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FlexSEM

The smart little SEM that flexibly adjusts to your skills and needs

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A SEM evolution

Tabletop SEMs have gone through a remarkable evolution during the past decade, establishing themselves as an optimum solution for users looking for the “next level” beyond optical stereo microscopy.

They inspect objects at higher magnification and resolution than classical optical microscopy can reach without being limited by an extremely shallow depth of focus. Furthermore, the backscattered electron detectors of typical tabletop SEMs offer additional information on the distribution of different materials, which can be quantified by executing proper EDX analysis.

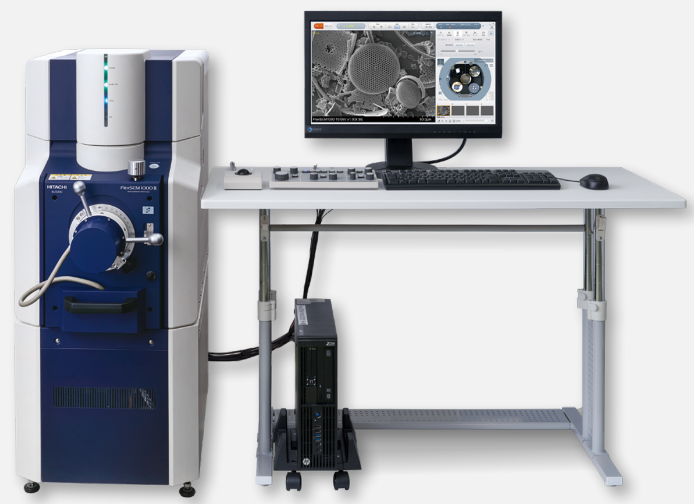
However, the technical consequences of instrument miniaturization and price level restrictions of the tabletop SEM concept set natural limits to the obtainable image resolution. Users who routinely need to resolve structures smaller than about half a micrometer won’t be satisfied with a tabletop SEM.

In the past, users with a higher imaging demand had no choice but to take the big leap towards the purchase of a classical room-filling SEM with its large footprint, including external facilities, and an unrestricted operation concept which typically calls for expert knowledge to achieve the instrument’s full potential.

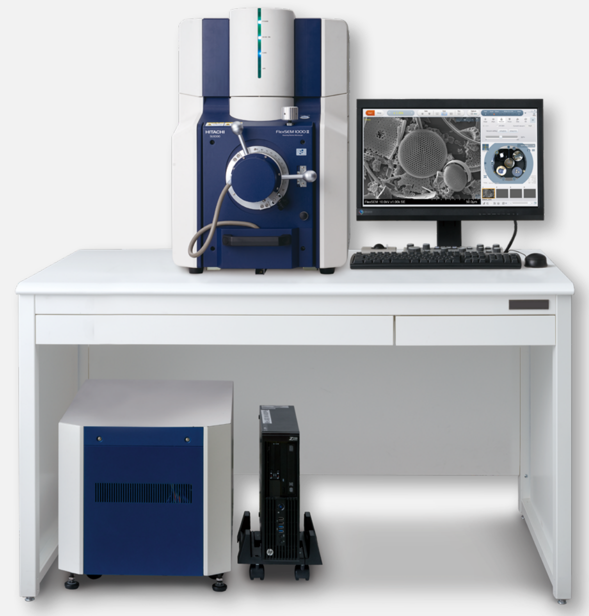
In this article we will introduce a smart solution to this problem: The Hitachi FlexSEM, an extremely powerful little SEM with a novel compact layout, developed in response to exactly such considerations as described above. It combines a high and easily obtainable performance close to that of a classical full-scale SEM with an ultra-compact (just 45cm wide) tabletop-SEM-like body, includes user-customizable software, is fully user-maintainable, and comes with an attractive price tag.

- **4nm @ 20kV** High-resolution electron optics with beam energies between 300eV and 20keV
- High and adjustable low vacuum up to **100Pa**
- **SE** and **4+1** segment backscatter detector standard, low vacuum SE optional (UVD); can also be used for cathodoluminescence and STEM imaging, optical colour navigation camera and chamberscope
- **5-axis** sample stage for samples up to max. 153mm diameter and 40mm height

Concept and outline



FlexSEM in stand-alone setup



FlexSEM in desktop setup

A general problem for a typical ultra-compact tabletop SEM is that its small size comes at the cost of functionality: The vacuum system is fixed to a certain operation mode, and the miniaturized electron optic system does not allow the application of high-quality low-aberration lens systems. Sometimes this can be somewhat compensated by the use of special electron sources like LaB6 / CeB6 or even Field Emission sources which can improve the resolution of compromised electron optics, but such approaches typically bring more problems than benefits in terms of general usability, maintainability, handling, and cost. This was clearly not the direction for Hitachi to go in when developing a high-performance yet highly compact and mobile new SEM.

