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Beyond Traditional SEM

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Thanks to the Purdue Electron Microscopy Center (PEMC) and the expertise of the staff there, and through my business (Cubic Labs LLC), I am enjoying the opportunity to learn and operate a new SEM: the Thermon Fisher Apreo S2 with its Trinity Detection System. Learning this new instrument is exciting because of the additional imaging possibilities. The capabilities of the Apreo S2 are a serious advance in electron microscopy and are worth knowing about if you send materials out for SEM.

Traditional SEM Detection

If you've worked with scanning electron microscopes, you're familiar with the two standard imaging modes: back-scattered electron (BSE) imaging for compositional contrast and secondary electron (SE) imaging—typically using an Everhardt-Thornley Detector (ETD)—for topographic detail. It is important to understand the physical phenomena these modes are based on when interpreting images. They also have inherent limitations that become critical when analyzing complex materials like battery components, where composition, morphology, and surface charge properties all matter simultaneously.

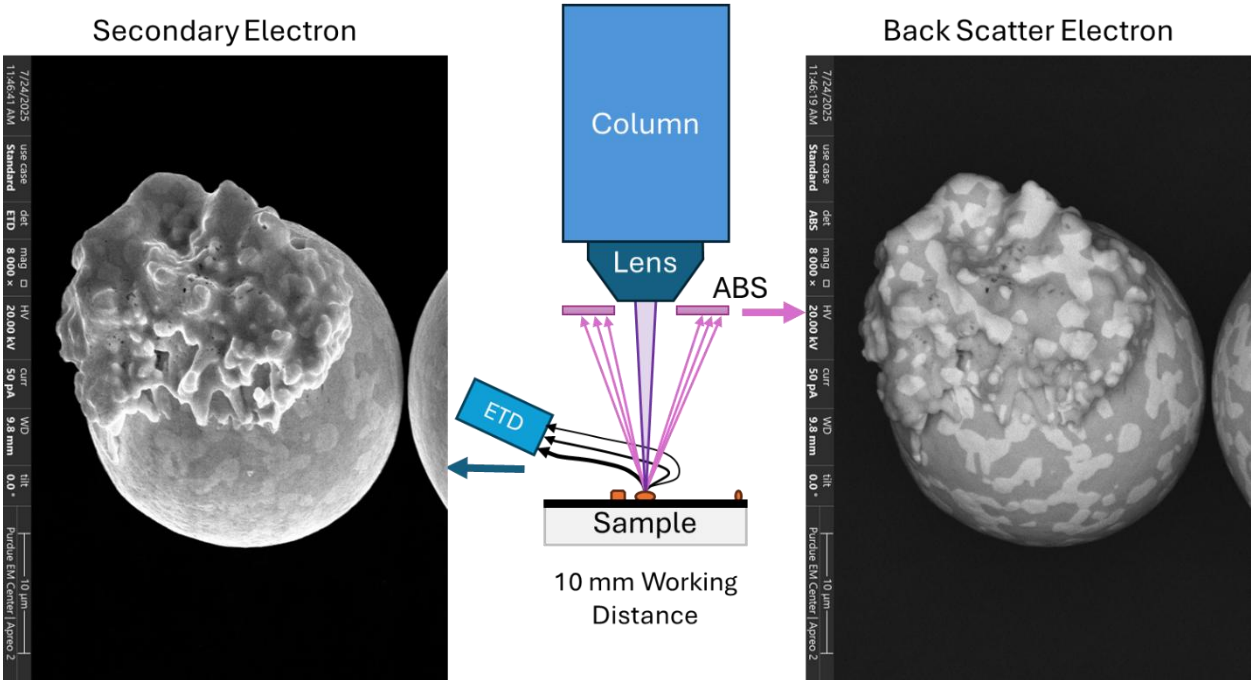

Figure 1. Secondary electron (left) and backscattered electron (right) images of tin/bismuth solder showing the contrast between topographic detail (SE) and compositional contrast (BSE). Tin appears darker (Z=50) while bismuth appears brighter (Z=83) in the BSE image. 20 kV, 9.8 mm working distance.

