Scanning Electron Microscopes:

10 points to Consider when Evaluating Solutions

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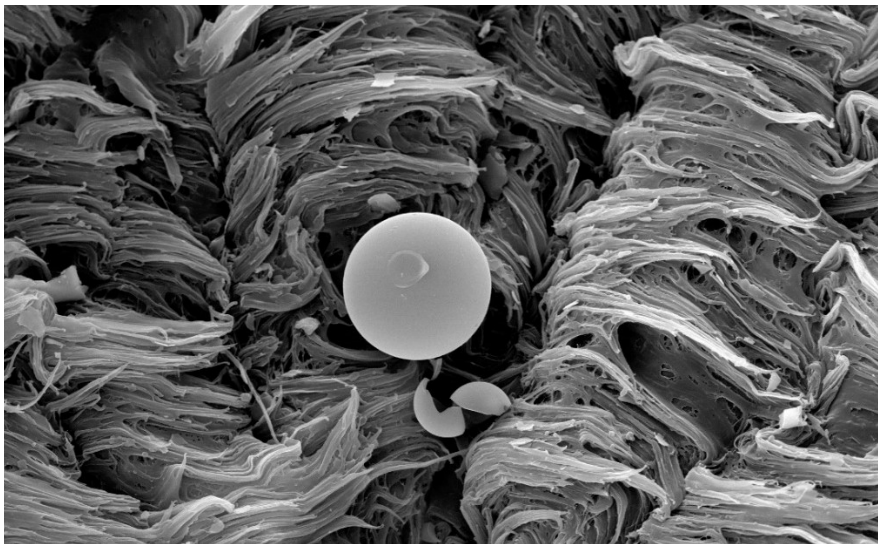
Scanning Electron Microscope – Buying Guide

10 Points to Consider when Evaluating Solutions



Introduction

The market for tabletop and full-size Scanning Electron Microscopes has increased considerably as systems have become more mainstream via easier to use controls and software and due to a general shift toward smaller, faster, and more economical instrumentation as compared to traditional expensive systems often requiring dedicated operators. For a prospective buyer, the landscape of current offerings can be difficult to ascertain what features are important. Although modern entry-level electron microscopes effectively bridge the gap between Optical Microscopes and traditionally expensive SEMs, some offerings will deprive users of some major elements necessary for an effective SEM workflow.

SEM systems can range in cost from around US$50,000 to over US$1,000,000. The range of capabilities is therefore very wide and increased precision of resolution (magnification) and sample size have an exponential affect on price. Therefore, it is necessary to formulate a clear plan about what your needs are in advance of exploring the fascinating choices that exist amongst the numerous suppliers.

We recently met with several microscopists having years of experience and asked them what they thought were important things to investigate when evaluating a new Scanning Electron Microscope. Here is a summary of 10 key questions to consider asking yourself and prospective suppliers. This guide will help you answer those questions to help you make the best buying decision.

1) Who's Going to Use it… and for What Type of Application?

Will there be one or a few experienced users or will there be multiple users of varying levels of EM experience? Are the users of the system experienced with SEM or is a "black box" solution more appropriate?

Most systems on the market today have good features that allow a novice user to achieve good imaging performance. Ask about the features present to assist novice users and prevent potential damage but also consider if those choices might limit the system capabilities in the future.

The second half of this question concentrates on the application. Standard desktop SEMs are typically suitable for single-user or basic applications, but if a laboratory has a larger user group with different experience levels and needs, then a more sophisticated Tabletop or entry-level Full-size SEM systems might be a better fit.

Do users' applications involve non-conductive or biological samples? While low vacuum mode for charge reduction is offered by most SEMs, magnification is rather limited on many sample types. Sputter coating, sample freezing or drying should still be considered as it often provides much better imaging and is worth the effort and cost of appropriate equipment. For all microscopy methods, both optical or electron, the quality of the imaging will more often be limited by the sample preparation and the sample characteristics than the microscope itself. Be prepared to address this rather than assuming a charge reduction mode will allow you to take shortcuts in the SEM workflow.