Here is the outline of the FlexSEM:
The FlexSEM is compact, with a 165kg mass, and due to a wheeled chassis is highly mobile. It can be installed on a workbench (like a tabletop system) or can be used in a standalone configuration and does not require external facilities except for a 230V power outlet and a small rotary pump.

However, it is still large enough to incorporate classical high-performance Tungsten-source-equipped electron optics with up to 20kV accelerating voltage, and a sophisticated TMP driven vacuum system that supports both a true high-vacuum mode for high-resolution imaging and a dedicated and controllable low-vacuum mode with adjustable chamber pressures up to 100Pa.

This enables not only the charge-up-free observation and analysis of uncoated non-conductive specimens, but also allows the observation, in combination with an optional Peltier cooling stage, of moist biological specimens. The 5-axis specimen stage with -20° to +90° tilt capability can be fully withdrawn from the chamber for easy setting of samples up to 80mm in diameter and 40mm in height. Also, an EDX system with a sensor size of up to $60mm^2$ can be attached, and a chamber access port for cabling of other potential accessories is provided. The entire system can be fully powered down when not in use and restarts in less than 5 minutes.

Operation complexity can be flexibly adjusted according to each user's skills and needs, and any operation is supported by powerful automated functions, a colour specimen camera for sample stage navigation, recipe memory, stage trackball, an operating knob panel, and so forth.

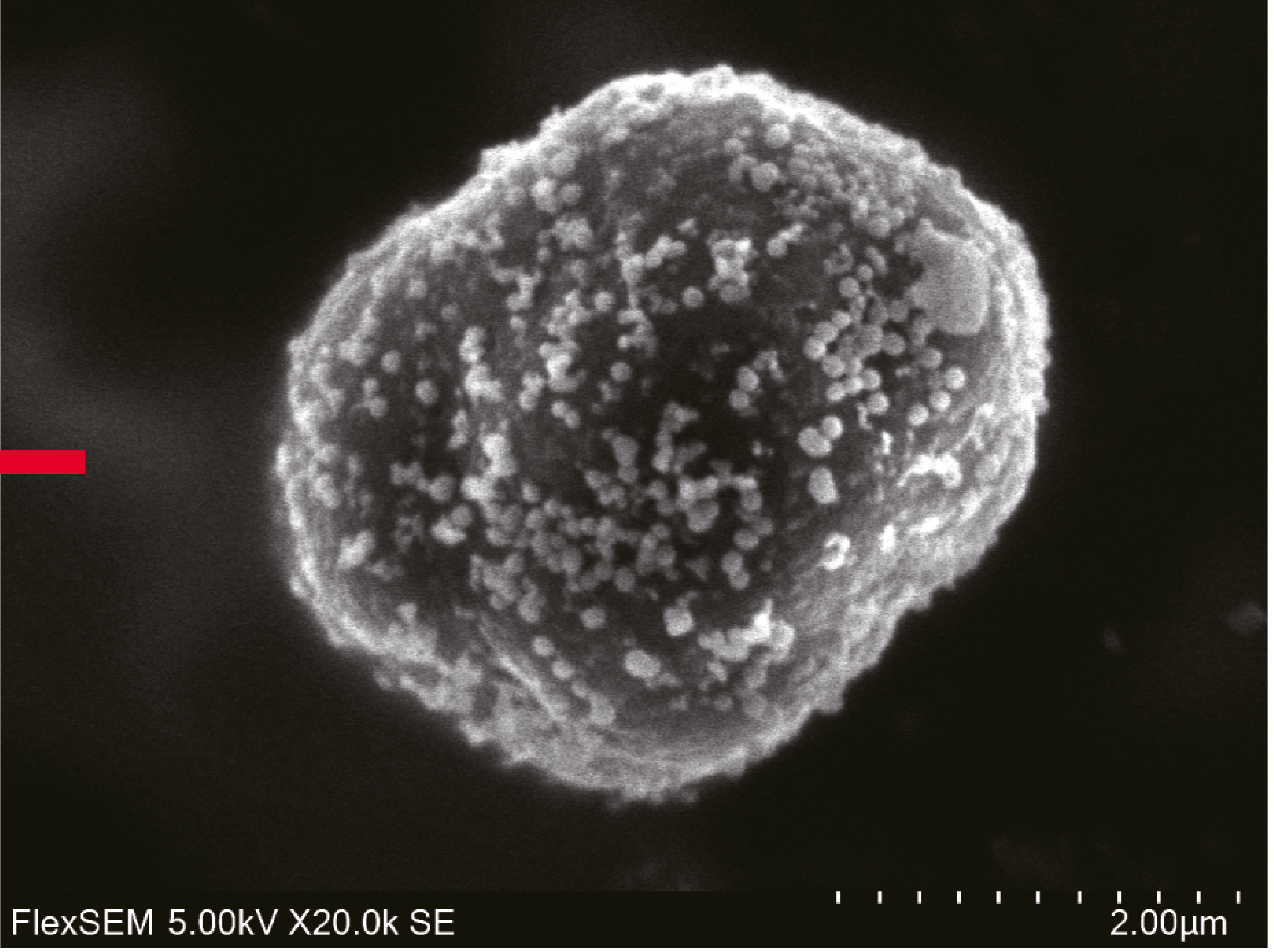


Figure 2a. Toner particle, imaged at 5kV in high-vacuum mode with the Everhart-Thornley-SE detector.
Magnification (polaroid base) is 20.000x.

