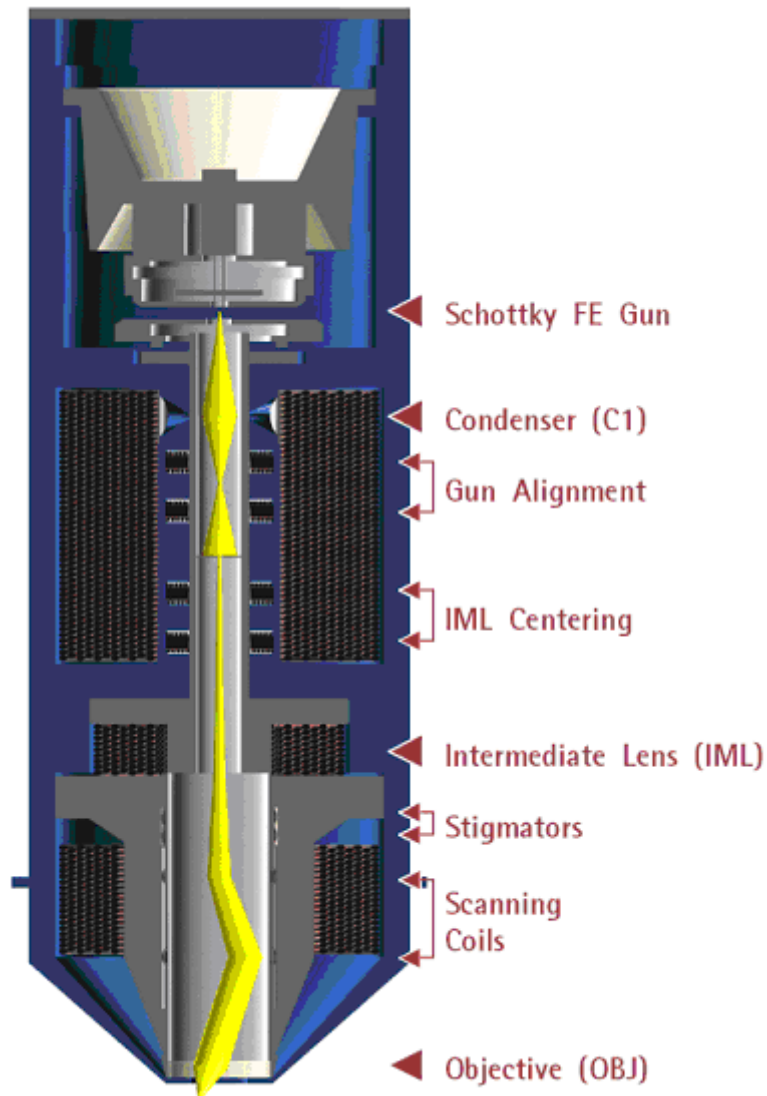
The column of the MIRA3 microscope consists of the following main parts:

- **The electron gun** is the source of accelerated electrons. It consists of a suppressor, an extractor and an anode. The filament tip is connected to the negative electric potential while the anode is on zero potential. The filament tip is made of a tungsten wire with about 0.5 μm radius sharp peak. The filament tip is fixed to the tungsten wire heated to a temperature of 1800 K. Electrons are emitted by the tunneling through the surface barrier with contribution of the strong electrostatic field with an intensity of 10^8 V/m (Schottky effect).

The tip's high temperature helps to prevent contamination of the tip and together with an atomic layer of the ZrO on the surface helps improve conditions for electron emission. The extractor ensures a high electrostatic field on the filament tip. It is

located right in front of the filament tip and it has a positive voltage potential of several kilovolts (extracting voltage).

The MIRA3 cross-section and schematic representation of its optical elements:



The electron flow from the gun is specified by the *emission current*, which depends on the extracting voltage. Electron emission from the side of the filament is suppressed by the suppressor, which is located right behind the filament tip. The suppressor potential is several hundreds of volts lower than the filament tip potential. The *accelerating voltage* between the cathode and the anode determines the overall energy of the electrons.