2) Where will you need to use the SEM – is a floor model or tabletop more appropriate?

Traditionally, SEMs needed a separate dedicated room or area in a lab isolated from vibration, thermal, electrical and acoustical disturbances. Additional cost was incurred for highly trained staff to operate so adoption of Scanning Electron Microscopy was not widespread until modern electronics and software became a reality starting around 2005-2010.

Although rigorous parameters often still apply for highly complex research on larger SEMs, modern Tabletop (or Desktop) and entry-level full-size SEMs provide the perfect solution if a facility is involved in general research, QA/QC, process development, failure analysis and/or education. Tabletop and smaller Full-Size SEMs can also reduce the work load of more advanced SEMs having a much higher operating cost.

Your first inclination might be to focus on one of the fairly new, compact Tabletop or Desktop SEM systems to avoid on-going service or maintenance costs common to older or more expensive large floor model systems. Over the last few years, a number of compact floor models have been introduced that are often easier to service than tabletop systems which often are tightly stuffed full of components in order to reduce the overall size. Unless there are physical constraints that prevent a compact floor model being placed in your facility, be observant as to how easily a Tabletop SEM can be serviced or parts replaced by yourself or a suppliers technician. There is no longer a reason to compromise with a Desktop SEM that possibly limits your capabilities and future expandability.

The cost of Tabletop systems and newer compact floor models have grown much closer and often overlap which has blurred the right choice from a cost viewpoint. The size of compact floor models are now very similar to the footprint of tabletop or desktop SEM systems.

3) Will You Need Elemental Analysis?

Another major stumbling block with many of the earlier systems (pre-2012) was combining a tabletop SEM with microanalysis or elemental analysis capabilities. A range of solutions are now available on the market, with some SEM companies providing their own, proprietary EDS hardware and software whilst others, readily interface with commercially available systems from major third-party manufacturers such as Bruker, Oxford and EDAX offering much greater expandability to meet users' specific application requirements (Figure 1). The software from these third-party suppliers is much more developed, often with guaranteed quantitative results given it is their specialty.

Simply put, SEM manufacturers make great microscopes and EDS manufacturers make great elemental micro-analysis tools. Be cautious of simplified EDS capabilities from SEM suppliers offering their own proprietary EDS solutions and make sure it does what you need and can be expanded with more advanced software capabilities in the future should they be needed.

Another point to consider is whether you will be tasked with one of the many automated particle or feature analysis methods dictated by ASTM or ISO for things like Steel Inclusions, Contamination, Wear Debris, Cleanliness, and more. If that is a possibility, will the EDS be upgradeable to achieve this functionality?

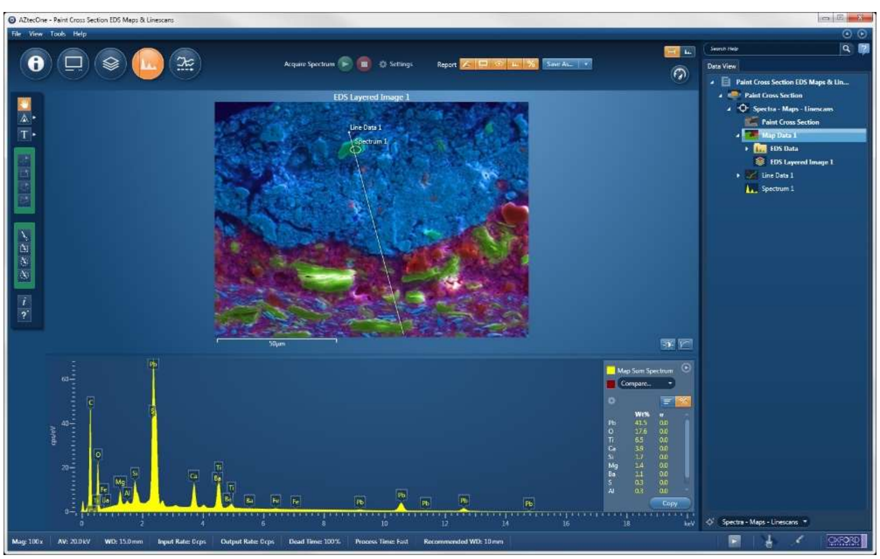


Figure 1. *SEM systems that integrate smoothly with commercially available EDS systems perform the best for quantitative analysis and future upgradability.*

4) What Accelerating Voltage Best Suits Your Application?