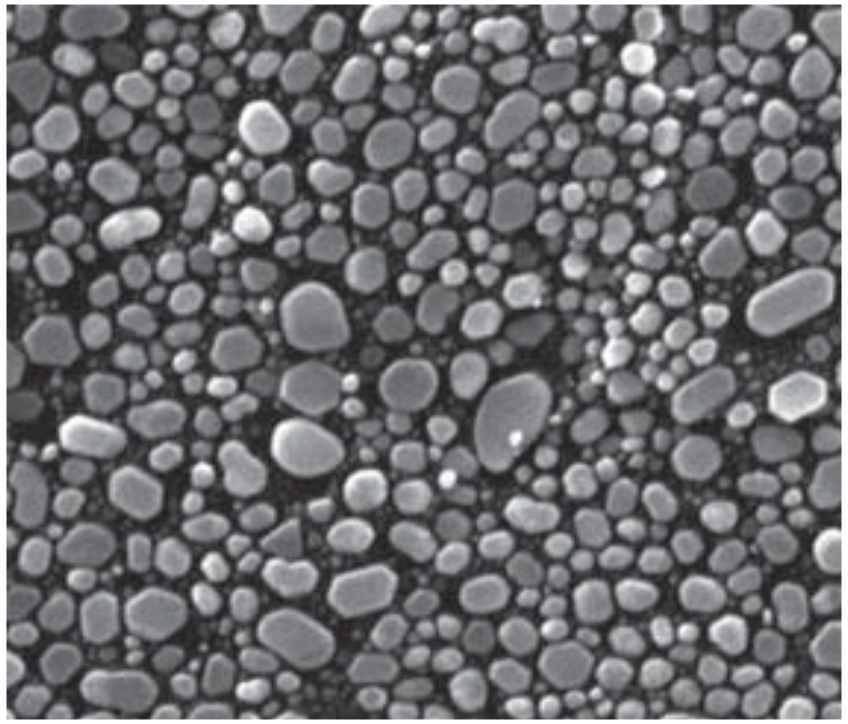


Figure 2b. Gold grains on carbon substrate.
Accelerating voltage 20kV, magnification 60.000x.

Figure 3. FlexSEM's electron gun flipped open for direct access to the filament cartridge.

The heart of the FlexSEM

Electron optics

At the core of the FlexSEM is a powerful electron optics, covering an accelerating voltage range from 300V up to 20kV at which an SE image resolution of 4nm at high vacuum conditions is guaranteed.

While 20kV are typically required and sufficient to perform EDX elemental identification of most elements in accordance with ISO standards (e.g. for Asbestos analysis), such high accelerating voltages are mostly not optimal for best real-world sample imaging when details on fine surface structures are desired. Here the recommended working conditions stretch from lower to medium accelerating voltages over a range of 1kV to 10kV. The FlexSEM covers such needs: It is equipped with a dynamic gun bias system that maintains a nearly constant high gun brightness throughout the entire accelerating voltage range. This bright electron beam is shaped by a double-condenser-optics system and a low-aberration objective lens into a fine spot on the sample so that high quality imaging with an SE resolution of just 15nm at 1kV accelerating voltage becomes possible.

The probe current can be accurately adjusted over a wide range by changing the condenser lens 1 excitation, while the condenser lens 2 always optimizes the beam entry into the objective lens. For simplicity, the user only has to select a "spot intensity" value between 1 and 100 - there is no need to care about such lens details. The FlexSEM does not include any movable apertures, thus beam alignment is automated and very stable over time.

The FlexSEM uses pre-centered cartridge type tungsten hairpin filaments as an electron source. They come "ready to use"; when a filament exchange is required, the FlexSEM specimen chamber is vented, the gun is flipped open, and the old filament with the Wehnelt suppressor screwed on is taken out. The Wehnelt cap is transferred to the new filament cartridge, which is inserted into the gun holder. The gun head is flipped back, the chamber is evacuated, and a single function in the "Beam Adjustment" menu box will do the rest: Saturate the filament heating current, optimize the beam path through the optics for maximum beam current on the sample – done.

The entire procedure takes less than 10 minutes, can be easily executed by any user (supported by step-by-step menu guidance if desired). With this implementation, their general robustness, low vacuum requirements and last but not least the low price tag, make tungsten filaments the ideal electron sources for such a powerful yet compact SEM like the FlexSEM.

