JH TECHNOLOGIES™

# Low Vacuum Scanning Electron Microscopy

*Faster Analysis with Less Sample Preparation*

A Practical Summary | Featuring the Coxem EM-40 Desktop SEM

Authored by Kenneth Hirscht and Yi Zhang PhD


**EXECUTIVE SUMMARY**

Scanning Electron Microscopes (SEMs) are powerful tools for examining materials at extremely small scales. SEM workflows commonly involve preparation steps, such as adding metal coatings onto the sample, which enables imaging across a range of materials. Low Vacuum (LV) offers an alternative approach. By admitting a small amount of atmospheric gas into the chamber, which aids in electron discharge, LV mode allows non-conductive, delicate, and even moist samples to be imaged with less preparation. This white paper explains what LV mode is, how it works, and demonstrates through four real-world case studies that it is a useful complement to conventional SEM techniques, simplifying the workflow, reducing costs, and expanding options for fragile or sensitive samples.


## 1. What Is a Scanning Electron Microscope?

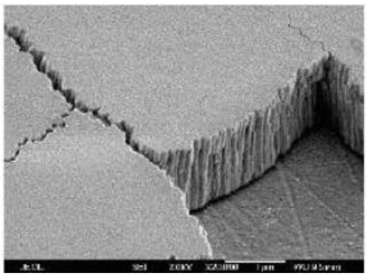
A Scanning Electron Microscope is a type of microscope that uses a focused beam of electrons (rather than visible light) to examine the surface of a material. Because electrons have a much shorter wavelength than light, SEMs can reveal details far too small to see with a conventional optical microscope. They are widely used across industries including materials science, electronics, pharmaceuticals, forensics, and biology.

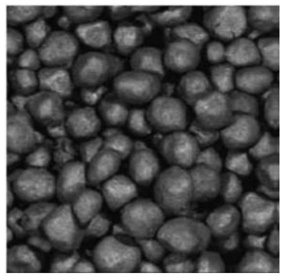
### What an SEM Can Tell You

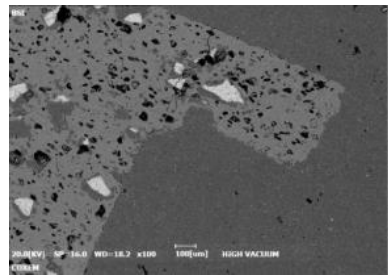
SEMs provide three distinct types of information about a material's structure and composition, which can be related back to material strength, conductivity, reactivity, and other key properties.

- Topography: The microscope reveals the texture, roughness, and three-dimensional features of a sample's surface.
- Morphology: The size, shape, and arrangement of the tiny particles or structures that make up the material.

- Composition: When paired with an appropriate detector, an SEM can identify which chemical elements are present in a sample and quantify their relative concentration.


Topography


Morphology


Composition

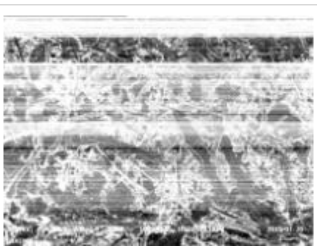
## 2. The Challenge: Why Sample Preparation Matters

For high-quality imaging in an SEM, the incident electrons must not accumulate on the sample surface. Surface charge buildup causes distortion on the image, leading to results that are unreliable.

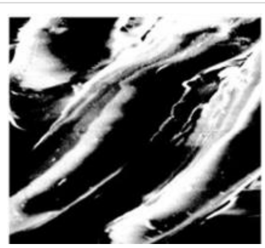
### The Conductivity Problem

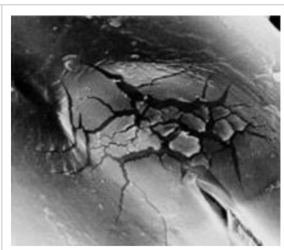
Metals exhibit high conductivity, which allows excess electrons to drain efficiently from the sample surface to electrical ground. However, many everyday materials such as plastics, ceramics, biological tissues, paper, are electrically insulating. When these non-conductive samples are examined in an SEM, electrons pile up on the surface and cause a range of imaging defects:

- Bright "glowing" areas or streaks across the image
- Scan lines and dark shadows
- A "moving" image that does not show true-to-life contrast
- Exaggerated brightness at edges and corners


"Scan Line"


"Charging"


"Moving Image"


"Edge" Effect

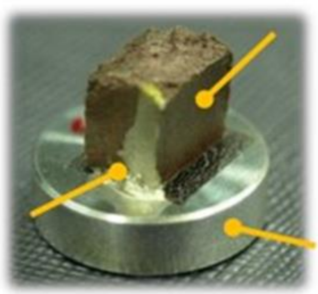
JH TECHNOLOGIES™

| In Plain Terms | *Think of it like trying to take a photograph of a mirror in direct sunlight, where the reflection overwhelms the camera and you cannot see the object clearly. Charge build-up does the same thing to an SEM image.* |
| --- | --- |