When the primary electron beam strikes your sample, it generates backscattered electrons (BSE) with varying energies and angles, plus secondary electrons (SE) with different energy levels (Figure 1). Most SEMs employ two common detection strategies:

Secondary Electrons (ETD): The Everhardt-Thornley detector sits to the side of the sample chamber, collecting low-energy secondary electrons (SE) that are attracted to it by a positive bias. This provides excellent topographic information—you see surface features, texture, and three-dimensional morphology. However, the ETD's side-mounted position means it collects electrons from a limited angular range, and its sensitivity to working distance and sample geometry can create shadowing artifacts. Secondary electrons come from inelastic collisions between the primary beam and the surface electrons in the sample – most of the energy is lost to heat, and the resulting slow secondary electrons are like a puff of dust kicked up from the surface. The ETD, with its bias voltage, sort of “vacuums up” this electron “dust”.

Backscattered Electrons (BSE): Traditional below-the-lens BSE detectors collect high-energy electrons that have bounced back from the sample. Heavier elements backscatter more electrons, creating compositional contrast. But these detectors have a critical limitation: they sit below the final lens, far from the sample. This means they collect only a fraction of the BSE signal, resulting in lower signal-to-noise ratios—especially problematic at low beam voltages needed for beam-sensitive materials. Back-scattered electrons come from elastic collisions between the primary beam and the electrons in the orbital shells. The electron concentration in these shells depends on the atomic number and density of the sample in these locations, so the contrast is partly due to the composition of the sample. BSE images look flat, due to the detector looking directly down at the sample. The energy in these elastically scattered electrons is nearly the same as the primary beam energy, like how the momentum of a cue ball is transferred to a pool ball.

There is, in fact, some topographic contrast in BSE images and some composition contrast in SE images. Creating a flat, polished sample can be useful for maximizing the amount of compositional contrast in BSE images, while coating the sample in gold or platinum can increase the topographic contrast in SE images.

The Apreo S2 ETD can be operated with different voltages on the grid to filter secondary electrons of different energies or repel electrons altogether. This last feature may sound unusual, but it enables the ETD to detect the light emitted from the sample, providing a partial ability to detect cathode luminescence, albeit without color information. Similarly, this Apreo S2 is equipped with two different BSE detectors – Angular Back Scatter (ABS) and Concentric Back Scatter (CBS). ABS has several sectors designed to create the illusion of shadows, if a more topographic image is needed. CBS has sectors in concentric rings – this allows the detection of backscatter electrons emitted from specific angular ranges.

Both configurations compromise resolution. The ETD requires working distances of 10mm or more for optimal signal collection, which limits resolution. BSE detection can suffer from poor signal collection efficiency, forcing you to use higher beam currents or longer dwell times, which can damage delicate samples. The Apreo S2's Trinity system addresses these limitations through a fundamentally different approach.

The Apreo S2 Trinity Detection System

The Apreo S2's Trinity Detection system (Figure 2) provides three new and unique imaging modes by placing three detectors *within the electron optical column itself* - two in-lens (T1, T2) and one in-column (T3). These detectors are located inside the column and lens of the microscope, so any BSE detector must be moved out of the way before operating these detectors. An 8 kV bias on the column's A-tube (connecting T1, T2, and T3) attracts low-energy electrons upward.

This design works best at smaller working distances and has three advantages:

1. **Superior Signal Collection**: T1 sits just millimeters above the pole piece, collecting higher energy, high-angle electrons over a much larger solid angle than traditional below-lens detectors. The result is exceptional signal-to-noise ratios at extremely low beam voltages and currents. This low-voltage/current operation is especially useful for delicate samples like biological tissue, pharmaceuticals and organic compounds, polymers, and battery materials.
2. **Higher Spatial Resolution**: T2 is more sensitive to low and mid-energy secondary electrons, but with short working distances, down to 2 mm, and the low voltage and current, the Apreo S2 can resolve features down to 2 nm with careful adjustment of beam voltage and current.
3. **Charge Contrast**: The T3 detector is sensitive to the lowest energy secondary electrons that are associated with differences in retained charge on the sample. This provides new information, usually lost in traditional SE detectors like ETD! Higher localized charge can indicate areas of defects in crystals or discontinuous coatings, differences in electrical conductivity, or electric fields inherent to the sample.

All three detectors are operated simultaneously, so all three can be triggered to take an image *at the same time* from three different detectors. This ensures that all three views are perfectly registered to the same location. This is a time saver during the imaging session.