Are users' samples beam-sensitive? Most Tabletop SEMs are restricted to 5 kV on the low end, so if your samples are beam sensitive, consider a system with variable voltages down to 1kV which is more comparable to full-size SEM that often allow voltages down to 0.1kV. Equally important is to test how well the SE detector can image at those low voltages.

Will users be doing EDS? The majority of tabletop SEMs are restricted to 15 kV maximum accelerating voltage for the electron beam. This limited accelerating voltage does not promote collecting satisfactory spectra in the range above 8-15 keV for many critical elements like Molybdenum, Bromine, Zinc and several others. Further, 15 kV forces the use of spectral peaks at energies less than 5 keV where there are frequently many overlapping elements. As shown in Figure 2, an electron beam with accelerating voltage up to 30 kV can generate better imaging and better EDS results by matching the beam to the composition of the sample.

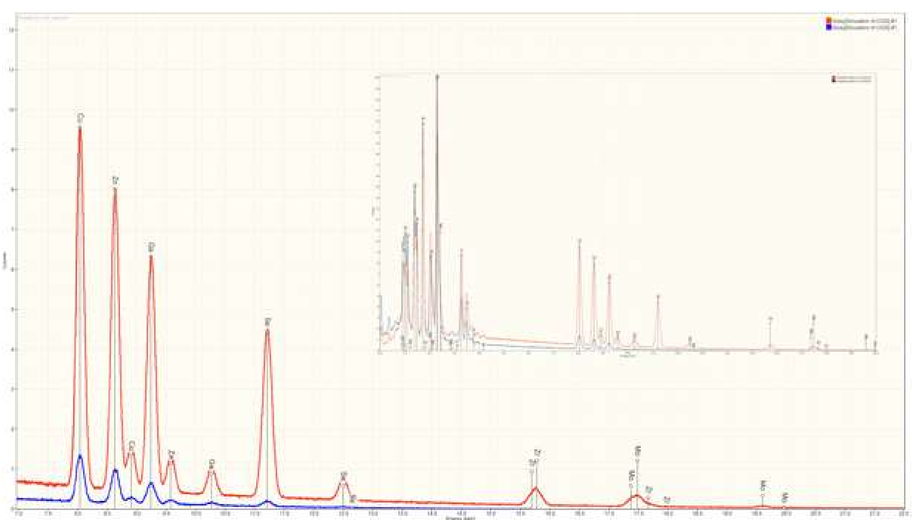


Figure 2. *EDS Spectra of CIGS Solar cross section at 15 kV (blue) and 30 kV (red) zoomed to 7 keV to 22 keV range showing increased precision and peak detection using 30 kV. Inset – full spectra showing cluttered region below 5 keV.*

Another consideration is charging. As shown in Figure 3, a good tabletop SEM will be able to capture images in high vacuum mode of un-coated nonconductive samples by using beam control features like widely adjustable spot size, bias adjustment and detector amplification. While a low vacuum or charge reduction model might seem the first choice, there are compromises in allowable magnification before image quality deteriorates.