## Traditional Solutions and Their Drawbacks

The standard fix for non-conductive samples is to coat them with a nanometers-thin layer of electrically conductive material. Common preparation includes at least one of the following:

- Sputter coating: applying a nanometer-thin metal film using specialized equipment. Gold or gold-palladium alloy is commonly used
- Carbon coating: Like sputtering, useful for when chemical analysis of the sample is also required
- Critical point drying: a technique for biological or wet samples that removes water without collapsing the sample's structure. Subsequent metal coating is required
- Mounting in conductive media: embedding the sample in a material that conducts electricity



**Irregular Silver-Painted Specimen on Stub**

**Sputter Coated Cross-Section Specimen in Epoxy Resin**

These steps can resolve the charging problem, but the costs are not negligible:

- Time: preparation can add hours to what would otherwise be a quick analysis
- Equipment and consumables: sputter coaters and critical point dryers represent significant additional investment and skilled operators.
- Risk of altering the sample: the coating process can change the sample's surface appearance or interfere with subsequent testing
- Difficulty with complex shapes: uneven or porous surfaces may not coat uniformly, leaving problem areas

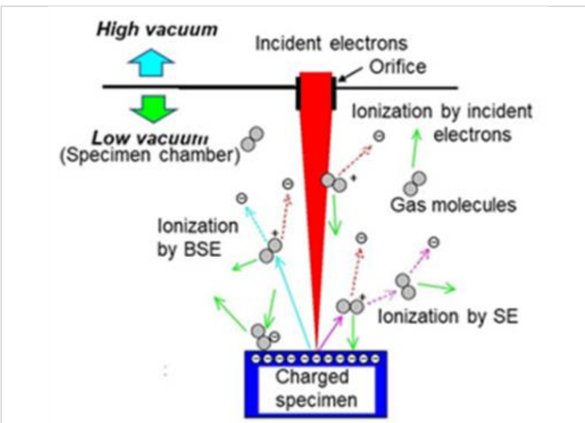
## 3. Low Vacuum Mode: A Simpler Path to Results

Low Vacuum (LV) mode addresses the charging problem in an entirely different way, not by making the sample conductive, but by providing alternative pathways for excess charge to escape.

### How It Works

A standard SEM operates at very low pressure, roughly 0.00005 Torr (referred to as High Vacuum, or HV). At this pressure, the chamber is almost entirely empty of air molecules, which is good for image quality, but leaves no mechanism for charge to drain from a non-conductive sample. In Low Vacuum mode, the chamber pressure is raised to ~ 0.1 - 0.2 Torr. Here is what happens:

1. The electron beam ionizes (electrically charges) some of those air molecules
2. These ionized molecules are attracted to the charge building up on the sample surface
3. The excess charge is neutralized before it can cause image distortion




**Mechanism of Charge Neutralization in Low Vacuum SEM**
Source: www.jeol.com

**Charge Dissipation: In Real Life**

*Imagine static electricity building on a latex balloon as you rub it on your hair. If the air around you is dry, you can build up a lot of charge because it can't escape from the balloon until you touch something. However, in humid air, the charge doesn't build up well. Charges are reduced because the moisture in the air conducts the charges away. Similarly, in LV mode, the charges are reduced because the extra molecules of air turn into ions and conduct the charges away from the sample.*

### The Detector Used in Low Vacuum Mode

Secondary Electron (SE) imaging is the conventional mode on most SEMs and works by collecting low-energy electrons emitted directly from the sample surface when the primary beam strikes it. In LV mode, however, the increased presence of air molecules in the chamber interferes with these low-energy electrons before they can reach the detector, scattering or absorbing the signal, and degrading image quality. The solution is to use a dedicated LV imaging detector. On the Coxem EM-40 desktop SEM used in this study, a Backscattered Electron (BSE) detector is employed in LV mode. The BSE detector captures a type of higher-energy electrons emitted from the sample (called backscattered electrons) that are far less susceptible to this interference and delivers reliable images.