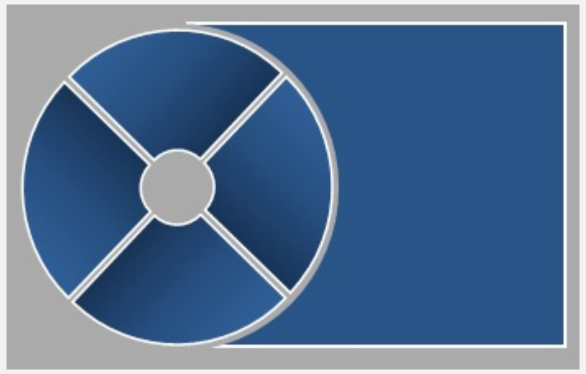


Figure 4a. The FlesxSEM BSE detector system

The detection system of the FlexSEM

The FlexSEM comes as standard with two dedicated vacuum operation modes: High-vacuum mode for the observation of electrically conductive specimens, and a variable-pressure mode for the analysis of non-conductive or moist specimens, allowing for chamber pressures up to 100Pa.

Accordingly, the FlexSEM is equipped as standard with suitable electron detectors. Besides an Everhart-Thornley type detector for high-resolution SE imaging in high-vacuum mode, there is a set of 5 high-sensitivity backscattered electron detectors mounted on a carrier arm underneath the objective lens, usable in both vacuum modes.

Figure 4a shows the layout of the BSE detector set: 4 detectors are arranged as 90° segments of a circle, while the 5th element is located at a side. This geometry allows the generation of different image impressions: With the circle segments combined, a homogenously illuminated material/crystal orientation contrast rich image is obtained ("BSE-COMPO"). When adding the 5th (side) detector to the circle, a variably adjustable topographical (shadow) impression is added to the "conventional" material /orientational contrast image.

The result is a 3-dimensional impression ("BSE-3D"), allowing to judge the specimen's shape in conjunction with the material/crystal information. Pure topographical images can be generated when grouping each two neighbored detectors and subtracting the signal of the two groups ("BSE-TOPO"). Finally, with the optional 3D-Viewing function, simultaneous read-out of the 4 quadrant detector images is possible. The Hitachi Map3D software package uses those 4 directional images to generate a quantitative surface height image of the specimen, from which parameters such as roughness, step heights, etc., can be extracted.

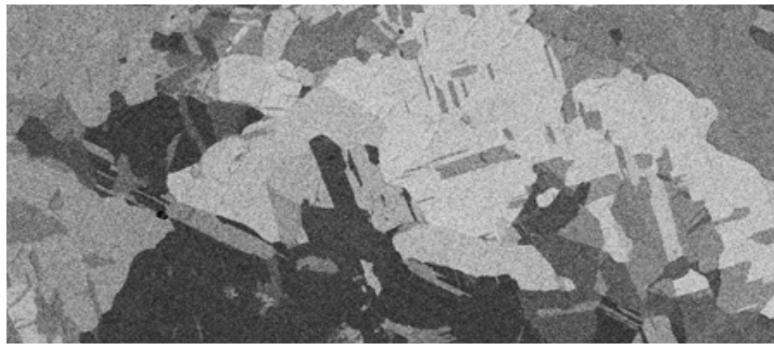
In Figure 4b only grain orientation contrast without any topography is seen by the COMPO mode. In Figure 4c, by the 3D setup, sample topography (rolling traces) appear overlaid on the grain orientation contrast. In Figure 4d, pure topographical information is displayed by the TOPO mode. By changing the segment grouping the "illumination direction" can be adjusted in 90° steps – this helps to emphasize or suppress pattern running preferentially in certain directions.

The FlexSEM BSE detector system is able to work with high efficiency from low accelerating voltages of just around 1.5kV up to the highest accelerating voltage of 20kV. This allows it to perform very surface-sensitive yet multi-mode BSE imaging on even sensitive or very fine-structured samples and also deliver high-contrast images under conditions necessary for EDX analysis. In short – an optimum detection unit for all conditions, from high to low vacuum and from low to high accelerating voltages.