The whole system behaves as an electron virtual source located in the region of the end of the tip with a characteristic size of approximately 20 nm, energy of the electrons in the range from 200 eV to 30 keV and emission current up to 300 μA .

An important parameter of the gun is the **angular intensity** of the electron emission which depends mainly on the extractor voltage. The value of this parameter is important for electron emitter lifetime, therefore the angular intensity must be calibrated if necessary (see chapter 4.1.3). The angular intensity is also used for

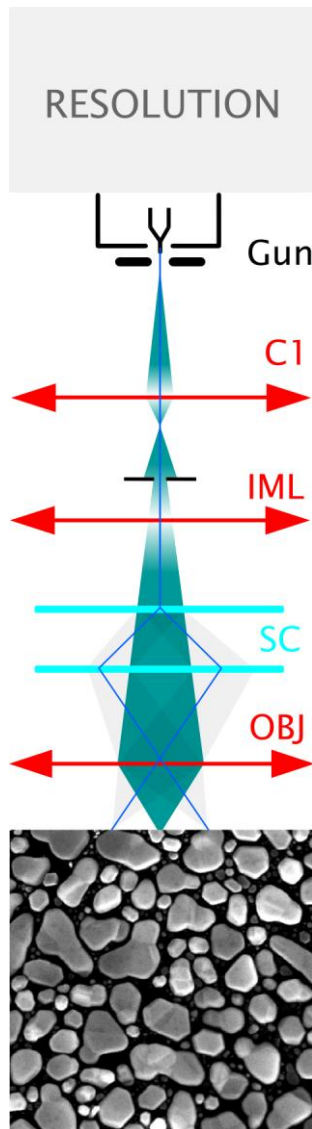
precise calculation of the beam current on the sample. The In-Flight Beam Tracing procedure is utilized in this calculation.

- **The condenser C1** is a strong magnetic lens which controls the amount of electrons passing through the aperture diaphragm. The higher the condenser excitation, the shorter the focal distance and thus the beam cross-over is further from the aperture diaphragm. By moving the cross-over towards the aperture diaphragm the beam current becomes higher. The condenser current and thus its focal length can be controlled by means of preset BI (Beam Intensity, BI 1 – BI 20) steps, or by entering the direct beam current value (BI Continual) or by the spot size value (Spot Size) which is strictly related to the beam current.
- **The gun centering** is formed by a system of electromagnetic deflection coils under the gun. It is intended for tilting the electron beam emitted from the gun, so that it enters the axis of the optical system of the column. It is controlled by the **Gun Tilt** function. The gun can be centered optimally by the automatic function which can be activated by the **Adjustment >>> Auto Gun Centering** button.
- The fixed **aperture diaphragm** trims the final displaying beam. It is located under the condenser and gun centering coils. The size of the diaphragm is chosen according to the optimal aperture angle of the electron beam and determines the maximum resolution ability of the column.
- The auxiliary **IML lens** is a magnetic lens used for the aperture change of the beam entering the objective lens or for beam displaying if the objective lens is off. The change of the IML excitation causes a shifting of the electron beam across the optical axis and it is therefore necessary to compensate this shifting by means of the centering coils **IML Centering**.
- **The stigmator** is an electromagnetic with an octupole design. It is intended for compensation of astigmatism in all displaying modes.
- **The scanning coils** are formed by two stages of the deflection coils. A scanning ramp is connected to the coils. The ramp frequency determines the scanning speed of the electron beam; the amplitude determines the microscope's field of view and the magnification.
- **The objective** is the last magnetic lens of the column that forms the resulting electron beam. In the usual modes the excitation of the OBJ determines the working distance – the distance between the focused specimen surface and the lower objective pole piece. In the MIRA3 with In-Beam technology the lens is combined electrostatic-magnetic for further improvement in microscope performance.

4.1.1 Electron Column Displaying Modes

RESOLUTION Mode

This is the basic and most common displaying mode. The IML lens is switched off, the OBJ lens is excited and it focuses the final electron beam.



