Lambda

Benchtop Scanning Electron Microscope

thermo scientific

Authorised Distributor

Phenom

Making SEM Personal

Contents

Overview

Phenom World, Eindhoven, Netherlands, is the leading manufacturer of benchtop SEM systems. Originally developed by FEI Company, Phenom World is now part of Thermo Fisher Scientific.

The development of the Phenom benchtop systems began in 2005. The main development goals were:

- Completely new development and miniaturization of electron gun
- Potential use of faster processors
- Fast sample throughput
- Maximum efficiency in terms of size
- Significant simplification of the operation

In 2007 the Phenom was released as the first real desktop system.

In March 2015, the fourth generation of the proven Phenom was presented to the market.

In August 2017, Phenom World released the 5th Generation of the leading desktop SEM Phenom with increased magnification and market leading resolution.

In August 2018, Phenom World (now part of Thermo Fisher Scientific) launched the Phenom Pharos, which is a desktop FEG (Field Emission Gun) SEM. The FEG source makes crisp, high-brightness images and the benefits of a FEG source accessible to everyone.

Fig. 1 Phenom Pure

Phenom World provides six models of SEM :

- **Phenom Pure**
- **Phenom Pro**
- **Phenom Pro X**
- **Phenom XL**
- **Phenom Pharos**

All now available with SED option.

The **Phenom Pure** is an entry-level system at a very attractive price. This is available in particular to customers, who wish to expand from light microscopy into SEM.

The **Phenom Pro** is the most powerful benchtop scanning electron microscope on the market. It has a maximum magnification of 150,000x and a pixel resolution of ≤1.3nm. The **Phenom ProX** has the same outside appearance and handles very similar to the **Pure** and **Pro** however it has Energy Dispersive X-Ray (EDX) Spectroscopy built into the SEM. It is truly is an all in one system with both high resolution and EDX.

The **Phenom XL** is characterised by greater variability, in particular with a very large sample chamber, as well as optional secondary electrons and EDX detector. The user interface is identical to all Phenom systems.

The new **Phenom Pharos** is a desktop SEM with a FEG source, which has been designed in such a way that the power of a FEG source, gives crisp, high brightness images that can be accessed by all. Standard options are a backscatter electron detector (BSD). Optional detectors include both secondary electron detector (SED) and/or energy dispersive x-ray detector (EDX), along with sophisticated analytical software.

Fig. 2 Phenom Pro with Pro Suite (option)

Fig. 4 Phenom XL with large sample chamber

Fig. 3 Phenom Pro X with integrated EDX analysis

Fig. 5 Phenom Pharos

Not shown: Diaphragm pump and power supply

Phenom XL
sample containers

Phenom XL
Tensile sample holder

Phenom XL
Filter sample insert

Phenom XL
Resin sample holder insert

Phenom First Impressions

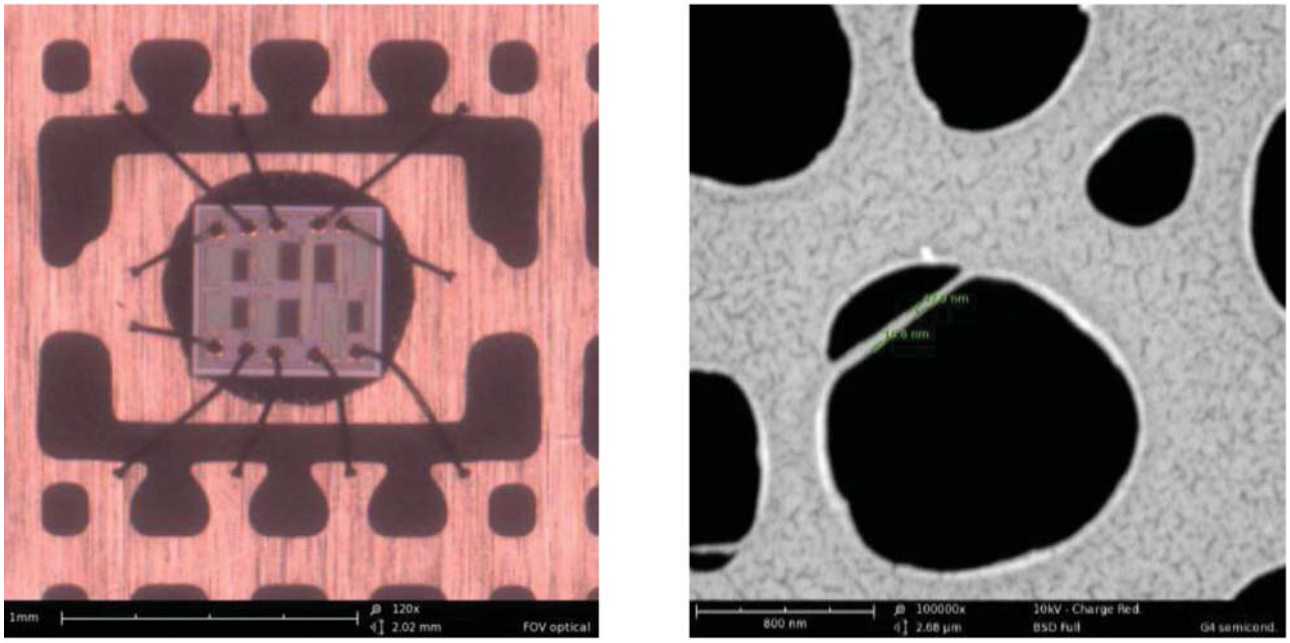

Fig. 5 Left: Sample micro-electronic component; 120x magnification viewing via CCD camera for Nav Cam.
Right: SEM image copper grid at 100,000x magnification.

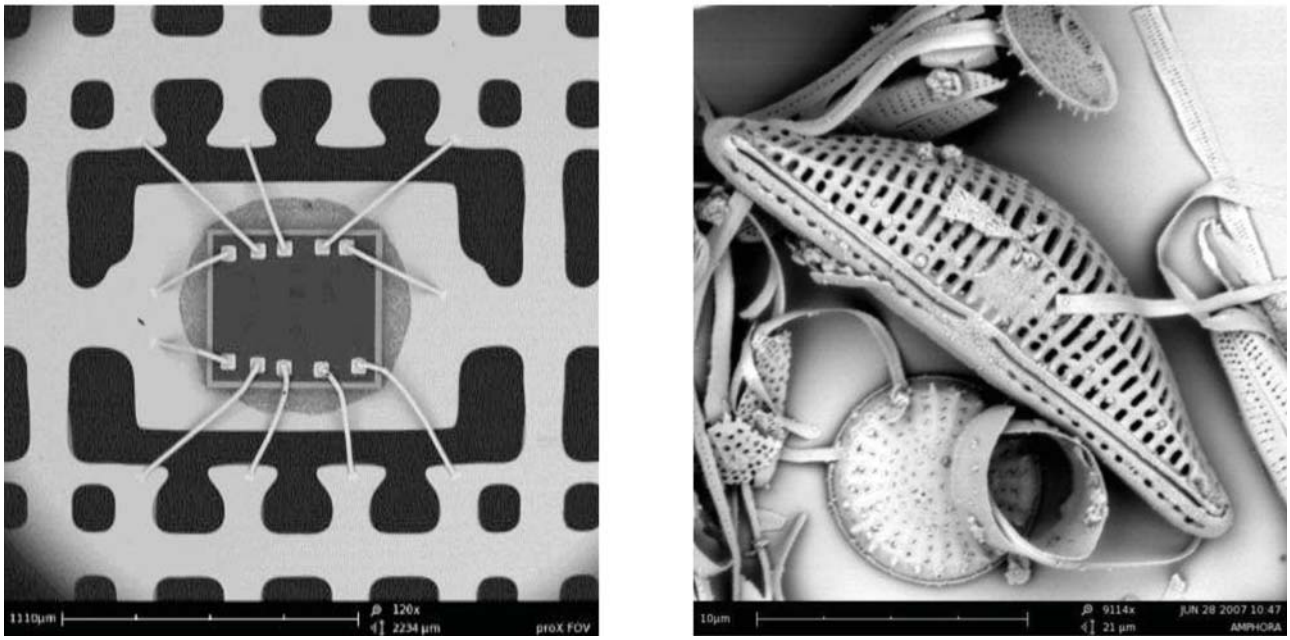

Fig. 6 Left: Micro-electronic component viewed now in SEM at 120x magnification, the contrast of materials provided by BSD.
Right: Diatom frustules ~2.25 x 2.5mm

Operating Concept

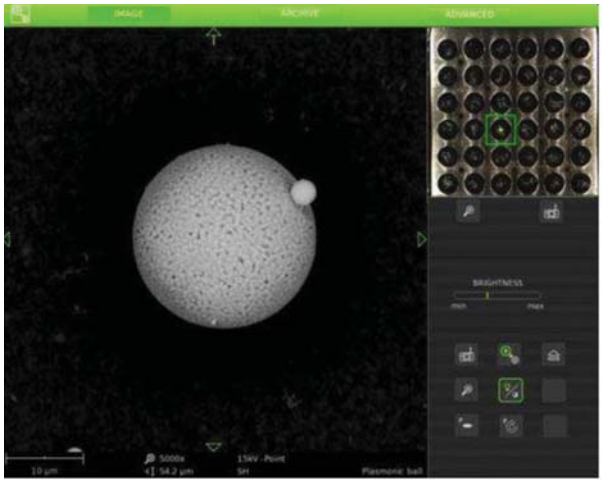

Fig. 7 Live imaging form the Phenom XL:
Top right: Digital image for navigation on the sample at the
Right bottom: SEM image in the smallest magnification
Links: SEM live image

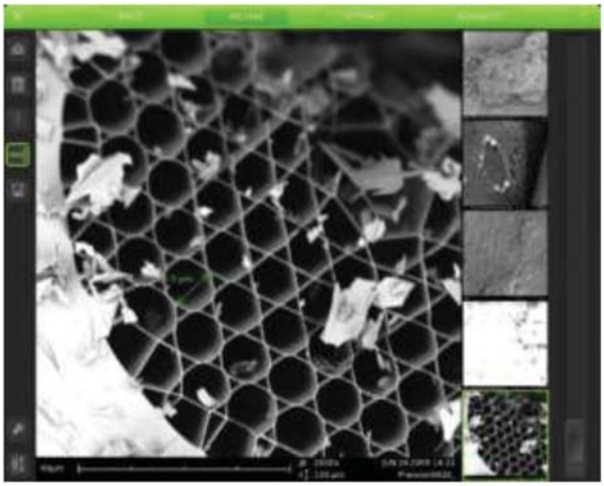

Fig. 8 Image archive with an integrated measuring function

Fig. 9 Phenom interface settings menu

Phenom benchtop electron microscopes have a built-in computer with a LINUX operating system and a fully integrated user interface. Therefore, no separate PC is required to control the SEM. Providing a great advantage in terms of the long term reliability and the maintenance of the entire system.