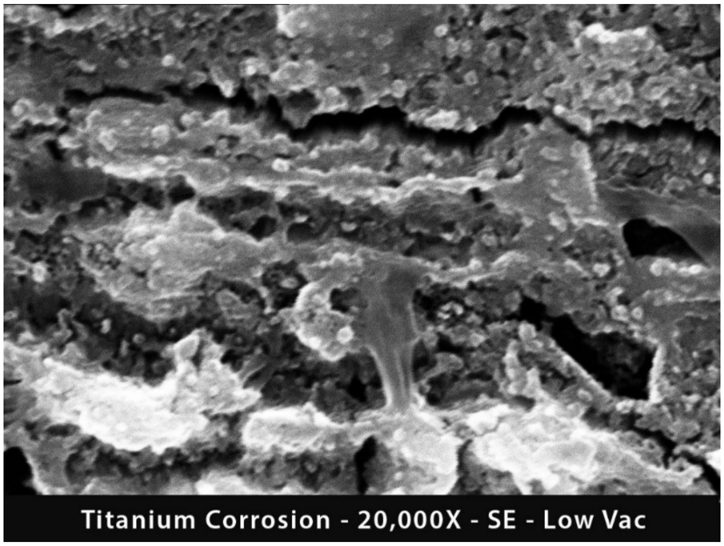


Figure 3. *The ability to collect SE images on non-conductive samples at varying accelerating voltages allows detailed analysis of surface processes.*

5) What type of Imaging capabilities will you need?

There are many ways through which an electron beam interacts with the sample, as illustrated in Figure 4. Most SEM suppliers offering tabletop SEMs usually promote models having a single backscatter electron detector (BSE) for imaging and offer secondary electron imaging as "optional". BSE is helpful for seeing elemental contrast or atomic number in the sample (Figure 4c), but not surface topography (Figure 4b). Usually, these will be 4-quadrant BSE detectors that are capable of creating pseudo-topography images using a combination of varied settings for the detector quadrants. Yet, the latest entrants in the market now provide either a standard or optional Secondary Electron (SE) detector that creates excellent images for surface morphology and topography.

Users should look for SE detectors to be true Everhart-Thornley type – the same as used in full-size SEM. Determine if the SE detector will allow imaging in charge reduction or low vacuum modes in the case of non-conductive samples. The range of contrast with the SE detector is usually an important capability to ascertain as some SEM systems on the market produce very flat images lacking any contrast. Without a true Everhart-Thornley type SE detector your images will never give the best topographic information and will lack the contrast of an image acquired with higher end SEM systems.

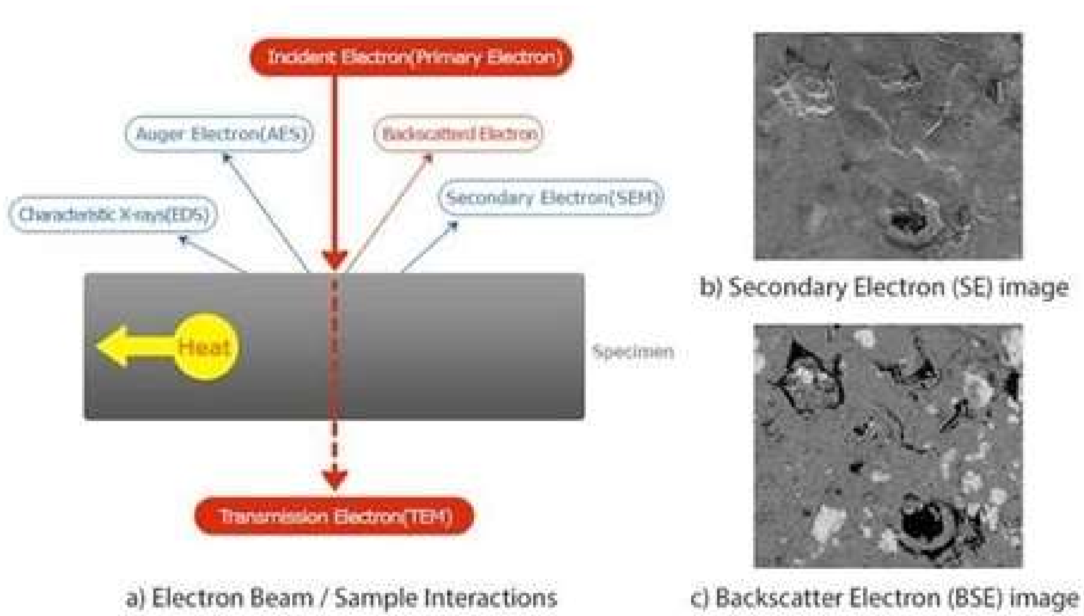


Figure 4. *(a) Electron beam/sample interactions (b) Secondary electrons ("SE") capture surface topography while (c) Backscattered Electrons ("BSE") image contrast based on the atomic weight of individual elements.*