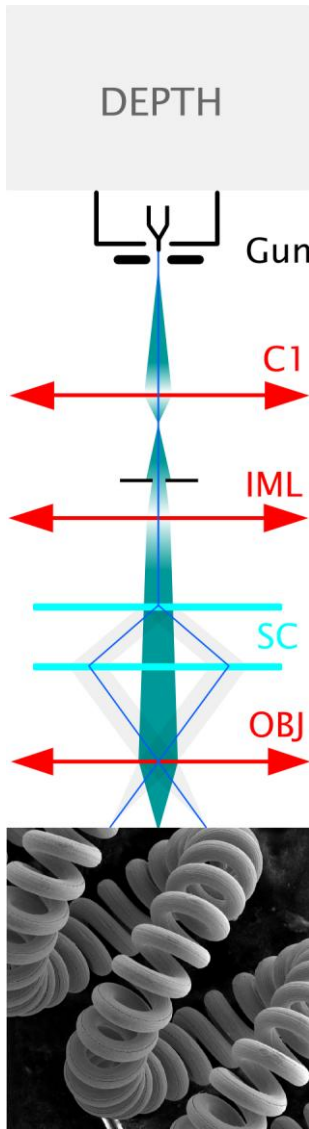
Characteristic:

- high resolution
- low depth of focus

The MIRA3 works like the other common three lens microscopes without IML in this mode. The aperture is nearly optimal for lower BI values (small spot size, low beam current) short working distances (4–5) mm and for the accelerating voltage 30 kV. The pivot point of the scanning and the electric image shifts are close to the principal plane of the objective OBJ so that the curvature of the field, distortion and field of view are as good as possible. The centering of the objective OBJ is performed by defined beam tilt of the central electron beam, which does not cause image shift. This mode is intended for displaying with the highest resolution.

DEPTH Mode

The DEPTH mode differs from the previous mode by the auxiliary lens IML being switched on.



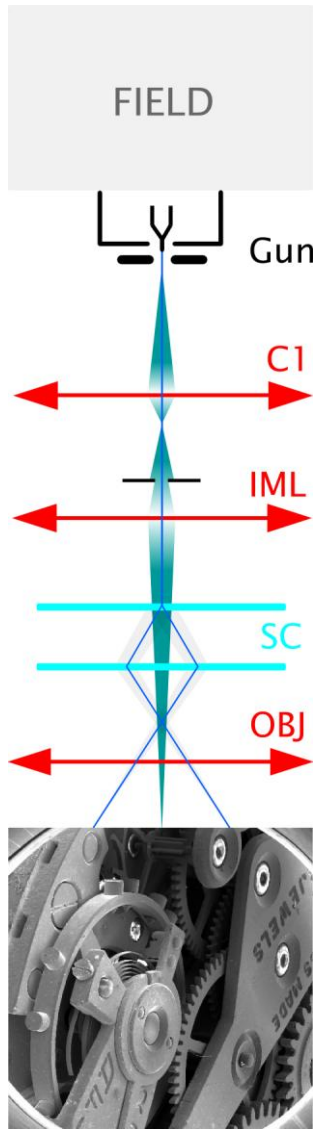
Characteristics:

- good resolution
- increased depth of focus

The aperture of the final beam is lower, but the spot size is bigger in comparison with RESOLUTION mode. The beam in the probe stays unchanged. This mode is used if necessary to have a greater depth of focus.

FIELD Mode

The FIELD mode utilizes the intermediate lens IML for the electron beam focusing while the objective OBJ is off.