User Interface
The operation of the electron microscope is carried out using the intuitive user interface, mouse and a rotary knob. Other input devices are not required. Optionally, a touch monitor can be connected.

All functions available are with a context-oriented help function. Only those functions are displayed and selected in the respective mode.

The data bar at the bottom of the screen contains all the important information about the image. The scale is equipped with a very high level of accuracy is permanently calibrated.

Navigation
Through the unique appearance of the samples in 3 areas; digital image, SEM image in the lowest magnification and live image, navigation on the sample easily performed. The position of the electron beam is presented on screen by a yellow square. There is no time delay in the exact position on the sample at any magnification.

By clicking on a position on the screen is the test of high-precision adjustment motors in x and y direction is image becomes centred.

Adjustment
All calibration functions (source tilt and stigmator) are possible via the user interface. The calibration functions are password-protected. An incorrect/accidental adjustment is not possible.

Image Memory
Images can be stored via a USB interface or via a LAN interface on any data storage archive. There is no facility to store image data on the Phenom.

Detectors

Backscatter Electron Detector (BSD/BSED)
All Phenom benchtop electron microscopes are equipped as standard with a 4-quadrant semiconductor-back-scattering detector.

Secondary Electron Detector (SE/SED)
All **Phenom G5** systems can be optionally equipped with a SE-detector (Everhart Thornley).

EDX Detector
The **Phenom Pro X** is delivered by default with this detector, all other Phenom electron microscopes can use an EDX as this can be retrofitted.

Contrast of Materials (BSD detector)
For imaging contrast within the materials or for visual identification of composites it is possible to optimise the detection of the back scattered electrons. The detector is split into quadrants: all receiving the electrons from a multitude of directions and amplifications. A subtraction factor is applied in order to only present electrons of specific regions of the detector.

The signal is dependent on several factors:

- Total number (Z) of the elements in the sample (the higher the number, the brighter the gray value appears in the picture)
- The alignment or the structure of the surface
- The acceleration voltage
- The BSD detector element contrasts, as well as topographic contrast with grazing light effects
- It is on the surface of the sample is only a low vacuum is required
- It can be used with very low voltage acceleration voltage

Topography Contrast (BSD)
By applying a subtraction factor to the total electrons detected by the BSD it is possible to assess the surface topography of the sample. This raises the element contrast considerably, so that a good representation of the topography is possible *(Fig 11*).

Topography Contrast (SE detector)
Due to the very low energy of the secondary electron, it is possible for them to only escape from the top 300Å the surface of the sample. Secondary electrons are thus especially important for high-resolution images of the finest structures because of the small reaction volume. SED is optionally available in all the Phenom systems.

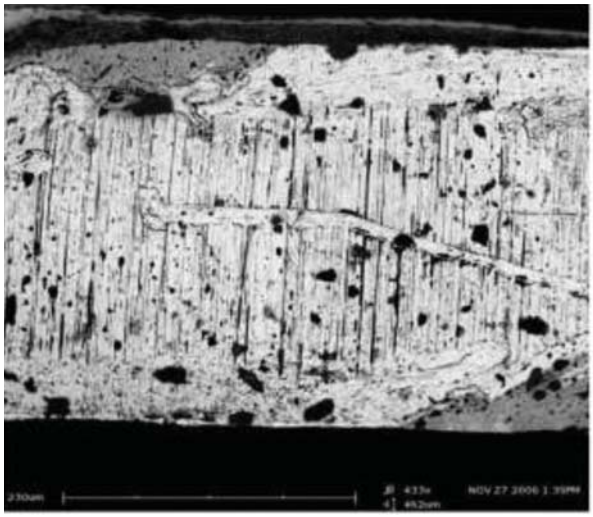

Fig. 10 Contrast of materials (BSD composite mode)

Fig. 11 Topography contrast (BSD)

Fig. 12 Topography contrast (SE) platelets with fibrin thread

Vacuum

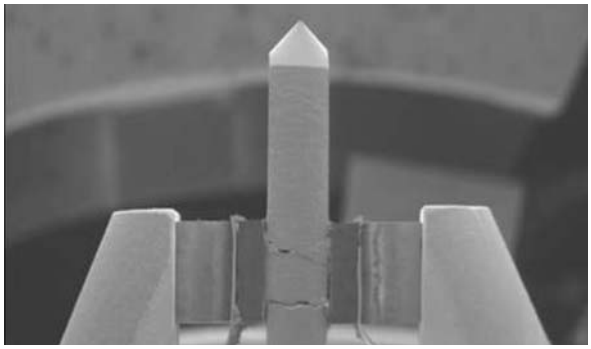

Fig. 13 CeB_6-cathode

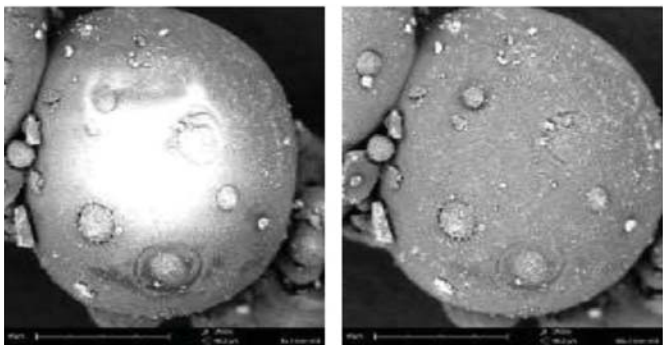

Fig. 14 Left: No charge reduction
Right: Charge reduction sample holder

In the electron column there is a permanent high vacuum; ≤10^{-7} mbar. The high vacuum is achieved by a turbo molecular pump and is maintained at this level.

In the sample chamber below the aperture is at lower vacuum:

- High vacuum <1Pa
- Standard vacuum 10 Pa
- Batch reduction 60 Pa

The advantage of the low vacuum is that by ionization of the residual gas in the sample chamber, the charge of non-conductive samples is reduced significantly.

By use of the specific sample holders and the design of the vacuum chamber within the Phenom SEMs it is possible to reach a pressure of ~9x10^{-1} mbar at the sample surface. This increased pressure does not unduly affect the source life but enables higher resolution imaging.

Batch Reduction Mode
Non-conductive samples tend to charge in the vacuum of the sample chamber, this as a result of bombardment of the electron beam in the scan field, building up a negative potential. The absorbed electrons flow direction and not mass is the cause leading to the so-called boost effect; seen on the SEM image as unwanted white illumination; either flashes of information lost regions.

The charge reduction mode reduces this effect without the quality of the image being strongly influenced as the vacuum at the cathode is disturbed.

The water contained in the residual gas molecules are ionized by the electron beam. The potential equalisation on the surface of the sample reduces the charging tilt significantly. Many non-conductive materials can therefore be investigated in the charge reduction mode without the requirement for sputtering.

CeB_6-Electron Source

Why CeB_6?
The electron source is made from Cerium Hexaboride (CeB_6). The design of the electron source allows a very fine focused electron beam and guarantees a high resolution even at low acceleration voltages all within a short time. In benchtop electron microscopy generally there are two different source types are employed:

- Wolfram (tungsten)
- LaB_6 and CeB_6

Tungsten cathodes are quite inexpensive, but have a very limited life and behave like the filament in a light bulb: they burn suddenly and the brightness diminishes over time.

More significantly the W-cathodes require an order of magnitude of more energy than needed in the Lab_6- or CeB_6-cathode to achieve comparable resolutions.

Advantages of the CeB_6-cathode:

- CeB_6 cathodes already deliver at low acceleration voltages a finely focused electron beam.
- Currently at 5kV can be a magnification range of 20x up to approx. 30,000x.
- Low acceleration voltages allow the figure of thin coverings even at high magnifications.
- Low acceleration reduction voltages mean that insulating samples to charge less.
- CeB_6 cathodes mean significantly less maintenance effort.

EDX Analysis

Utilising the inelastic scattering of the electron beam radiation interacting with the sample material it is possible to determined elemental compositions.

In an electron column, electrons are accelerated through an electric field, requiring kinetic energy. The energy is deposited in the sample and depending on the physical characteristics of the material, yields a variety of signals for analysis.

The interaction causes the primary electron to lose some or all of its energy however it produces a continuous spectrum of radiation; this is seen as the spectrum background. It is also known as decelerating radiation or continuum radiation.

Inelastic scattering is based on inner electron transitions between inner atomic shells. The electron from the primary electron beam dislodges an electron from an inner orbital. An electron from a higher energy shell fills the vacancy, what is key is that the electron loses energy in the process. This lost energy appears as emitted radiation of energy and is characterised as an x-ray.