Would having the ability to do Transmission Electron Microscopy be advantageous to examine tissue sections, nanoparticles or metallic thin sections? Many full-size SEM and a few Tabletop SEM are available with STEM detectors that allow analysis of samples on standard TEM grids. This can give the SEM a dual capability further expanding its usefulness for your lab.

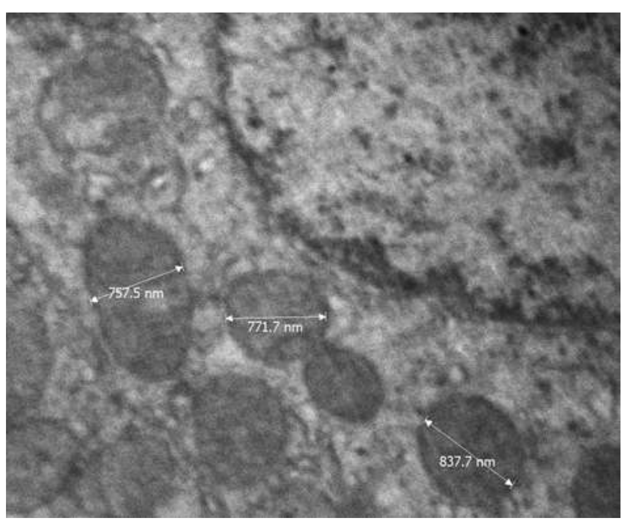


Figure 5. *TEM image of Kidney tissue section using a true STEM detector capable of producing Bright or Dark field images.*

6) What About Magnification and Resolution?

Magnifications of 100,000x or more are advertised by most tabletop SEM companies. Users should consider what that number actually means in terms of their application. Most importantly, the actual true **Magnification** is highly dependent on the actual size the image displayed whereas **Resolution** is a better measure of the microscope's true capabilities.

What may be 10,000x on a microscope display could well be 100,000x when projected in a presentation, but the important thing is whether that increase is really giving users any extra information. At some point, magnifying a digital image reaches a point known as "hollow or empty magnification" where no additional detail can be revealed as a result of the image resolution. Avoid being dazzled by ridiculous claims approaching 1,000,000X magnification that some suppliers are boasting. At 1,000,000X, a single ATOM (which is around 0.1 nm) would display at 100 microns wide in an image, about 5 times the diameter of a human hair and easily visible but we know this is not possible at this price range.

Resolution refers to the ability to separate and sufficiently image fine detail like shown in Figure 6. The actual image **Resolution** is also a function of the electron optics and set points of the imaging controls. Consider the type of electron gun and factors that impact beam cohesion such as a fixed aperture or the ability to vary the aperture size allowing the optics to be adjusted to produce the best image detail. Similarly, having functional control over beam stigmation at high magnification will produce better images.

A users' best guide is their own application. What do users actually need to "see" in their sample? While lower end desktop SEMs will be fine for samples with lower resolution needs, users should plan to invest more for a desktop SEM that will easily resolve finer detail in the sub-micron range.