Characteristics:

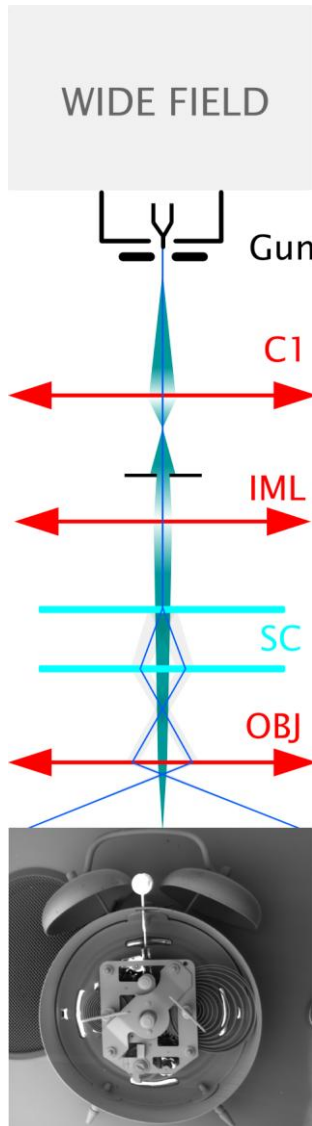
- large field of view
- high depth of focus
- worse resolution

The beam aperture is very small and the depth of focus is usually higher than the field of view. As the objective OBJ is off in this case, it does not affect the middle beam and thus does not need to pass near the centre of the objective OBJ. The position of the pivot point of scanning is optimized according to the field of view. The centering coils IML center the supplemental intermediate lens IML to avoid image movement during focusing. The DC component of the scanning coils is set up so that no image shift occurs if switched from RESOLUTION mode to FIELD mode.

The disadvantage of this mode is a bigger spot size; the maximum magnification used is a few thousand. The mode is used for the searching of the parts of the specimen to be examined.

WIDE FIELD Mode

The WIDE FIELD mode uses the intermediate lens IML for focusing the electron beam, while the objective OBJ is excited to a high value.



Characteristics:

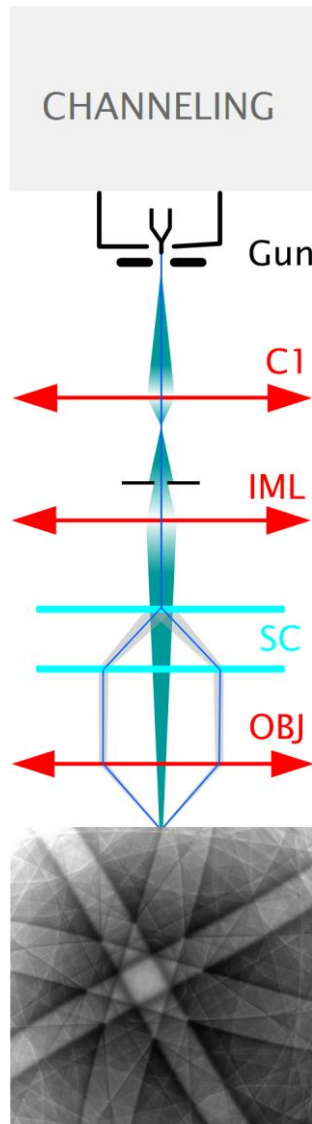
- extra large field of view
- image distortion is corrected and minimized

Highly excited objective multiplies the deflection of the beam. The aperture of the beam is very small and the depth of focus is very high. The IML Centering coil serves for minimizing the image shift when focusing.

The mode is used to search for the part of the specimen to be examined. To know the proper magnification value, the objective must be well focused. This might be a little difficult due to the high depth of focus.

CHANNELING Mode

In CHANNELING mode, the scanning and lens focusing is controlled so that the electron beam touches the same point of the specimen surface all the time. By means of scanning the beam, only the angle of incidence of the electron beam is changed, i.e. the rocking beam.



Characteristics:

- the position of the specified point in the image depends on the beam tilt
- it is the mode for ECP acquisition – Electron Channeling Pattern

CI The resulting image is the amount of electrons dependent on the impacting beam angle. The excitation ratio of the scanning coils is set up so that the beam utilizes the whole area of the objective lens bore and enters the lens parallel to the optical axis.

IML All electron beams parallel to the optic axis are focused by the lens into a single point on the specimen surface. As a consequence, the scanning is transformed into beam tilting, i.e. the resulting pivot point of the scanning lies on the specimen surface plane.