Thus generating an energy difference signature depending on the position the electron movement from within the Orbital, for example the x-ray quanta with K_α, L_α, M_α…. such x-rays are element specific.

The energy of a x-ray line gives information about the elements present and the height of the peaks convey the concentration of the element within the sample at that point.

The new **Phenom ProX** was designed to meet the needs of an integrated fast EDX analysis.

What systems can be connected to an EDX Detector for analysis?

- All Phenom systems as of serial number 600 can be retrofitted with an EDX Detector.
- The **Phenom ProX** is manufactured with an EDX Detector onboard.

Intuitive Operation
The operation of the EDX analysis software is based on the proven Phenom operating concept which is intuitive and easy to understand.

- **Image Acquisition**
  - Point analysis has a max. 10 per BSD image but remains unlimited number of analysis per project
  - Surface analysis
  - Mapping & line scan (optional)

- **EDX Analysis**
  - AutoID has a fully automatic element detection
  - Manual assignment of elements
  - Hide elements
  - Zoom range
  - ZAF correction (on/off)

- **Project**
  - Saving a project
  - Export of images, spectra and data (.csv file)
  - Addition of a project for a new analysis
  - Offline mode

The offline mode allows the editing of a project that has already acquired images and analysis. To access the EDX Detector of the SEM is therefore not required.

Fig. 15 Phenom Pro X with integrated EDX analysis

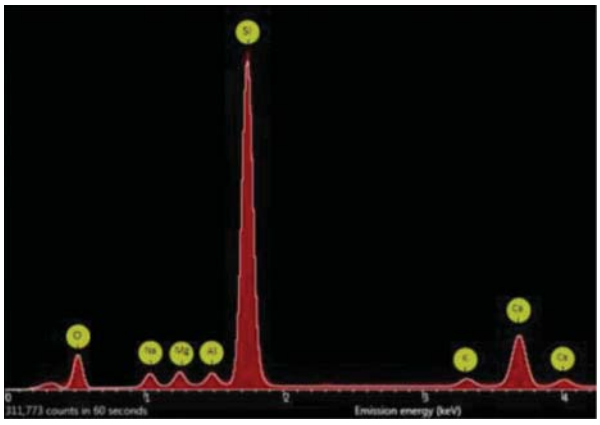

Fig. 16 EDX spectrum with element identifier of the peaks

Fig. 17 Elemental analysis has a work flow allowing both manual and automated elemental identification

EDX Detector Specifications

Detector

- Silicon drift detector (SDD)
- Thermo-electric cooling (no nitrogen cooling is required!)
- 25 mm² active detector surface

X-ray Window

- Ultra-thin silicon nitride (Si_3N_4)
- The detection element boron (5) to americium (95)

Energy Resolution

- Mn K_α ≤133 eV

X-ray Analysis

- Multi-channel analyser with 2,048 channels
- 10 eV/channel
- The maximum number per second rate: 300,000
- Elements as well as their oxides can be detected

The resolution of the EDX signal is dependent on the number of the elements present and their concentration. At low ordinal numbers the reaction volumes is up to a few cubic micrometers in size, with higher numbers it is in the small two-digit cubic nanometer range.

EDX Software

- In Pro Suite user interface is integrated
- Control of the electron microscope
- "Point and analyse" method
- Surface analysis
- Automatic peak identification
- Automatic peak emergence
- Confidence indicator for the reliability of the measurement

Data and Image Export

- Screenshot (JPG) with EDX spectra, weight percent, spot positions and reliability indicators
- EDX spectra (JPG or TIFF)
- Analysis results in CSV format
- Energy spectra in the numeric EMSA-Format
- Automatic report in DOCX format that can be edited with all common document editing programmes

Mapping and Line Scan (Option)

In contrast to the features analysis, the element spectra of the scan field without local information detected, when mapping the element spectrum for each pixel of the scan sector.

The scan sector is a freely selectable rectangle within the current SEM scan field.

This can be with the mapping element distribution with a (theoretical) local resolution of up to 100nm (at 45,000-fold magnification and a EDX resolution of 512 x 512 pixels).

- A maximum of 10 selectable items
- Individual overlay spectra plus BSD image
- 16 x 16 pixel resolution up to 512 x 512 pixels
- Pixel measuring time from 10 to 250ms
- On the number of scan cycles can be selected freely
- Regions can be selected freely to better understand elemental composition within a mapped area

Line Scan
Line scan is a consequence concatenated point analysis. The vector is within the SEM scan field selectable, the resolution is between 16 to 512 pixels.

The mapping results of the selected elements can be in any sequence overlap.

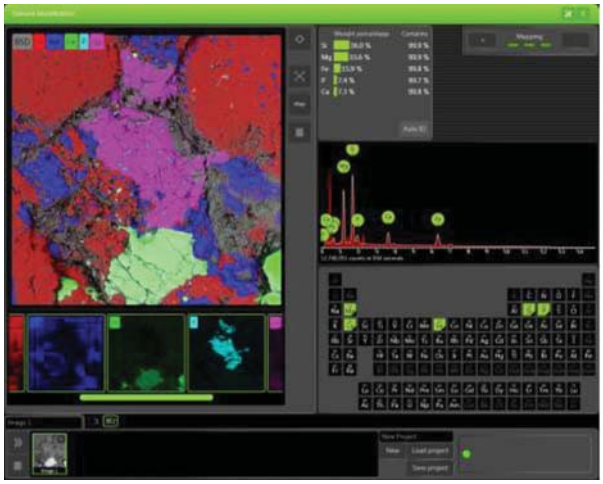

Fig. 18 Mapping user interface

Sample Holder

By default, all Phenom electron microscopes with a motorised sample stage with X and Y control. Control of the sample stage takes place via the user interface of the SEM.

Phenom is the only electron microscope with variable, SEM movable sample holders. The sample holders have developed for specific applications. To maximise the imaging capabilities of the Phenom SEM across a diverse range of subjects, perfect for shared use instruments.

Sample Loading
The sample is loaded on a standard aluminium pin stub – they are fixed into position by carbon sticky tabs. Pin stubs and fixing material consumables are commercially available materials.

The loading and unloading of the sample holder is fully automated. There is a maximum working distance of 35mm. This is important when imaging samples of larger dimensions, to increase depth of field or reduce possible charging effects. It is not possible to load samples that are sat too high in the sample holder as a protection plate deters this.

Loading times up to the first SEM image:

- **Phenom Pure, Pro, Pro X** and **Pharos**: <30 seconds
- **Phenom XL:** <45 seconds

Phenom is thus the fastest electron microscope in the world.

Sample Holder of the Phenom XL
The sample holder of the **Phenom X**L has the following internal dimensions: width 100mm, length 100mm, depth 65mm max (Fig.19).

The working distance can be continuously adjusted. Maximum sample size **Phenom XL**

You can sample up to a size of:

- Width 100mm
- Length 100mm
- Or at the same time up to 36 pin stubs of 12mm diameter (Fig.20)

Within the loading chamber the sample holder is scanned which produces a Nav Cam overview (*Fig. 21 top right of the image*). The image can be adjusted.

This compares to a sample chamber of 200mm x 200mm of a conventional SEM; where the loading/evacuation time is significantly longer as greater pumping times are necessary.

Fig. 19 Sample chamber Phenom XL

Fig. 20 Sample holder of Phenom XL with pin stubs being loaded

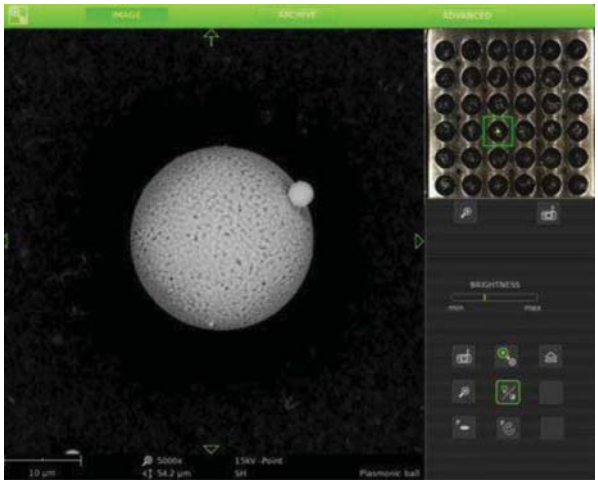

Fig. 21 User interface Phenom XL with 36 pin sample plates

Sample Holders for Phenom Pure, Pro, Pro X and Pharos

Fig. 22 25mm pin stub with two samples is mounted onto the Phenom sample holder

Fig. 23 The sample holder is loaded into the Phenom SEM either Phenom Pure, Pro, and Pro X

Fig. 24 Left: Standard pin stub sample holder
Right: Metallurgic sample holder for resins

Fig. 25 Left: Charge reduction sample holder for pin stubs
Right: Metallurgic charge reduction sample holder for resins

The following sample dimensions can be applied:

Phenom Pure, Pro and ProX

- Ø 32mm
- Maximum height 100mm

Phenom XL

- Ø up to 100mm x 100mm
- Maximum height 70mm

The sample holder of the **Phenom Pure, Pro** and **Pro X** are especially developed for powders or small samples. The **XL** allows larger samples and has a range of specialised attachments.

Standard Sample Holder
Is desgned to take aluminium pin stub samples of a diameter of up to max. 25mm. The maximum sample height 30mm. Graduated adjustment of the working distance is possible via a turntable stage in 0.5mm increments.

Sample Holder for Resins
The metallurgic sample holder allows easy inspection of resin embedded samples with a maximum diameter of 32mm and a height up to 30mm. The resin is supported from below by a sprung loaded platform within the sample older. Allowing various resin heights to be used. The resin is held in place via a bayonet locking mechanism. Spacer rings are available to increase working distances where necessary.