## 4. Practical Applications

Low Vacuum SEM is particularly well suited to the following industries and use cases:

- Polymers and plastics: packaging materials, fibers, films, and composites
- Life sciences and biology: tissue samples, pollen, insects, diatoms, and other biological specimens
- Porous materials: foams, paper, membranes, and filters
- Industrial cross sections: painted surfaces, coatings, adhesives, and laminated materials
- Failure analysis: rapid investigation of damaged or failed components without altering evidence
- Quality control: high-throughput inspection workflows where speed matters more than ultimate resolution

The four core benefits of LV mode for non-conductive materials can be summarized as:

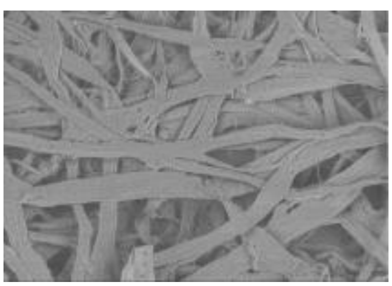
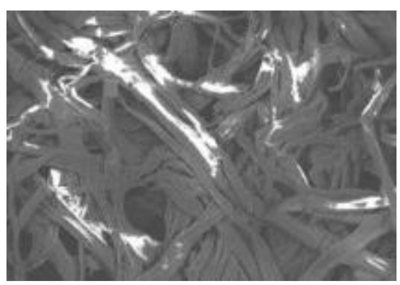
| | |
|---|---|
| **Avoid Charging** | No more image distortion from electron build-up on non-conductive surfaces. |
| **Prevent Beam Damage** | Sensitive materials such as biological tissue and polymers are not burned or altered by prolonged electron exposure. |
| **Preserve Surface Features** | The sample is imaged exactly as it is, without any coating that could mask or alter its true surface. |
| **Faster Turnaround** | Analysts can go from sample to image in minutes, improving throughput and reducing costs. |

## 5. Real-World Case Studies

To demonstrate the practical benefits of Low Vacuum imaging, four common material types were examined on the Coxem EM-40. Each material was tested under three conditions: High Vacuum with sputter coating (the widely used best-practice), High Vacuum without any coating, and Low Vacuum without any coating. Backscattered electron images were captured in each case.

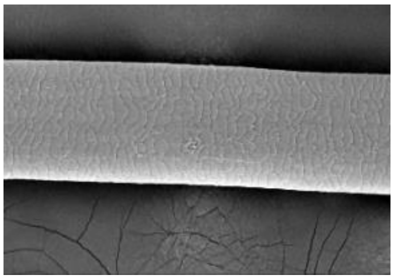
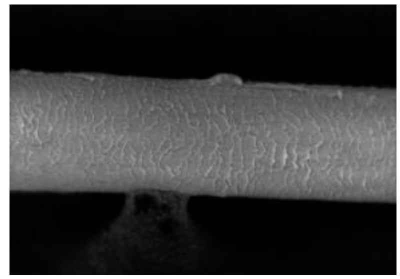
| | | | |
|---|---|---|---|
|  |  |  |  |
| **Paper Towel Fibers** | **Human Hair** | **Diatom Algae** | **Painted Metal Cross-Section** |

### Case Study 1: Paper Towel (Polymer Fiber Material)

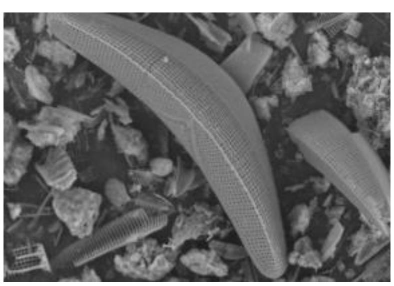
| | | |
|---|---|---|
|  |  |  |
| **Standard (High Vacuum, Gold-Sputtered Coating)** | **High Vacuum – No Coating** | **Low Vacuum - Key Takeaway** |
| HV with coating gave excellent detail and contrast. | HV without coating produced severe charging distortions that obscured the fiber structure entirely. | LV mode revealed a clear fiber structure with contrast comparable to the coated HV result. The porous polymer surface was preserved and free of beam damage. |

JH TECHNOLOGIES™

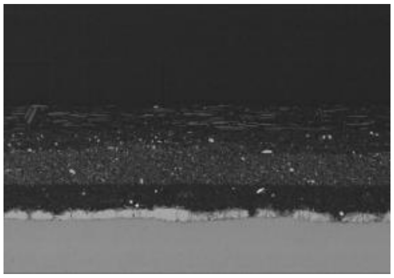
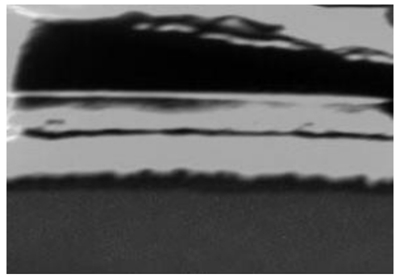
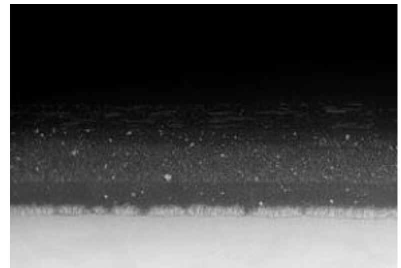
### Case Study 2: Human Hair (Beam-Sensitive Biological Material

| | | |
|---|---|---|
|  |  |  |
| **Standard (High Vacuum, Gold-Sputtered Coating)** | **High Vacuum – No Coating** | **Low Vacuum - Key Takeaway** |
| HV with coating showed the surface scale (cuticle) structure clearly. | HV without coating caused both charging artifacts and visible beam damage. After imaging, the hair sample was physically burned and deformed. | LV mode reduced both charging and beam-induced damage on the cuticle structure, making it the only viable option for examining uncoated hair or similar delicate biological materials. |