SC The intermediate lens focuses the beam into the upper focal point of the objective lens. The result is that the beam, after passing through the objective lens, is parallel and the angular resolution of ECP (Electron Channeling Pattern) images is at its maximum.

OBJ The mode is intended for the examination of crystallographic materials. In consideration of the optical abilities of the MIRA3 column, the minimum size of crystals is (100–150) μm .

Note: ECP patterns are produced by back scattered electrons, it is preferable to use a BSE detector for imaging if available.

4.GChamber and Sample Stage

The chamber is a sealed space under the column for placing your specimen for investigation. The specimen is fixed on the sample stage, thus allowing you to move your sample during the investigation process. The chamber must be evacuated during investigation.

Manipulators have *electrically isolated specimen holders*. The specimen holder is connected to pA-meter. The pA-meter also works as an acoustic contact indicator of the specimen to the chamber. If contact between the specimen holder and the chamber body occurs, all motorized axes will stop and an audible sound will indicate the contact (touch alarm).

The chamber and sample stage types:

Type	Motorized axes	Eucentricity
LM	X, Y, Z, Rotation, Tilt	automatic
XM	X, Y, Z, Rotation, Tilt	automatic
GM	X, Y, Z, Rotation, Tilt	automatic

The eucentric position is such a position of the specimen, where the observed area of the sample does not move when the sample itself is tilted. The auto-eucentric function can be activated by checking the **Keep view field** box in the **Stage Control** panel in the MiraTC software.

5 Vacuum Modes

The microscope allows the investigation of specimens in a pressure range of about 0.009 Pa to 500 Pa.

Mode	Pressure [Pa]	Microscope type	Note
high vacuum	< 0.009	LMH, XMH, GMH LMU, XMU, GMU	—
low vacuum	7–500	LMU, XMU, GMU	aperture in the objective

There is a differential pumping aperture in the objective. Sample observation is possible with chamber pressure up to 500 Pa.

6 Detectors

The detection system may contain a set of detectors designed for detecting various signals resulting from electron beam interaction with the sample surface. The microscope is always delivered with the SE detector.

Switching on

- In the case of adjustment of the required detector, select the appropriate one from the list box in the **SEM Detectors & Mixer** panel (see **Figure 8**). This procedure is valid for all detectors except the LVSTD, where further procedures are needed (see chapter 6.3). In the case of the InBeam detector, check the item **InBeam Mode** in the main SEM menu first.

6.1 SE Detector

The detector works in high vacuum only.

Secondary electrons enhance topographic contrast as opposed to material contrast of back-scattered electrons (BSE). The secondary electron (SE) detector is a basic standard detector always present in the microscope.

The SE detector is of an Everhart-Thornley type. The grid on the front part of the detector has positive potential. This attracts and accelerates the low-energy secondary electrons arising on the specimen surface and focuses them onto the scintillator. The light flashes, which result from the impingement of the electrons on the scintillator, are transferred through the light guide to the photo-multiplier outside the chamber of the microscope.

6.2 In-Beam SE Detector

The detector works in high vacuum only.

The so-called In-Beam detector is located in the objective lens and detects secondary electrons. It attracts electrons emanating from the sample surface into the objective lens and catches them there. This type of detection is sometimes called “in-lens” or “through-the-lens” in the literature.

This allows for the observation of specimens at very short working distances (WD) and thus with improved resolution. The standard SE detector at a short WD would not have a good signal because the path of secondary electrons from the specimen to the standard SE detector would be shielded by the column. Moreover, the combined electrostatic-magnetic lens gives further improvement of microscope performance.

In-Beam technology works in its own mode of the column (the item **InBeam Mode** in the main SEM menu is checked). Therefore, objective centering and stigmator parameters are different from the condition of disabled InBeam mode. The software automatically remembers the set of parameters when switching between these two. All optical modes are available in the In-Beam regime (RESOLUTION, DEPTH, FIELD, WIDE FIELD, and CHANNELING) and all detectors may be used (InBeam, SE, BSE and others). We recommend working with InBeam mode enabled all the time.