Phenom Charge Reduction Sample Holder
The charge reduction sample holder (CRSH) was specifically developed for applications where non-conductive samples can be imaged without coating. The sample holder works with a vacuum in the sample chamber of >0.7mbar. Sample dimensions are the same as the standard sample holder.

Use for Micro-Electronic Components
Should there be cause to inspect micro-electronic components in the electron microscope Phenom World has developed a holder. This also works for biological glass slides that been trimmed to size. The insert is coupled with the metallurgic sample holder. This greater reduced the contact required for the user to load samples onto the holder.

With the use of micro electronic components, the electrical component fixation is now a breeze. The copper brackets are arranged in such a way as to secure the sample without glue and without the risk of damage to the surface. The fixation is done without any tool and takes only seconds. This insert is suitable for components up to a size of 15mm x 25mm and 10mm in height.

Glass and silicon can be imaged without loading onto sticky carbon tabs, greatly reducing the need for these consumables.

Phenom for Cross-Section Imaging
It is often challenging preparing samples for imagining along the cross section, either for specific features or measurements of layer thickness. This insert allows samples to be pinched between plastic teeth, allowing various thicknesses of sample and presenting the sample to the electron beam. This insert is suitable for components up to a size of 10mm x 19mm and 10mm thick.

The sample may be used on other instruments after the inspection in the SEM for further investigations. This insert provides cross sectional views and is a free of fixation method i.e. doesn't require fixing the sample to a stub or embedding into resin therefore removing the lengthy process of cutting and polishing. Since the sample is not embedded the risk of introducing artefacts caused by the polishing is removed.

Sample Holder Micro Tool
The miniaturisation of precision tools always opens up new dimensions. Diameter of 100µm are today already state-of-the-art technology. Thus, cutting edges and coatings with conventional light microscopes are no longer feasible.

The non-destructive inspection of lengths, rod-shaped samples in the SEM has previously not been available in space below the detector. Phenom World has developed a holder for their electron microscopes with their greater magnification and depth for high-precision manufacturing.

The advantages of the sample holder at a glance:

- Sample dimensions:
  Length: 10mm to 100mm
  Diameter: 0.5mm to 10mm
- Tilt angle of -5° to 45°
- Free axle positioning
- Automatic and secure fixation without adhesive
- No contamination of the sample by adhesive

It is now possible for the first time, to image long objects such as for example:

- Micro cutters and drills
- Needles and syringes

Fig. 26 Micro electronics insert - also useful for trimmed glass slides or silicon coated with Poly-D-Lysin

Fig. 27 Above this cross section insert works with the metallurgic sample holders

Fig. 28 Tool insert sample holder

Active Sample Holders for Phenom Pure, Pro, Pro X and Pharos

Fig. 29 Tilt & rotation sample holder

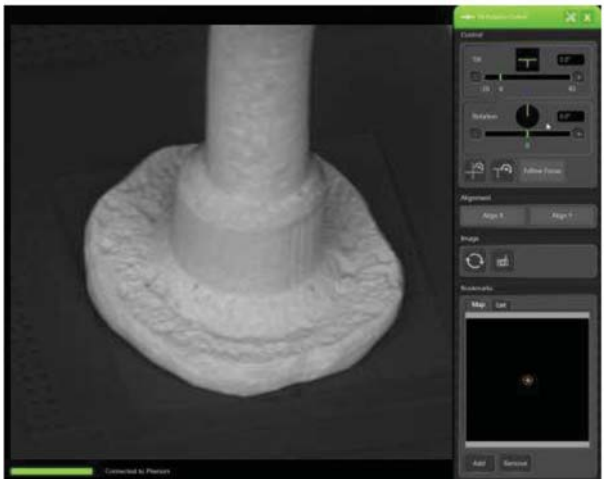

Fig. 30 User interface tilt & rotation

Fig. 31 Temperature controlled stage

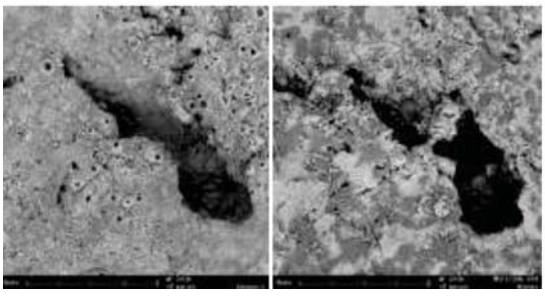

Fig. 32 Left: Sample melts at 30°C
Right: SEM Image without melting artifacts

In addition to the standard sample holders for both pin stubs and embedded resins there are a range of holders and inserts specifically developed for a range of applications. These have a degree of motorisation or additional electronics.

With the tilt & rotation sample holder it is possible to image samples loaded onto a 15mm pin stub with the capability of X-Y motorised stage in addition to tilting and rotation. The advantage of this solution is that there is an automatic correction of focus and object tracking. Thus, the navigation is still very simple.

Specification:

- Tilting -10° to +45°
- Continuous rotation
- Adjustable graduation min 0.2°
- Max. sample diameter: 12mm
- Max. sample height: 5mm
- Max. sample weight: 60g

Temperature Controlled Stage

Here it is possible to either reduce or increase the stage temperature to -25°C to +50°C. This is controlled externally.

The temperature controlled stage can be controlled, without limitation in the x and y direction.

Specification:

- Temperature range-25°C to +50°C
- Setting range in 0.1°C increments
- Accuracy: 1.5°C
- Cooling capacity: 20°C/min.
- Max. sample diameter: 25mm
- Max. sample height: 5mm
- Batch reduction mode

Phenom Images

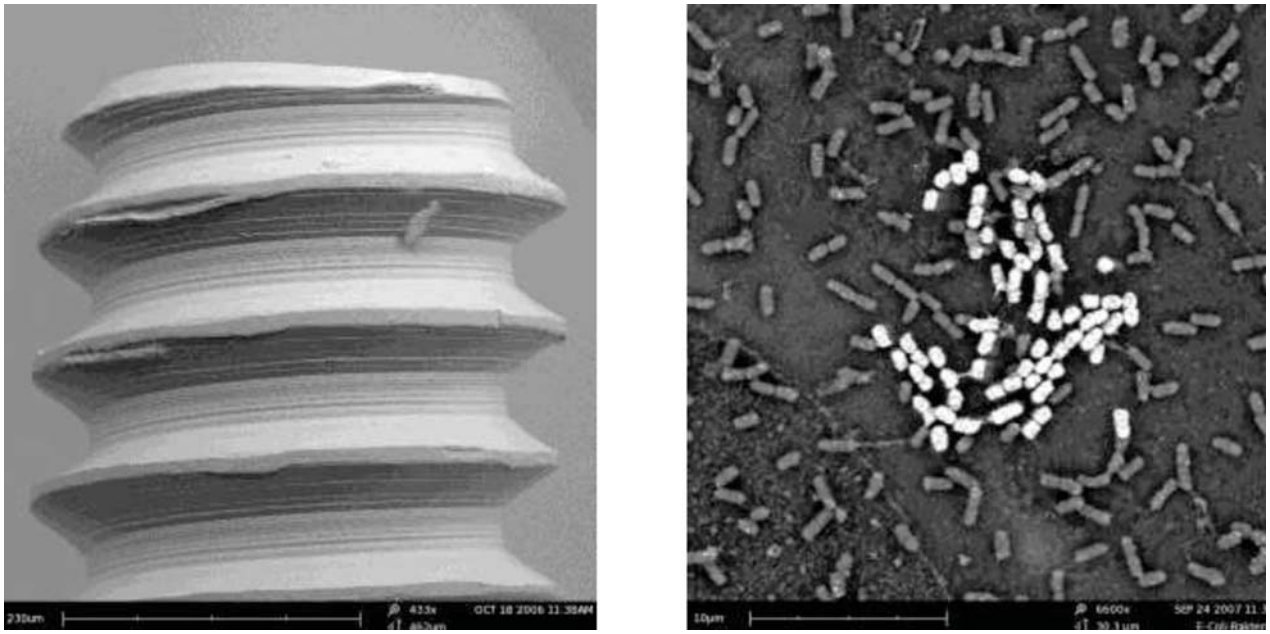

Fig.33 Left: Screw thread at 422x magnification with topographic contrast
Right: E. coli bacteria at 6600x magnification