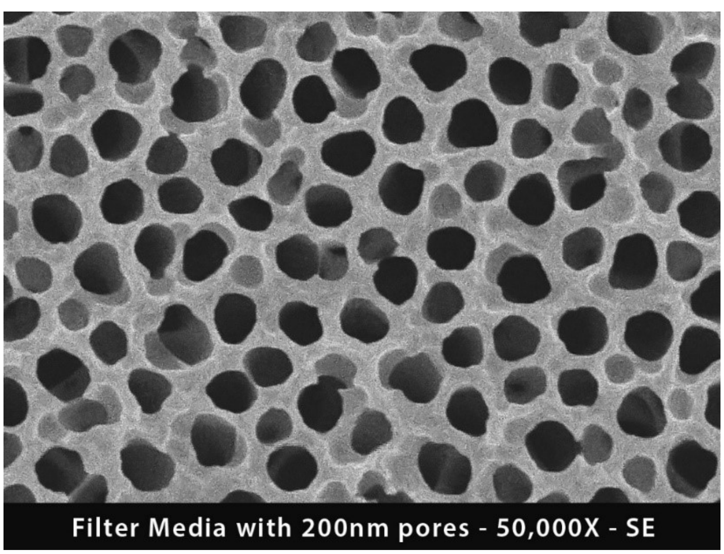


Figure 6. *Achieving higher resolution and magnification may require a larger investment but will your applications justify the extra cost?*

7) How Intuitive and Complete Are the Operating System and Software?

Maybe the most fundamental question to ask about any microscopy instrument is which computer operating system does it use and will that be compatible with your infrastructure? For instance, while most suppliers use a Windows operating system, one SEM brand usually avoids advising customers that they use a Linux operating system for the SEM and then add a Windows PC for EDS. Likewise, Microsoft will not be supporting Windows 7 much longer – is Windows 10 an option? Having a common operating system for the microscope and EDS will shorten the learning curve and simplify the workflow making overall operation faster and easier for users.

"What image controls do I need at my fingertips?" is the next question. As shown in Figure 7, the graphical user interface or GUI needs to be intuitive and should allow easy adjustment of the electron optics and the stage. Direct dimensional measurements and image annotation are also invaluable. Being able to view the BSE and SE images side by side can also be helpful.

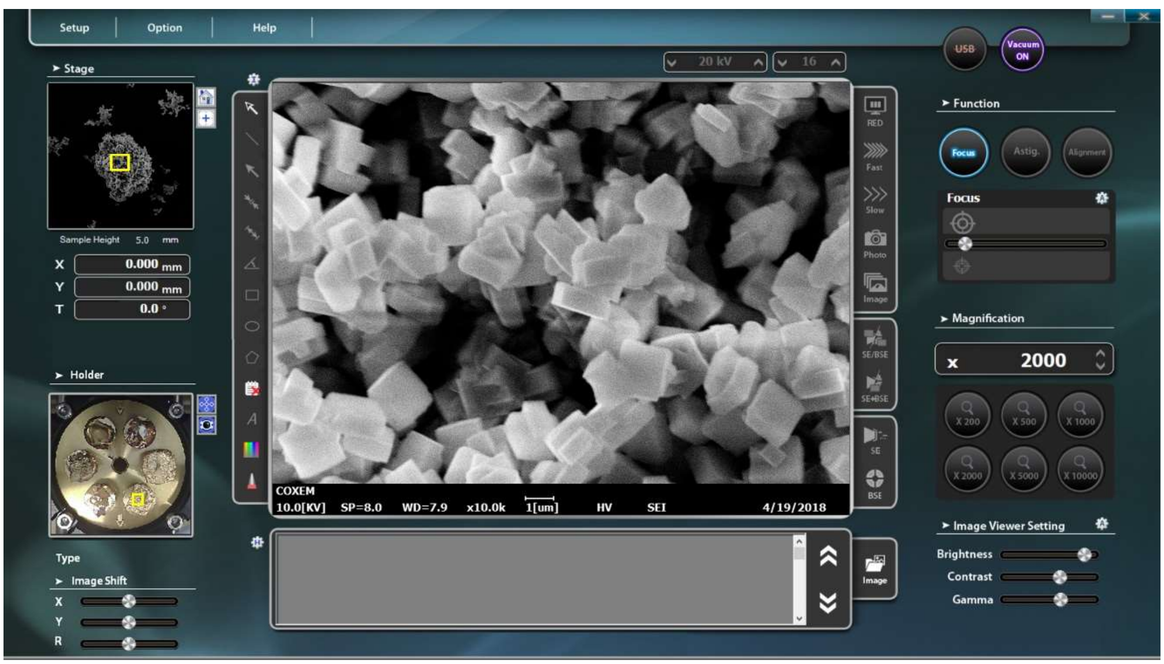


Figure 6. *A good software interface should provide quick access to commonly used controls without being overly complex and allow access to more complex features via sub-menus.*

If the SEM will be used in an upper academic environment or other location where users will potentially want to use more advanced SEM systems, does the software provide access to controls and procedures that allow them to learn the skills necessary to master the procedures necessary for more advanced SEM system. Features like Variable Apertures, Bias, adjustable Beam Current and more.