Images taken by the SE detector and the In-Beam detector may differ because the In-Beam detector observes a specimen from the top whereas the SE detector from the side. The resolution is better at a short WD using the In-Beam detector. The signal also varies with

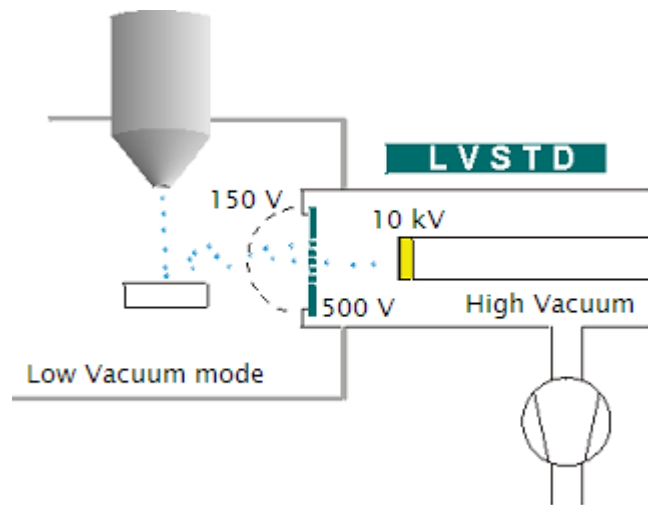
WD. It is generally recommended preferring the In-Beam detector at a WD shorter than about 5 mm and the standard SE detector at a WD longer than 5 mm. At a short WD be very careful not to hit the objective with the specimen.

6.3 LVSTD Detector

The detector works in low vacuum only.

The LVSTD detector (*Low Vacuum Secondary Tescan Detector*) is a detector of secondary electrons, specially designed for low vacuum mode. It is suitable for the investigation of non-conductive samples.

The LVSTD consists of a standard Everhart-Thornley detector situated in a separated detector chamber. This detector chamber is pumped by a small turbomolecular pump.



6.4 BSE Detector

The detector works in both high and low vacuum.

Back-scattered electrons (BSE) enhance material contrast of the sample. The BSE detector is of the scintillation type. An annular (YAG) mono-crystal scintillator with a conductive surface is placed in the optical axis directly under the lower pole extension of the objective. The high energy back-scattered electrons impinge the scintillator without any additional acceleration and excite the scintillator atoms that emit visible radiation photons successively. The photons are carried, by means of the light guide, through the side outlet of the scintillator to the cathode of the photo-multiplier. They are then processed in the same way as the signal coming from the secondary electrons.

The BSE detector is manufactured in an R-BSE (Retractable BSE) version. This modification allows the retraction of the detector from under the pole piece position if the detector is not used. This allows the specimens to be moved as close as possible to the objective when viewed by other detectors.

7 Control Elements

7.1 Keyboard

The keyboard is used for text and numeric input. Its usage does not differ from the system Windows practice.

Keyboard shortcut	Command
Ctrl + O	Open...
Ctrl + S	Save As...
Ctrl + P	Print...
Alt + X	Exit
Ctrl + H	View Header...
Ctrl + C	Copy to Clipboard...
Ctrl + V	Paste from Clipboard...
Ctrl + Alt + PgUp	Zoom All In
Ctrl + Alt + PgDn	Zoom All Out
Ctrl + PgUp	Zoom In
Ctrl + PgDn	Zoom Out
F1	Help – Contents
F11 hold down	Blocks the changing of the right parameter of the active function.
F12 hold down	Blocks the changing of the left parameter of the active function.

7.2 Mouse

The mouse usage follows the Windows system practice.

Mouse functions during normal scanning:

- Double-click with the left mouse button on the SEM Scanning window switches the Focus window on/off.
- Turning the mouse wheel changes the scan speed (the SEM Scanning window needs to be active).
- If the microscope is scanning over the whole SEM Scanning window, then
 - clicking the right mouse button opens the context menu for simple program control.
- If the microscope is scanning only in the Focus window, then
 - holding down the right mouse button and dragging the mouse cursor in the SEM Scanning window changes the dimensions of the Focus window.