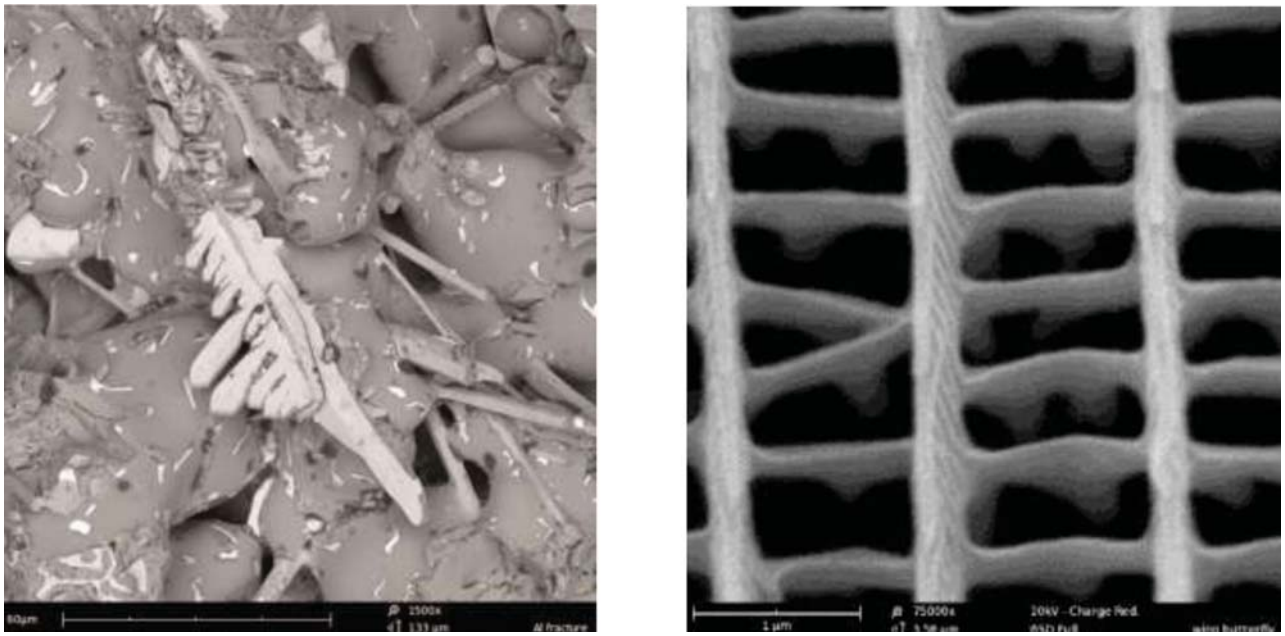

Fig.34 Left: Fracture surface of aluminium at 1500x magnification
Right: Butterfly wings at 75,000 magnification

The Phenom ProSuite Hardware

Fig. 35 Side profile of Phenom ProSuite: PC and router are mounted on the back of the monitor

Fig. 36 Pine orthopaedic bracket (~3mm x 3mm)

An optional hardware platform, consisting of:

- Mini-PC with Windows 7 Pro (64-bit)
- 19-inch monitor
- Network router
- Keyboard and mouse

Phenom ProX and **Phenom XL with EDX** are delivered with **Phenom ProSuite.**

Each suite has been developed to address current and future SEM applications in connection with the benchtop electron microscope Phenom. **ProSuite** is the basis for the following applications:

- The SEM remote user interface (RUI)
- Automated image mapping (AIM)

The following applications can be added in connection with **Phenom ProSuite** can be ordered.

- Particle Metric
- Poro Metric
- Fibre Metric
- 3D Roughness Reconstruction*

**All software applications can have additional offline user licenses accept for 3D Roughness and Reconstruction.*

SEM Remote User Interface (RUI)
RUI allows the complete control of the networked Phenom from a physical location away from the SEM via ProSuite.

- Access to the SEM remote user interface allows the Phenom from control.
- Ideal for monitoring and support users.
- The user interface can be live in the lecture room or a conference.

Automated Image Mapping (AIM)
Electron microscopy images are always a compromise between large field of view and high spatial resolution.

Automated image mapping is possible due to the accurate motorised sample chamber of the Phenom providing large visual fields with high local resolutions. AIM is created from a user-defined field of view a SEM image

Phenom Pure, Pro, **ProX** and **Pharos:** Max. 18mm x 18mm

Phenom XL: Max. 50mm x 50mm, optional 100mm x 100mm

- Automatic overview image
- Single axis selection of the desired field of view
- Fully automatic generation of image series
- Fully automatic composition
- Works in the material and topography mode
- The image tiles can then be evaluated with either Fibre, Particle and Poro Metric analysis
- This is not compatible with 3D roughness reconstruction

Particle Metric

The characterisation of particles is one of the most important tasks in the QC process of product development and production. Particle properties directly influence the characteristics of materials an example is powders for pharmaceutical products.

The physical characteristics of the particle are particularly important. Especially concerning questions of appearance, agglomeration behaviour, stability, aspect ratio, mixing ratio, foreign material share, etc...

The visual characterisation of particles based on light microscopy is limited due to size, working at micro-meters to millimetre scales. Difficulties are raised from the lack of depth of field and light may misrepresent important features.

Particle Metric is the first solution available that allows the characterisation of both micro and nano scale particles. This is possible due to the automated, easy to use software that allows both fast and efficient data collection from the SEM images.

Particle Metric is a development from Phenom World B.V., and is optimally adapted to the Phenom benchtop scanning electron microscope. The user interface is intuitive and enables a user independent reproducible analysis for evaluation purposes.

Particle Metric is compatible with all the Phenom SEMs. The only prerequisite is the application platform ProSuite under Windows 7 (64-bit) or above is running.

Source Data
The source data are with the Phenom benchtop electron microscope SEM recorded images:

- From live images on the SEM
- Saved stored images generated by the SEM (TIFF/JPG)
- Can be integrated with images from AIM

The user interface allows parameters to be adjusted to optimise the sensitivity of the software for particle detection. The software can detect up to 1,000 particles per minute.

The coverage area for the automatic detection ranges from 100nm to 100µm. Images from AIM can be loaded as a project and analysed. The system automatically colour codes particles by size and shape.

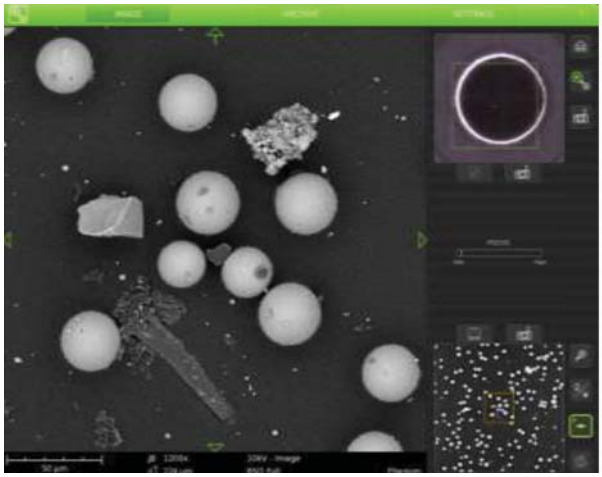

Fig. 37 Phenom live image

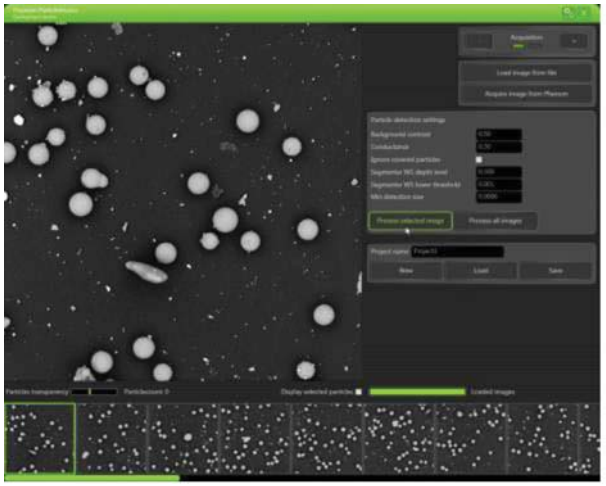

Fig. 38 Particle Metric: parameter to particle detection

Fig. 39 The result of the detection is initially displayed in colour

Particle Metric

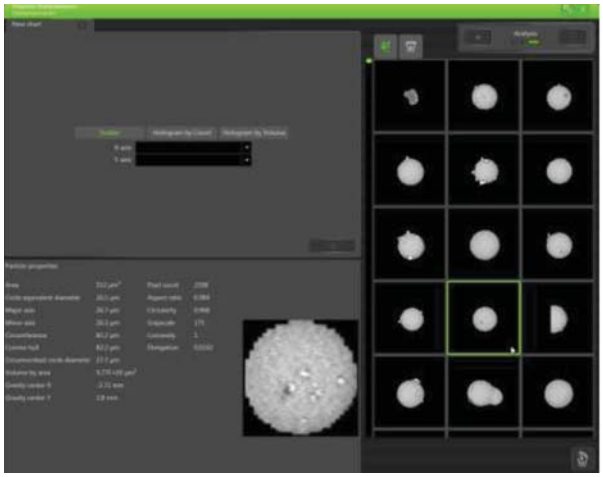

Fig. 40 Representation of the isolated particles in the image database

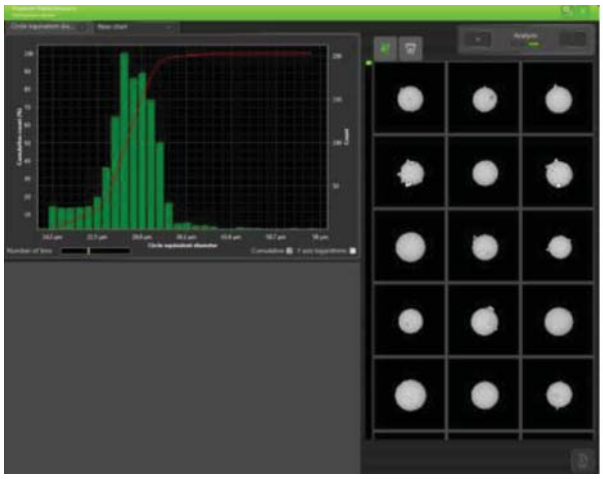

Fig. 41 Bar graph of a particle size distribution

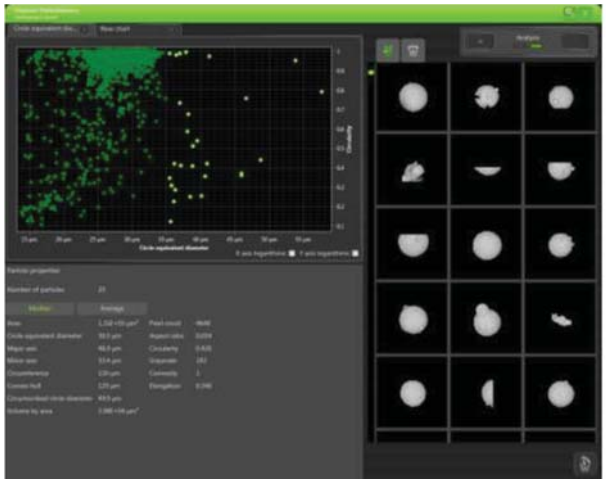

Fig. 42 Point diagram of a particle size distribution

Initially the software will identify all particles and automatically order them.