### Case Study 3: Diatom Algae (Fine Biological Microstructure

| | | |
|---|---|---|
|  |  |  |
| **Standard (High Vacuum)** | **High Vacuum – No Coating** | **Low Vacuum - Key Takeaway** |
| HV with coating resolved the microscopic pore structure of the diatom beautifully. | HV without coating produced poor contrast and uneven image quality, obscuring the delicate features. | LV mode preserved fine features without introducing preparation artifacts, making it ideal when the sample needs further analysis after imaging. |

### Case Study 4: Epoxy-Mounted Paint Cross Section (Layered Industrial Material)

| | | |
|---|---|---|
|  |  |  |
| **Standard (High Vacuum)** | **High Vacuum – No Coating** | **Low Vacuum - Key Takeaway** |
| HV with coating clearly showed the layered paint structure and embedded particles. | HV without coating was unusable, as charging effects were so severe that the microscope could not focus at all. | LV mode enabled fast cross-sectional analysis without coating, ideal for quality control situations where turnaround time matters. |

## 6. Summary of Benefits

The table below summarizes the key practical differences between the two imaging modes:

| Aspect | High Vacuum (Standard) | Low Vacuum |
|---|---|---|
| **Image Resolution** | Highest available | Slightly reduced |
| **Sample Preparation** | Coating equipment may be required | Minimal or none |
| **Charging Artifacts** | Common on non-conductive items | None |
| **Risk of Sample Damage** | Higher risk (beam and sample prep) | Minimal or none |
| **Cost per Analysis** | Higher, if coating with precious metals | Reduced, coating not needed |

Across all four case studies, LV mode without sputter coating consistently delivered results that were:

- Comparable in quality to coated HV images for routine analytical purposes
- Substantially better than uncoated HV images, where charging made results unusable
- Free from the surface alterations that coating can introduce
- Achievable with no additional equipment or consumables needed

| **Key Insight** | *Low Vacuum mode trades a small reduction in maximum resolution for much greater flexibility. For many routine applications, the resolution delivered by LV mode is more than sufficient, and the time savings are substantial.* |
|---|---|

## 7. When to Use Each Mode

Choosing between HV and LV mode does not have to be complicated. A simple decision framework:

| Choose HIGH VACUUM when… | Choose LOW VACUUM when… |
|---|---|
| Maximum possible resolution is required | The sample is non-conductive (plastics, ceramics, biological materials) |
| The sample is already conductive (e.g. metal) | The sample is delicate or beam-sensitive |
| Highly precise compositional analysis is needed | You need results quickly without a preparation step |
| Long-term archival image quality is the goal | You want to preserve the sample for follow-up testing |

## 8. The Coxem EM-40 Desktop SEM

The imaging results in this white paper were obtained using the Coxem EM-40, a compact, tabletop SEM designed to bring electron microscopy capabilities to a wider range of laboratories and facilities. Key features of the EM-40 relevant to LV imaging include:

- Variable pressure control in the range of 10 to 30 Pa, allowing adjustment to match the needs of each sample
- Integrated Backscattered Electron (BSE) and Secondary Electron (SE) detectors
- Compatibility with Energy Dispersive Spectroscopy (EDS) for elemental analysis alongside imaging
- Rapid switching between High Vacuum and Low Vacuum modes with no lengthy reconfiguration required
- Automated features including autofocus and brightness optimization to simplify operation

The EM-40's LV capability is delivered via a built-in chamber valve module, which keeps the instrument compact and cost-effective.


**COXEM EM-40 Table-top SEM**

## 9. Conclusion

Low Vacuum SEM is not a replacement for High Vacuum imaging; it is a powerful complement to it. When maximum resolution is the priority and sample preparation time is not a constraint, HV with sputter coating remains the gold standard. However, for the growing number of applications involving non-conductive, delicate, or time-sensitive samples, LV mode provides results of comparable quality in a fraction of the time, at lower cost, and without the risk of altering the sample.

The four case studies presented here (paper fiber, human hair, diatom algae, and a cross section of painted metal) demonstrate this clearly and consistently. In each case, LV imaging without any sample preparation delivered usable, high-quality results where uncoated HV imaging failed to deliver.

As detector technology and pressure-control systems continue to advance, the gap between Low Vacuum and High Vacuum resolution will narrow further. Low Vacuum SEM is well positioned to become the default starting point for any SEM workflow involving non-conductive or sensitive materials.