- holding down the left mouse button and dragging the mouse cursor in the SEM Scanning window moves the Focus window.
- double-clicking the right mouse button on the Focus window moves this window to the center of the image.
- clicking the right mouse button out of the Focus window opens the context menu.
- Clicking the mouse wheel on a selected object in the SEM Scanning window moves the stage so that the object lies in the center of the SEM Scanning window.
- Holding down the mouse wheel on a selected object and dragging the cursor to any position in the SEM Scanning window moves the object to the selected position in the SEM Scanning window.
- Holding down the mouse wheel on a selected object in the SEM Scanning window for longer than 0.8 seconds moves the stage so that the object lies in the centre of the SEM Scanning window and the magnification is increased by the factor set in the SEM -> Options -> Center Zoom.

Note: If an additional software module is active, the functions of the buttons can be different.

7.3 Trackball

The trackball is often used with the **Pad** panel.



Turning the trackball in the direction of the axis X changes the first parameter of the active function; turning the trackball in the direction of the axis Y changes the second parameter of the active function. Holding the F11 key locks the first parameter of the active function; using the F12 key locks the second parameter of the active function.

7.4 Control Panel

The control panel has several knobs and colour touch screen. It was developed by TESCAN exclusively for SEM control. It is not a standard SEM part.

The manual knob set provides the user with a simple and straightforward way of operating the microscope. It can control the stage, magnification, focus, beam intensity, scanning speed and other parameters.



Most common functions have dedicated knobs. The three upper knobs have variable function; their actual function is shown at the bottom of the touch screen. Several important parameters are shown in the middle of the display. There are also shortcuts to the automatic functions (focus, brightness/contrast, image acquisition) in the header.

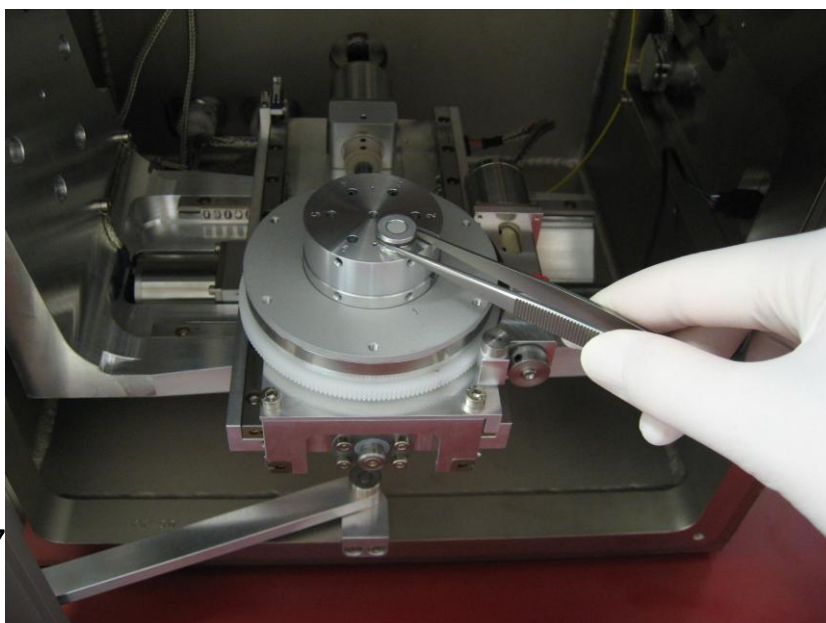
8.2 Specimen Exchange

The specimen should somehow be fixed or glued to the specimen stub, before it is inserted into the chamber. It is possible to use 12.5 mm specimen stubs or any other specimen holders, delivered as microscope accessories.

If the specimen is examined in high vacuum mode, it should be conductive or should be made conductive using one of the methods described in the technical information. The conductive surface of the specimen must be conductive contacted to the stub.

Non-conductive samples can be examined in low vacuum mode.