Now there are a large number of evaluation options available:

- Diameter
- The largest diameter (circle projection)
- Spherical
- Convexity
- Surface
- Scope
- The chord length min. and max.
- Aspect ratio
- Focalpoint (x,y)
- Gray value (BSD mode)

Provides information on mixture of ratios.

These parameters can be graphically presented in a number of different ways:

- Column graphs
- Scatter plots
- Definition of classes
- Accumulation curve
- Distribution of particle number
- Distribution according to calculated particle volume
- Linear and/or logarithmic scaling X, Y
- Free combination of the parameters on the X and Y

Integrated Reporting Tool
A project file is generated when saving the data – this can be viewed and further measurements can be completed based on the SEM imaged captured. Data can be reported into Open XML format to all created images, diagrams and measured data.

Recommended Accessories: Nebula dispenser

Dispersing of dry particles/powders (Nebula)

The optimal preparation of powders for the characterisation and evaluation with the SEM can be quite a challenge. Phenom recommends the use of the Nebula.

Here the Nebula provides optimum conditions for a proper grain size distribution measurements. Analysis is achieved significantly more accurate if the sample is loaded onto the pin stub a monolayer.

As a vacuum is created within the cylinder the particles are evenly distributed regardless of the dimensions and size. Particles adhere to the carbon sticky tab on the pin stub.

Nebula1 consists of a vacuum cylinder with inlet valve, a diaphragm pump and a manual vacuum control.

Technical data:

- Suitable for particle sizes of approx. 100nm to 1.5mm
- Dispersing vacuum: 10mBar to 0.8bar

The device ensures almost optimal distribution and dispersion of dry sensitive micro and nano scale particles under minimisation of agglomeration, screening and broken.

Mode of Operation:
Powder is loaded via the inlet valve, the powder is suddenly pulled into the cylinder and dispersed.

Fragile particles should be loaded carefully into a lower pressure with the cylinder to increase the particle dispersion whilst protecting the sample structure. Although you can increase the vacuum and therefore increase acceleration of the particles to deliberately smash dense particles or ones that easily aggregate.

After approximately 60 seconds, the process will be terminated and the sample can be removed from the cylinder and moved to the SEM. the vacuum cylinder must be cleaned in order to exclude the possibility of cross-contamination. The components can be easily and without tools disassembled.

Fig. 43 Nebula 1 - particle atomizer

Fig. 44 The powder is unloaded for the inlet valve

PoroMetric

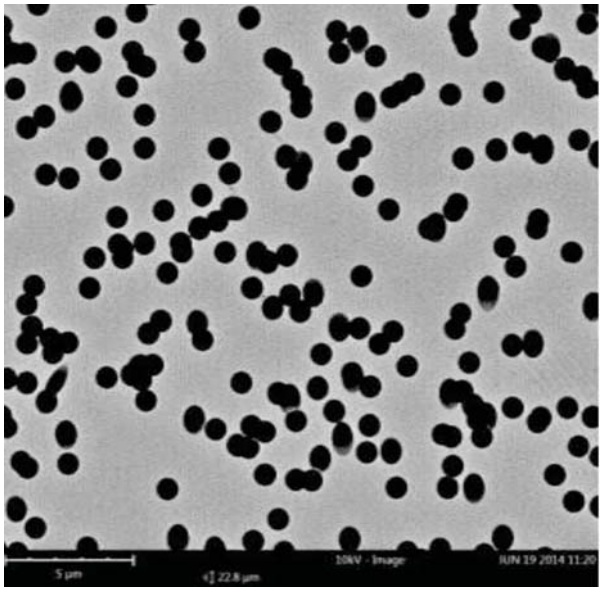

Fig. 45 SEM image of filter with randomly distributed pores

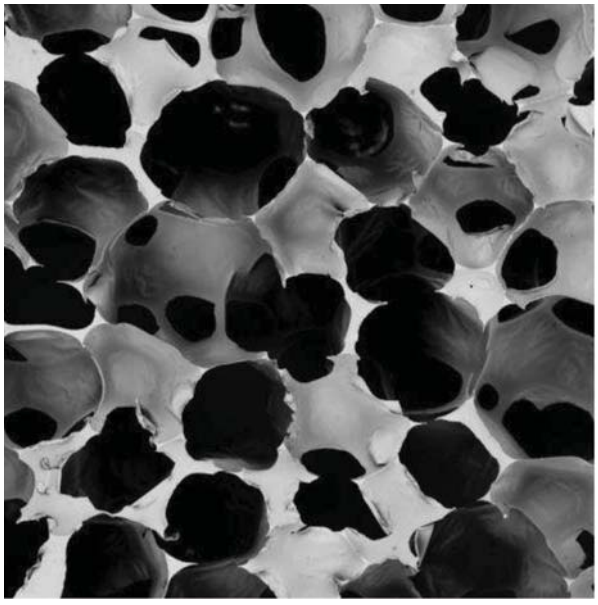

Fig. 46 Image above from honey comb material is typical application for Poro Metric analysis

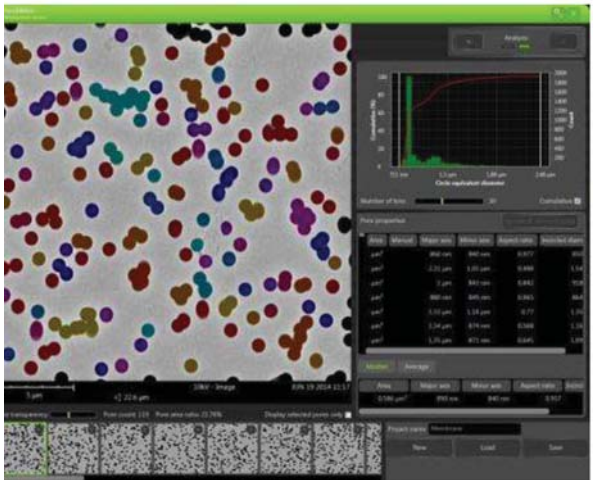

Fig. 47 Poro Metric interface with SEM image

Poro Metric analysis is used for the automated measurement and characterisation of pores. The software has been developed on the basis of the Phenom SEM BSD characterising pores in the size range between 100nm and 100µm automatically. The algorithm allows the calculation of up to 1,000 pores per minute.

This applies to pores on the surface of the sample. It is possible to capture and characterise larger surface areas via Automated Image Mapping (AIM). Each tile that contributes to the final mosaic image is passed through the analysis software.

In the field of view on the left the software has detected pores from an image received from the SEM and generated a table of data. This is fully automatically. There are various parameters that can be adjusted for the evaluation of the pores:

- Diameter
- The largest diameter (circle projection)
- Spherical
- Convexity
- Scope
- The chord length min. and max.
- Aspect ratio
- Calculated volume
- Etc...

Reporting
The reporting tool provides extensive statistical representations:

Column charts, point diagrams, definition of classes, accumulation curve, pore distribution by number, distribution after calculated pore volume, linear and/or logarithmic scaling X, Y, and much more.

When saving the results the software automatically generates a project file that can be viewed at any time and further measurements can be undertaken. At the same time a report is in open XML format to all created images, diagrams and measured data.

Phenom Poro Metric is with all the Phenom device versions compatible. The prerequisite is the application platform ProSuite.

3D-Roughness Reconstruction

It is not simple to identify and measure roughness. The roughness of shapes and surface textures, three-dimensional display is made significantly easier with 3D roughness reconstruction, this is an optional part of the Phenom ProSuite. This application software allows the fully automatic and fast measurement of height and thus roughness on the sample within the Phenom SEM.

The measuring method is based on the shape from shading (SFS) method. This is based on the brightness distribution in the grid of the four quadrants of the backscatter electron detector. The three-dimensional shape of the object is calculated based on this algorithm. The procedure is relatively quickly however imaging modifications cannot be made from within the application. The measurements recorded are based on the live image from the SEM.

In the first step of this analysis is to define the topography contrast gradient of the surface of the sample in both the X and Y direction. Importantly the signal recorded by a detector depends on the position of the detector and the material. This in turn affects the topography-dependent brightness coefficients. The roughness intensity can be determined by the X and Y gradients i.e. the partial derivatives of the surface z (x,y) to x and y.

The second step is to apply an algorithm to eliminate any outliers; the signals of the 4 quadrant with their well known positions.

Since the information provided is supplied data only from the surface topography contrast via the detector quadrants, and not from true shadows this procedure on surfaces with no steep edges and undercuts is limited.