8) Specimen Manipulation

When initially introduced, small stage size and chamber limited the adoption of table top technology. As technology and capabilities have progressed, so have the size of samples that can be imaged with some systems now allowing larger samples. SEMs look at the micro level so unless "whole" parts need to be examined non-destructively, resist the temptation to opt for a larger stage travel. The other advantage of larger stages is to allow loading multiple samples for automated overnight analysis but this is typically the domain of full-size SEM.

What about viewing angle? The ability to translate the sample in XYZ, tilt and rotate allows users to move features of interest to the middle of the field of view and view them from the most optimum viewing angle or to accentuate x-ray counts for EDS.

Tabletop and Full-Size SEMs are available with both manual and motorized stages. Entry level Tabletop SEMs have the ability to move the sample laterally side-to-side (X) or front-to-back (Y) in order to position the sample in the field of view. Motorized stages offer the convenience of software control of the positioning while a Manual stage is lower cost and allows easier modifications for special sample presentation requirements.

Most Tabletop SEMs use an external mode of Z or sample height adjustment. This is done for the purpose of making the SEM more robust and less prone to user damage. Since the vent-to-vacuum cycle is fairly short for Tabletop SEM, it is not considered problematic to make an external Z adjustment to attain the desired working distance. If Z height adjustment is needed while the sample is in the chamber, then customer should possible evaluate some of the entry level full-size SEM that provide this capability. Having no external Z control can be an advantage in a situation where novice users access the SEM, making it less prone to user damage but the lack of real-time sample positioning can have costs in productivity.

Having the ability to tilt the sample while imaging can be a great asset for what often appears to be flat featureless samples. When tilted, the surface detail often comes alive as shown below in Figure 7.

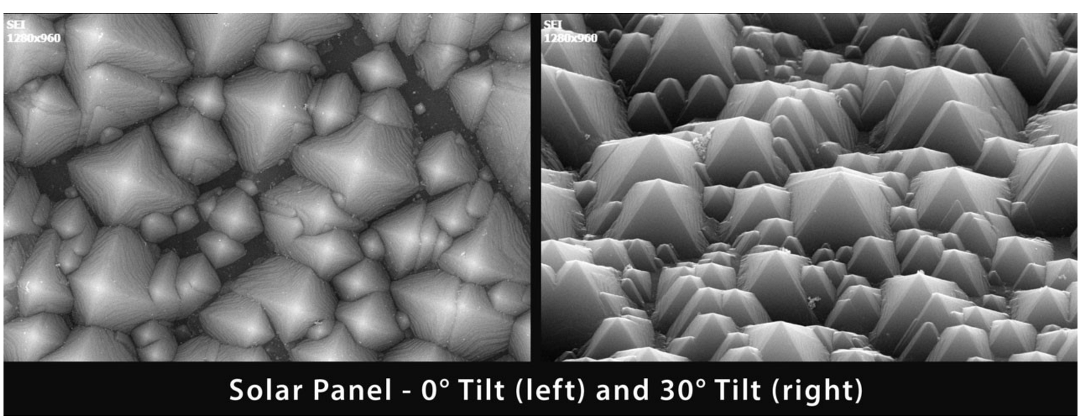


Figure 7. *Having the ability to Tilt a flat sample can often reveal interesting and complex details as shown here.*

With the advancements of these microscopes, many now offer a static digital optical image to assist with navigation, a sample selection map, or a low magnification SEM image, or even all three which really simplifies the task of optimal sample positioning. An internal chamber camera is invaluable for utilizing the Tilt and Z functions of multi-axis stages to assist with sample positioning and avoiding collisions with delicate internal microscope components. Intelligent software controls prevent samples from contacting sensitive SEM hardware as well as storage of coordinates for repetitive sample imaging.