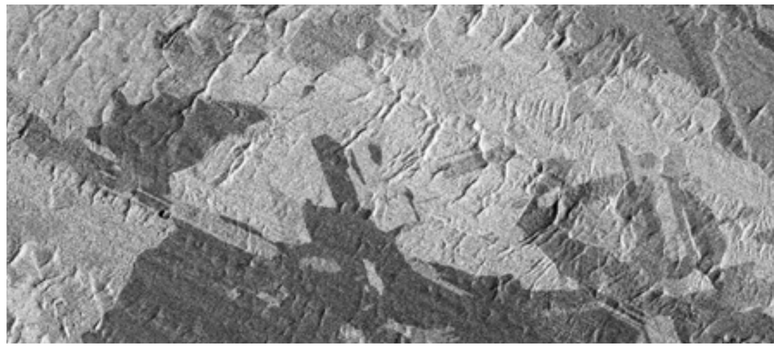
The BSE detection system is the default image sensor for the low-vacuum mode, where the classical Everhart-Thornley SE detector cannot be operated. With its variable imaging modes it usually covers most applications, as it can produce, besides the "flat" material contrast images, also highly topographical images. Some samples may still require "true" SE imaging in low-vacuum mode. Typically, these are organic (low atomic weight) materials with a low BSE yield, or high-aspect-ratio objects that need to be imaged at long working distances. Backscattered electrons are absorbed by interactions with the gas molecules in the chamber: thus, BSE imaging can become weak (blurry) under very long working distances and high chamber pressures. Here, the optional low-vacuum SE detector named "UVD" can help out. This detector principle translates secondary electrons emitted from a specimen into optical photons that can travel the distance from the specimen to the detector without significant chamber gas interactions. Compared to previous-generation low-vacuum SE detectors which rely on a charge cloud drift from specimen to a detector electrode, the UVD delivers contrast-rich SE like images somewhat independent of actual working distance and low-vacuum-mode chamber pressure. Figure 5 shows an example of a superabsorbent polymer, imaged with the UVD at an accelerating voltage of just 3kV under 30Pa chamber pressure.

Due to its "optical photon counting" principle, the UVD can be used as a monochrome cathode-luminescence (CL) detector in high-vacuum mode. Additionally, the FlexSEM's multi-detection system facilitates the simultaneous display and recording of two signals in dual full screen mode.

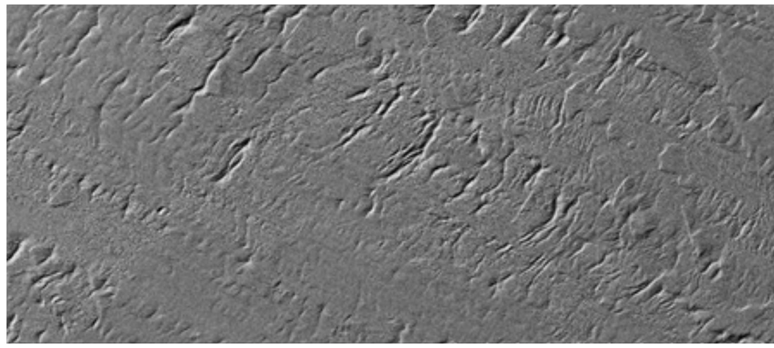
Examples of the different BSE imaging modes can be seen on the example of a rolled and briefly Ar ion beam polished Cu foil:



4b. Only grain orientation contrast without any topography is seen by the COMPO mode.



4c. By the 3D setup, sample topography (rolling traces) appear ocerlaid on the grain orientation contrast.



4d. Pure topographical information is displayed by the TOPO mode. By changing the segment grouping the "illumination direction" can be adjusted in 90° steps – this helps to emphasize or suppress pattern running preferentially in certain directions.