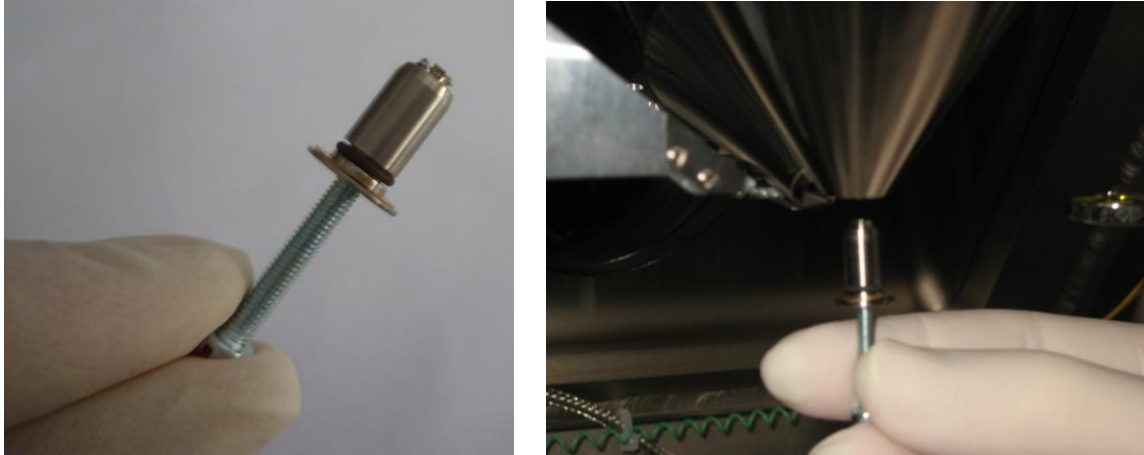
Figure



9.2 Insertion of the Final Aperture for the Low Vacuum Mode

This aperture is inserted into the objective and is accessible from the bottom – from the microscope chamber.

Figure 33



1. Before inserting the aperture into the objective, move the BSE detector to the home position.
2. Open the chamber door and insert the aperture holder into the objective with the wider part downwards (**Figure 33**).
3. To remove the aperture holder – use the screw included in the microscope accessories. Place the screw in the aperture holder and remove the aperture holder by pulling the screw downwards.

The apertures become contaminated during microscope usage, which can cause a decrease in the optical qualities of the column. They will need to be cleaned or replaced from time to time.

***Note:** During the manipulation with the aperture holder use the suitable gloves for prevention of pollution of it and inner microscope parts.*

9.4 Specimen Holders

The specimen holders differ according to the type of delivered microscope, here is only an overview of the possible types.



Standard specimen holder \varnothing 12.5 mm, height 3 mm:

the most common holder suitable for smaller specimen. The specimen is normally glued with conductive glue or stuck on with double-sided sealing tape.



Specimen holder GM163-A, \varnothing 14 mm, height 20 mm:

extension for small specimen holders for work at very short working distances.



Specimen holder HM113:

designed for small round-shaped samples up to a max. diameter of \varnothing 12 mm.



Specimen holder HM116:

designed for round-shaped samples up to a max. diameter of \varnothing 20 mm.

**Specimen holder TE0038B:**

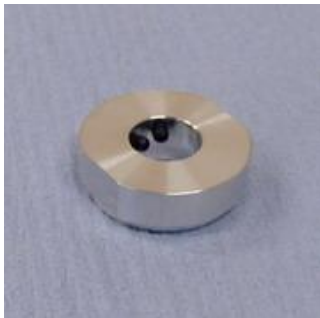
designed for standard $\varnothing 30$ mm samples.

**Specimen holder HM114:**

designed for flat samples up to a width of 20 mm.

**Specimen holder GM153:**

replacement of the standard seven-position specimen holder (the seven-position holder must be removed). Designed for rod-shaped samples of a diameter up to 26 mm.

**Specimen holder HM154-A:**

CAMSCAN $\varnothing 12.5$ mm specimen holder adaptor.