Features at a glance:

- Display of 3D surfaces and structural anomalies
- Interpretation interpretation of three-dimensional structures in the submicron range
- Examine fracture surfaces
- Inspect wear mechanisms
- Representation of roughness R_a medium roughness and R_z medium roughness
- Can be used with electric conductive surfaces
- Can be used on uncoated samples with charge reduction sample holder
- In comparison with light microscopy, this application software has the following benefits:
- No glare
- Depth of up to approx. 800µm
- Representation of topography contrast

Specifications

- Field of view of 10µm to 2mm edge length
- 3D reconstruction in a few seconds
- High colour coded 2D or 3D image
- 3D filter for representation of the roughness
- Fully automatic roughness values
  R_a (mean roughness)
  R_z (medium roughness)
  S_a (surface roughness)
- Image resolution of 512 x 512 pixels
- User-specific ripple filter
  - Up to 5 measuring lines
  - Height profile
  - Position identification

Data output

- 2D and 3D images
- Heat map profile
- Profile lines
- Automatic export as .csv file

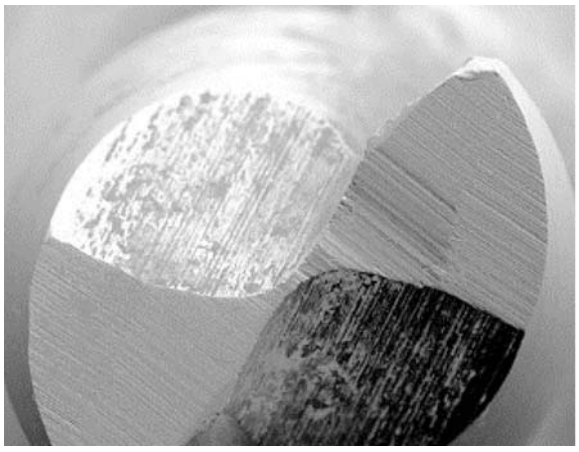

Fig. 48 SEM recording drill tip (600x) BSD topography

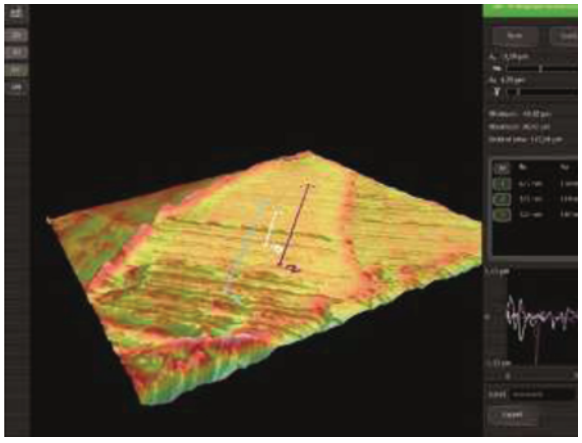

Fig. 49 3D reconstruction of the cutting surface

Fibre Metric

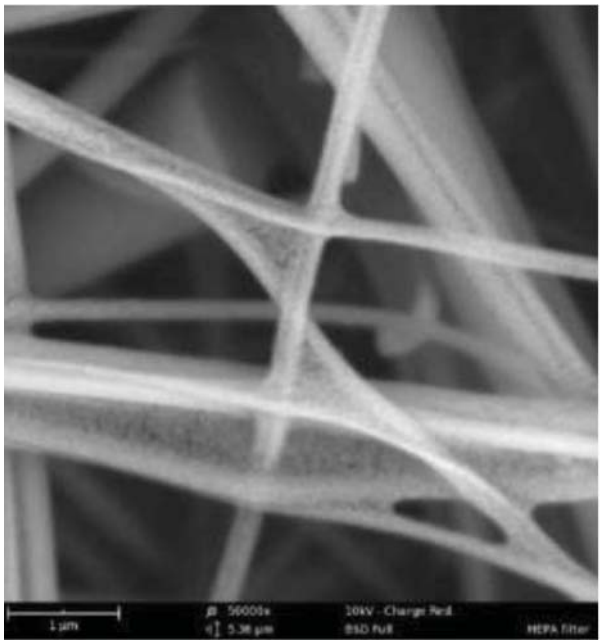

Fig. 50 SEM image of a HEPA filter (50,000x BSD 10kV)

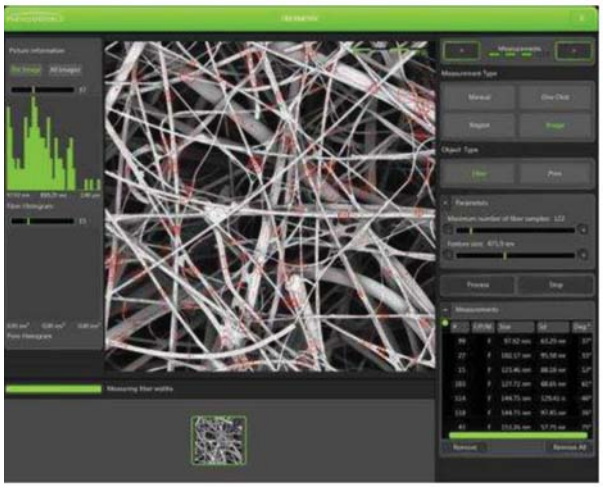

Fig. 51 Automatic fibre and pore analysis

Analytical Tools for Fibres
With the Fibre Metric software application Phenom World have developed an automated system to enable the statistical analysis of fibres utilising the SEM image. Producing an efficient and effective method of characterising fibres.

CFM - Click Fibre Measure
This feature automatically detects image elements when it comes to fibres or pores. In fibres, the thickness is measured in the pore space.

AIC - Automated Image Characterisation
After manual selection of an area of the image are automatic measurement functions for

- Fibre diameter
- The fibre direction (orientation)
- Pore area

In automatic mode, fibres in a thickness range of >= 100nm to <= 40µm are automatically measured. The theoretical maximum viewing area of 18 x 18mm is evaluated automatically or manually. Fibres can be measured manually – by utilising specific keystrokes, images can be zoomed in and out as well as contrast/brightness alterations make to emphasise pixel boundaries.

Specifications
The statistics module calculates from up to 1,000 individual measured values per image, or from up to 100,000 individual measurements per project the frequency distributions and makes them both tabular and graphical form.

- Automatic fibre thickness recognition
- Automatic pore area calculation
- Semi-automatic fibre thickness measurement
- Manual fibre thickness measurement
- Automatic measurement data management

Data output

XML/.csv data file with individual results for:

- Fibre thickness and direction in µm
- Fibre orientation in radians
  - Pore surface in µm² or nm²