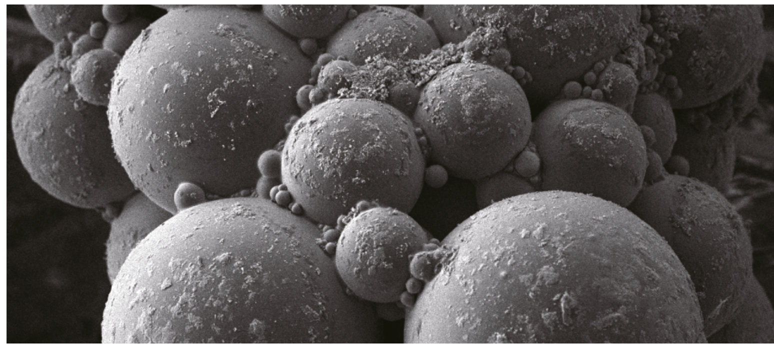
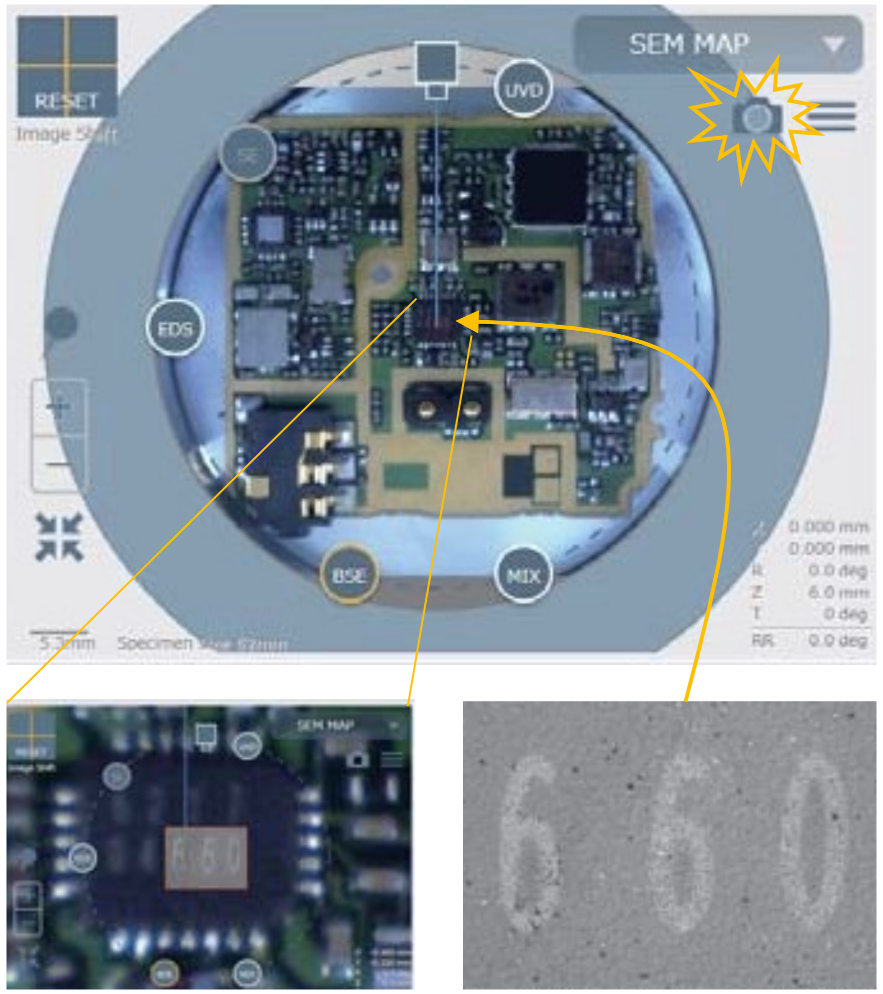


Figure 5. Super-absorbent polymer. No metal coating applied. Low-vacuum mode 30Pa, SE signal (UVD).

Operability and user interface

The FlexSEM flexibly adapts to the skill level of each operator. The system's base concept is "convenient & risk-free operation".

During sample loading, measures are taken to prevent collisions between sample and SEM lens or detectors: Cup-like sample holders with height-adjustable inner stubs make it easy to set a correct sample height. Simply put, no part of the specimen may extend beyond the upper edges of the cup-shape holder. This is even verified when closing the drawer-type chamber door – a height gauge at the chamber entrance, resembling the objective lens and the BSE detector contours inside of the specimen chamber, stops any sample of unacceptable height from entering the SEM chamber (of course, experienced users are free to use conventional sample holders). Furthermore, when tilting the specimen stage during observation, the FlexSEM software automatically sets safe limits for tilt angles and working distances based on the sample size. Although the Tilt and Z axes of the FlexSEM stage are not motorized, they are still monitored by the FlexSEM software so that their actual status is always known.



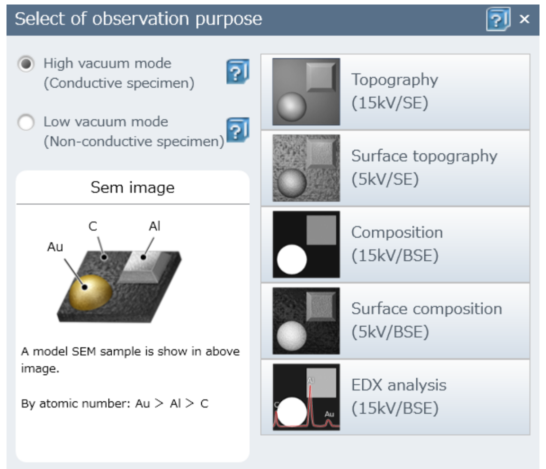
For easy orientation on specimen tables and convenient stage navigation, the FlexSEM incorporates a colour camera at the specimen chamber entrance. This camera acquires a high-resolution colour photo of any specimen loaded and makes this image available in the "SemMap" navigation window. Here, the image may be zoomed-in for better orientation, it rotates with stage or scan direction changes, and the position of relevant detectors is marked at the image periphery for a direct understanding of any directional or shading effect. It is also possible to import externally created images and to validate them by a 3-point alignment for easy navigation.

Finally, a Snapshot button allows the instrument to instantly patch currently displayed low-magnification SEM images directly onto the proper location of the optical navigation image, so that locally fine navigation based on SEM image definition is enabled.

For reporting purposes, the navigation image may be exported with the locations of recent SEM image acquisitions on that specimen marked on it; the marking numbers match to the image numbering when saving is performed in auto-naming-mode.

The safe procedure of specimen registration, photo-documentation and loading is identical for all users. However, for the actual SEM operation, three different skill levels can be handled.