EDS manufacturers also offer analytical tools that require motorized stage control via the EDS software to perform tasks like Automated Particle Analysis on filters, metal inclusions, large area mapping and image stitching, and much more. This capability turns the SEM/EDS into a very intelligent analytical tool.

A second component of this stage equation is beam shift, which enables a feature to be centered in the field of view without physically moving it. The ability to shift the beam and quickly center features up to 50 microns laterally will be very helpful to productivity and user satisfaction.

Finally, what about temperature? A system that enables adding cooling stages can considerably enhance results, particularly for polymer or delicate biological samples, or to image moist sample without pre-drying or to run transient imaging studies that require variation of sample temperature. Devices are also available for high temperature study up to 1200°C, or for looking at particles suspended in fluids and emulsions that cannot be exposed to vacuum.

Especially with Tabletop SEM, when adding any of these add-on stage accessories, what functionality is lost in the SEM? Do you lose the ability to do EDS simultaneously? Do you lose range of motion for the stage?

9) What About Service?

Service is a major cost-of-ownership factor that can tilt the buying decision in favor of tabletop SEMs over conventional large floor models routinely needing coverage under costly maintenance contracts. As the actual user, is it possible to perform trouble shooting on-site or through remote access? Most entry level full-size SEM systems are no more complex to service and maintain as Tabletop SEM. Be sure to ask about cost of service and if it is done on-site or requires shipping the SEM back to the manufacturer.

Does the SEM supplier provide a comprehensive maintenance manual to allow you to perform part exchanges without paying for expensive service engineer labor? Ask to look inside the outer cover of the SEM. Does the system lend itself to easy access to parts or is it crammed so tightly to make it compact that you wouldn't want to try and replace internal parts yourself? Are the circuit boards easily removeable? Are various microscope functions controlled by lower cost discrete circuit boards or does the SEM use a large (expensive) motherboard type design?

How easy is it to service the apertures, column and filaments? Can all this service be done yourself or in-house, or will you have to pack up the system and ship it to a factory service center? This might mean being without the SEM system for 2 weeks a year simply for a filament exchange. For filaments that can be exchanged in your lab, do they include a pre-centered Wehnelt so that exchange can be done easily and quickly in under 10 minutes?

Lastly, consider the prospective supplier's business model. Do they strongly urge or promote a menu of service contracts? That should indicate if their revenue is dependent on service contracts and indicates a prevalence of possible issues you might face in the future that will affect your total cost of ownership.

10) What's the Projected Growth Path for Your Lab?

Finally, users should consider the future. Is this SEM going to be the only step in your analytical electron microscopy arsenal or does the laboratory need to shift to a full size system or work along-side other available SEMs? If the later, then how far will an entry-level system without full-featured software take users? How easy it will be for users to make that change or move from platform to platform?

On the other hand, if an existing full-sized SEM is utilized near capacity or getting "gray" around the edges, a Tabletop SEM or entry level floor model system could reduce the workload and operation cost on those systems. Or is electron microscopy becoming so extensively used by the institution or facility that it needs to add a powerful, user-friendly system for more routine analysis work that is accessible directly in Undergraduate labs or by Engineers and technical staff closer to the factory floor?

Finally, does the organization presently send out much of its SEM work but requires something in-house for those rapid, routine analyzes? If so, then a tabletop SEM or entry level floor model SEM can provide an excellent solution to address that.

Summary

As with all microscopy, the key to success is to match the instrument to the application. The question is invariably, "How good is good enough?" The next generation of advanced tabletop SEMs and entry level floor model SEM system now provide much of the same functionality that was seen only in much more expensive floor model SEMs a few short years ago. Now these systems come in robust, easy-to-train and easy-to-use formats. Their cost of ownership won't break your lab budget surely helping satisfy your management team.