Image formats: JPG, TIF, max. 2,048 x 2,048 pixels

***Histograms: fibre thickness and pore surfaces*

False Coloured Phenom SEM Images

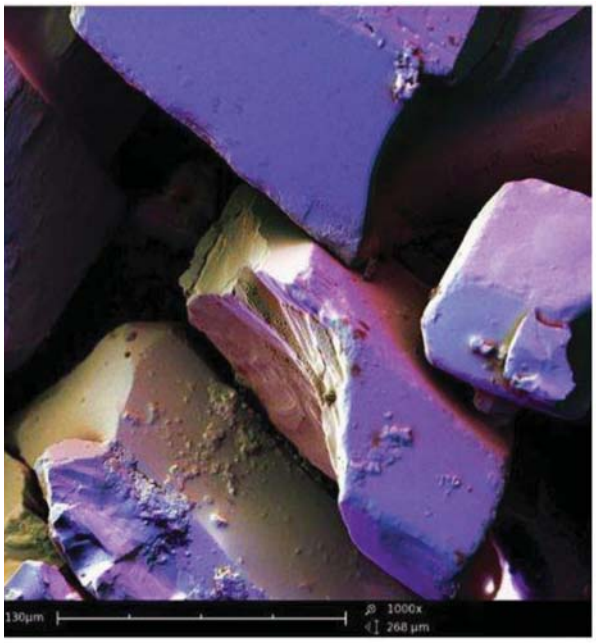

Fig. 52 Sugar crystals, 1,000x magnification

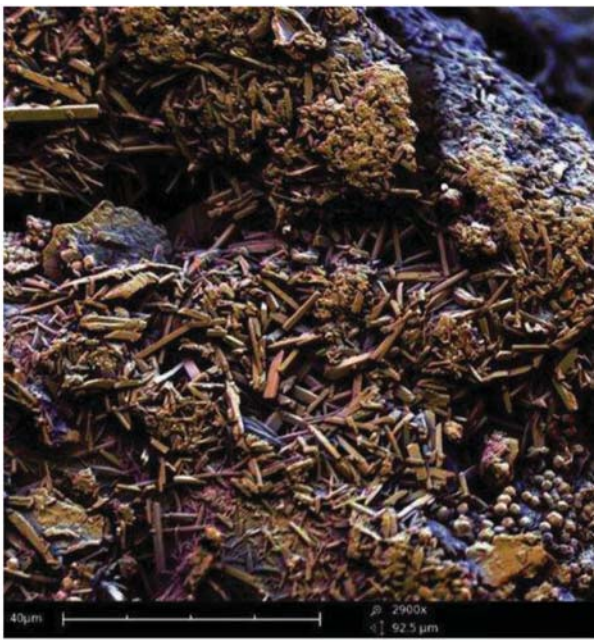

Fig. 53 Peppercorn 2,900x magnification

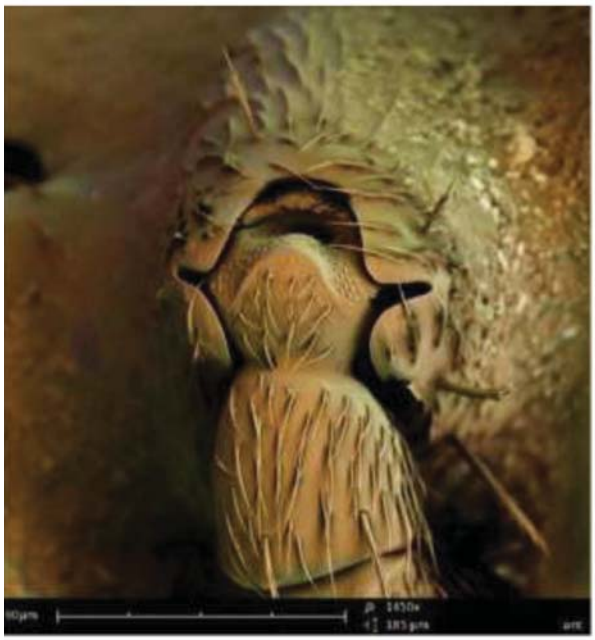

Fig. 54 Elbow joint of a ant, 1,450x magnification

Fig. 55 Fly eye, 3,900x magnification

Specifications Phenom Pure, Pro, Pro X and Pharos

	Phenom Pure	Phenom Pro	Phenom ProX
SEM-detector	4-quadrant backscatter electron detector (BSD)		
	Element contrast, topography (A and B), SCAN		
SEM-detector modes	ROTATION		
Secondary electron detector	Optional on all systems		
Magnification	70 - 65,000x		80 - 150,000x
Additional digital zoom	12x		
Working distance (SEM)	30mm		
Field of View (SEM)	>2mm to <15µm		>2mm to <2.0µm
Electron source (drop-in source)	CeB6 (Cerium Hexaboride), life > 1,500h		
Accelerating voltages	5kV (Upgrade 4,8-10kV)	4.8 - 15kV	4.8 - 15kV
Beam current	300Pa and 1nA	300Pa and 1nA	300Pa - 14nA
Resolution (7x7 pixels)	<25nm	<10nm	<10nm
Beam shift	Max. 50µm, automatic switching between stage move and beam shift		
Positioning accuracy	10nm		
Context-oriented help function	✓		
"Never-lost-Navigation"	✓		
Optical navigation camera	SW-CCD camera, 20x	Colour CCD camera, 20x-120x zoom	
Sample loading times	5 seconds - Navigation camera		
	<30 seconds - SEM-picture display		
Vacuum control	Fully automatic vacuum control with external, oil-free diaphragm pump and integrated turbomolecular pump		
Motorized X and Y axis	Minimum step size >= 1µm		
Control units	19" - Monitor, USB-knob, USB mouse, USB keyboard		
Image Formats	BMP, JPG, TIFF (max. 2,048 x 2,048 pixels)		
Data storage	Directly to a USB flash drive or on a network drive		
Integrated EDX analysis	Upgrade Required		
EDX detection and analysis	Silicon drift detector (SDD), thermo-electric cooling, active detector area 25mm²,		
Including Phenom ProX Suite	Ultra-thin silicon nitride (Si2N4) window, energy resolution in Mn Kα 133eV,		
On Windows 10 PC	Multi-channel analyser with 2048 channels per 10 eV/channel, max. input count rate: 300,000 CPS, Element Detection: B (5) to (95), automatic peak identification, volume share and Reliability Indicator		
X-ray regulation and CE conformity			
Classification in accordance with	The x-ray mission is less than 1µSv/h at a distance of 10cm to the device housing.		
X-Ray Ordinance (ROV)	The maximum acceleration voltage is less than 30kV.		
CE declaration of conformity	The EMC directive 2004/108/EC, 2006/95/EC, the low voltage directive		
	96/29/EURATOM ionizing radiation, following article 3.2.e		
	CE EN613 26/1 and CE EN6101 01/1		

	Phenom XL	Phenom Pharos
SEM-detector	4-quadrant backscatter electron detector (BSD)	
	Element contrast, topography (A and B), SCAN	
SEM-detector modes	ROTATION	
Secondary electron detector	Optional on all systems	
Magnification	80-100,000x	200-1,000,000
Additional digital zoom	12x	12x
Working distance (SEM)		2mm to 30mm
Field of View (SEM)		>2mm to <2.0µm
Electron source (drop-in source)	CeB6	FEG, life >10,000 hrs
Accelerating voltages	5kV, 10kV, 15kV and 20.5kV option	2-15kV
Beam current	300Pa and 1nA	
Resolution (7x7 pixels)	<14nm	<2.5nm at 15kV, 10nm at 3kV
Beam shift	Max. 50µm, automatic switching between stage move and beam shift	
Positioning accuracy	10nm	
Context-oriented help function	✓	
"Never-lost-Navigation"	✓	
Optical navigation camera	Colour CCD camera, 20x to 120x zoom	
Sample loading times	5 seconds - Navigation camera <45 secs - SEM	<30 secs - SEM picture display
Vacuum control	Fully automatic vacuum control with external, oil-free diaphragm pump	
Vacuum observation mode	High Vac 1Pa Mid Vac 10Pa Low Vac 60Pa	
Motorized X and Y axis	Minimum step size >= 1µm	
Control units	19" - Monitor, USB-knob, USB mouse, USB keyboard	
Image Formats	BMP, JPG, TIFF (max. 2,048 x 2,048 pixels)	
Data storage	Directly to a USB flash drive, HDD on PC, Pro-Suite or on a network drive	
Integrated EDX analysis	Upgrade Required	
EDX detection and analysis	Silicon drift detector (SDD), thermo-electric cooling, active detector area 25mm²,	
Including Phenom ProX Suite	Ultra-thin silicon nitride (Si2N4) window, energy resolution in Mn Kα 133eV,	
On Windows 10 PC	Multi-channel analyser with 2048 channels per 10eV/channel, max. input count rate: 300,000 CPS, Element Detection: B (5) to (95), automatic peak identification, volume share and Reliability Indicator	
X-ray regulation and CE conformity		
Classification in accordance with	The x-ray mission is less than 1µSv/h at a distance of 10cm to the device housing.	
X-Ray Ordinance (ROV)	The maximum acceleration voltage is less than 30kV.	
CE declaration of conformity	The EMC directive 2004/108/EC, 2006/95/EC, the low voltage directive	
	96/29/EURATOM ionizing radiation, following article 3.2.e	
	CE EN613 26/1 and CE EN6101 01/1	

Phenom SEM Images

Fig. 56 African ant 300x magnification; compound eye, mandibles and antenna

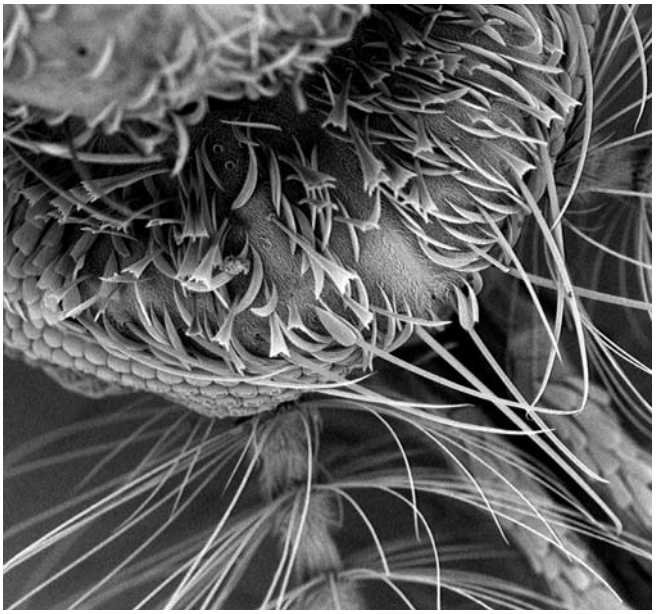

Fig. 57 Mosquito 1,000x magnification; maxillary palps, antenna and compound eye

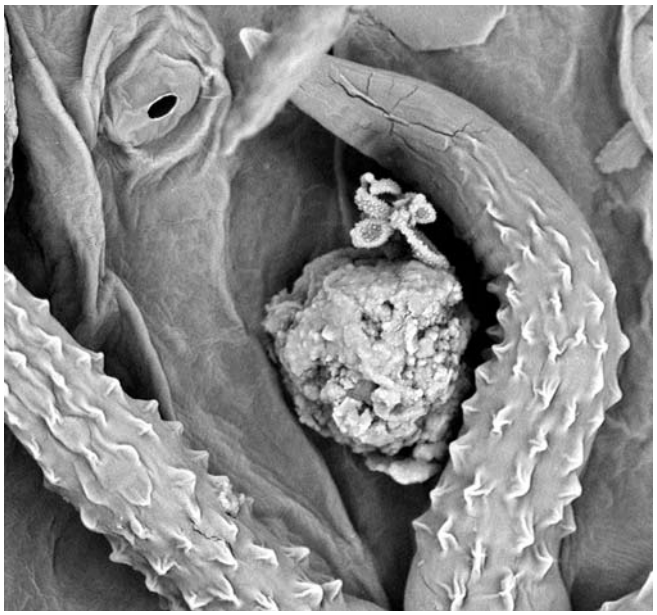

Fig. 58 Leaf tissue 3,000x magnification; modified leaf hair, stomata and dust particle

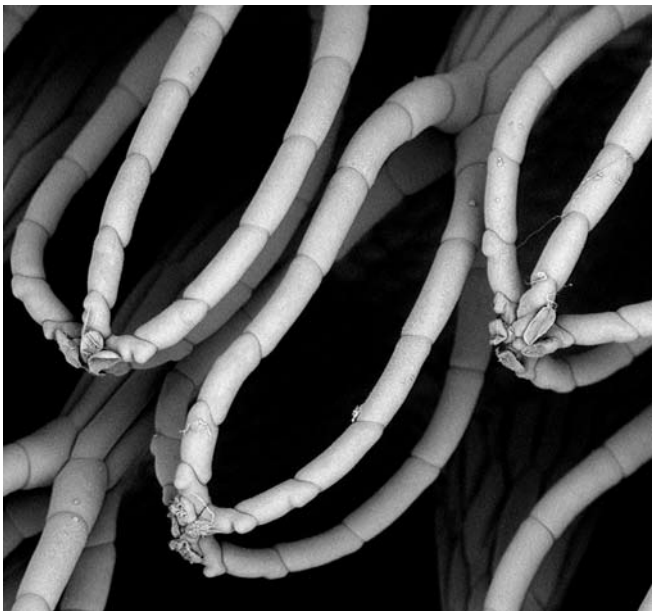

Fig. 59 Salvina leaf tissue 300x magnification; egg beater leaf hairs

Notes

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