For absolute beginners who might be unfamiliar with SEM-typical phrases such as “accelerating voltage” or “spot intensity” and a proper choice out of them for the desired application, the FlexSEM offers a selection of “application purposes”. This are basic desires for each SEM analysis, such as “surface composition”, “surface topography”, or “EDX analysis”, and so forth. For each purpose, the FlexSEM has a pre-defined and self-aligned optimum working condition which is known to provide the desired output to the user. That way, even unexperienced users can take good-quality images of their sample in a short time.



For routine tasks and somewhat experienced operators, the FlexSEM offers the use of an “operating condition” recipe memory. Here, FlexSEM superusers can store individually defined conditions known to be optimal for frequently required (repeating) tasks. Selecting a recipe loads the vacuum mode, the electron optical conditions, and the assignment of the detectors to the primary and secondary screen.

Finally, for experienced users, FlexSEM offers full access to each electron optical parameter within the available limits.

The FlexSEM can be operated in different ways. All functions are operated as standard via PC mouse or Touch Screen. Reliable and fast automatic functions for brightness/contrast and focus are available. Optionally, the instrument can connect to a trackball for manual stage X, Y fine operation, and a “knob panel” holding the most routinely used functions such as focus, brightness/contrast, electrical image fine shift, scan speed settings, magnification, etc. This knob panel is especially appreciated by experienced SEM users and can deliver higher operation throughput than a mouse-only operating style.

It is possible to customize the “quick access button” menus for each login account. While a novice user might appreciate a tidy user interface with an absolute minimum of buttons and functions in order not to be distracted by a large variety of “unknown” function buttons, a more experienced user might want to have fast access to helpful and frequently used functions without needing to start them via the main menu tree. The FlexSEM is flexible enough to allow all these options.

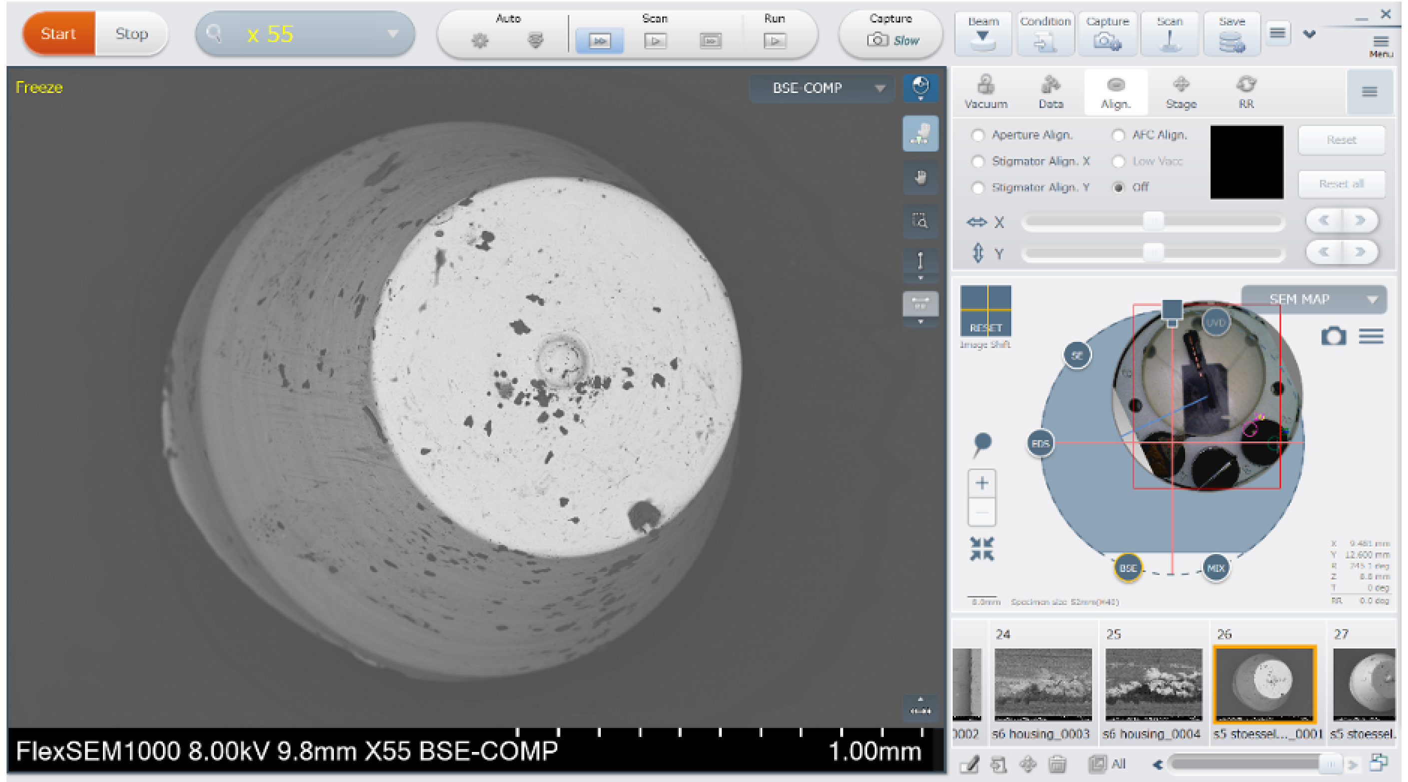


Figure 6. Basic FlexSEM graphical user interface, configured in single-screen mode. The SEM-Map function at the right side shows the colour navigation image, or optionally a second detector signal. At the lower right the thumbnail gallery of already recorded images is shown. Each image recording site can be revisited.

Advanced analytics

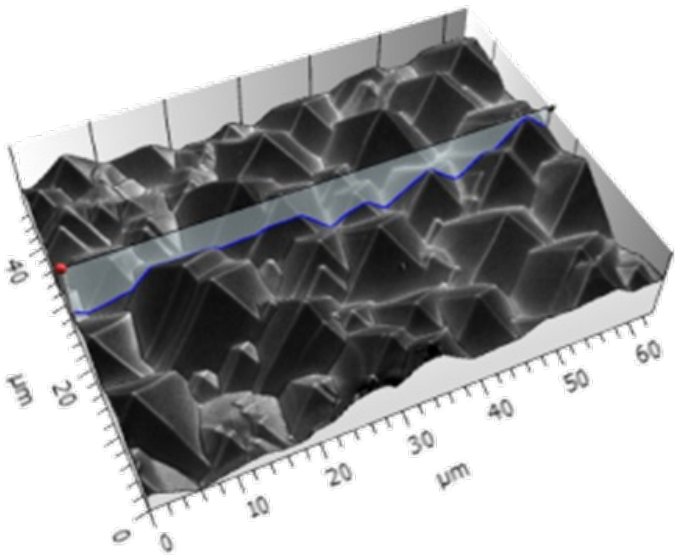
EDX, 3D metrology, particle and fiber metrology

The FlexSEM also supports special analytical applications which go beyond simple imaging.

Firstly, it supports professional elemental EDX analysis technologies by renowned s companies such as Oxford Instruments and Bruker. Special compact detectors with 30mm² or 60mm² SDD can be fully integrated into the FlexSEM's body and allow for high count rates of several kilo-counts per second. The instrument's maximum accelerating voltage of 20kV supports K-line detection of heavier atomic weight elements and conforms to DIN/ISO norms for asbestos analysis. Point/area spectra, line scans and element distribution mappings are available. Use is easy - load a suitable operating condition from the FlexSEM's recipe memory and execute the EDX software running on the standard Windows 11 operating PC. Images and EDX results can be stored in the same data folder. Another advantage of using EDX experts' equipment is the possibility to upgrade the EDX software to professional level, and even to automated routines such as automatic particle analysis.

Another special analytical technique made possible by the instrument is the elevation of classical 2-D SEM to the third dimension. The 4 BSE detector circle quadrants can simultaneously deliver 4 images of the same object, but "quasi-illuminated" from the individual viewing perspective of each detector element. Together with a proprietary height calibration routine, the optional Hitachi Map3D Software will reconstruct an accurate 3D surface model of the inspected sample region. Height profiles can be extracted for measurement of step heights or surface roughness parameters according to ISO standards. Also, surface and volume measurements are possible.

Hitachi Map3D includes many additional helpful functions, such as pore/particle extraction and metrology, stitching of large high-pixel-density image fields out of individual images acquired with the optional "ZigZag-capture" module, and simple image segmentation for colourisation.



Maintainability and cost considerations

For regular preventive maintenance of the FlexSEM, the user has the choice between a professional Hitachi service or a complete do-it-yourself approach. The tungsten hairpin filament cartridge type electron source is easy to change and to activate within minutes, and all fixed electron optics apertures are mounted within a "liner tube" which can easily be fully removed from the SEM column for aperture change and cleaning. This is especially helpful in situations where some charged particle or fiber might have migrated to an aperture: Simply open the gun head, pull out the liner tube, check and eventually clean/replace the aperture, and re-insert it - done. No need to call a service technician, and no need to pump the system for 24 or 60 hours before it can be used again.

With the FlexSEM, the annual maintenance cost can be kept below €1,000 – an important consideration when deciding on a compact SEM.

In conclusion

The Hitachi FlexSEM is a very compact, yet powerful and easy-to-use SEM. Its performance and functionality range are comparable to today's full scale variable pressure SEMs and significantly exceeds the capabilities of the classical tabletop SEMs. It flexibly adjusts to a user's needs and skills. What's more, it makes a compelling choice due to its affordable price and low maintenance costs.

Contact us

Speak with an expert or book a demonstration.

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