The ETD and BSE detectors have their place, as the longer working distances provide the exceptional depth of field that SEM images are known for. The Trinity detectors require the sample to have a limited range of feature heights. The Trinity detectors provide additional tools for the microscopists. They also work with the Energy Dispersive X-ray spectrometer in place.

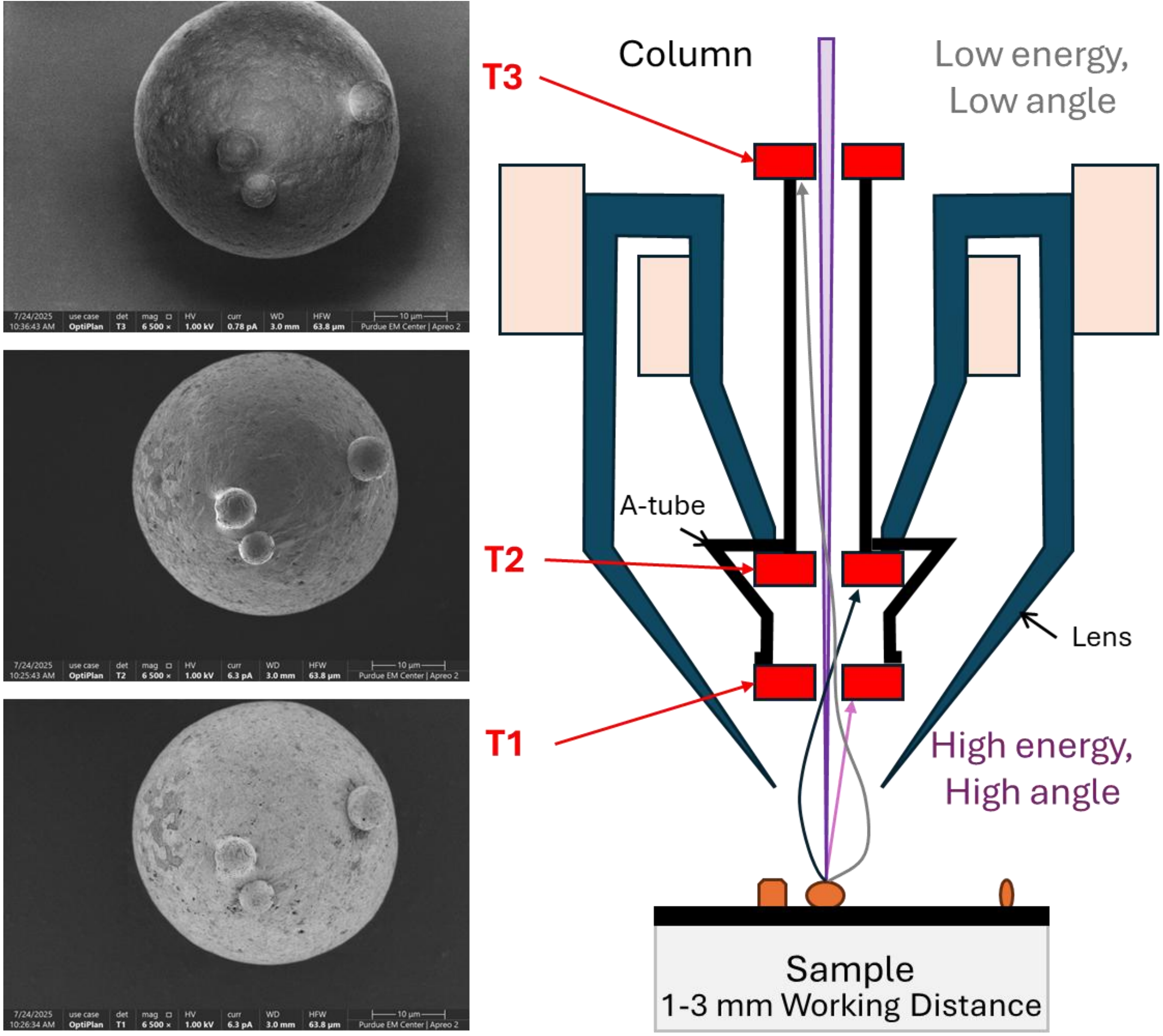

Figure 2. Trinity Detection System schematic (right) showing the three in-column detectors (T1, T2, T3) positioned to sort electrons by energy and angle. Sample images (left) of a bismuth-rich solder particle demonstrating how each detector reveals different information from the same location. 1 kV, 3 mm working distance.

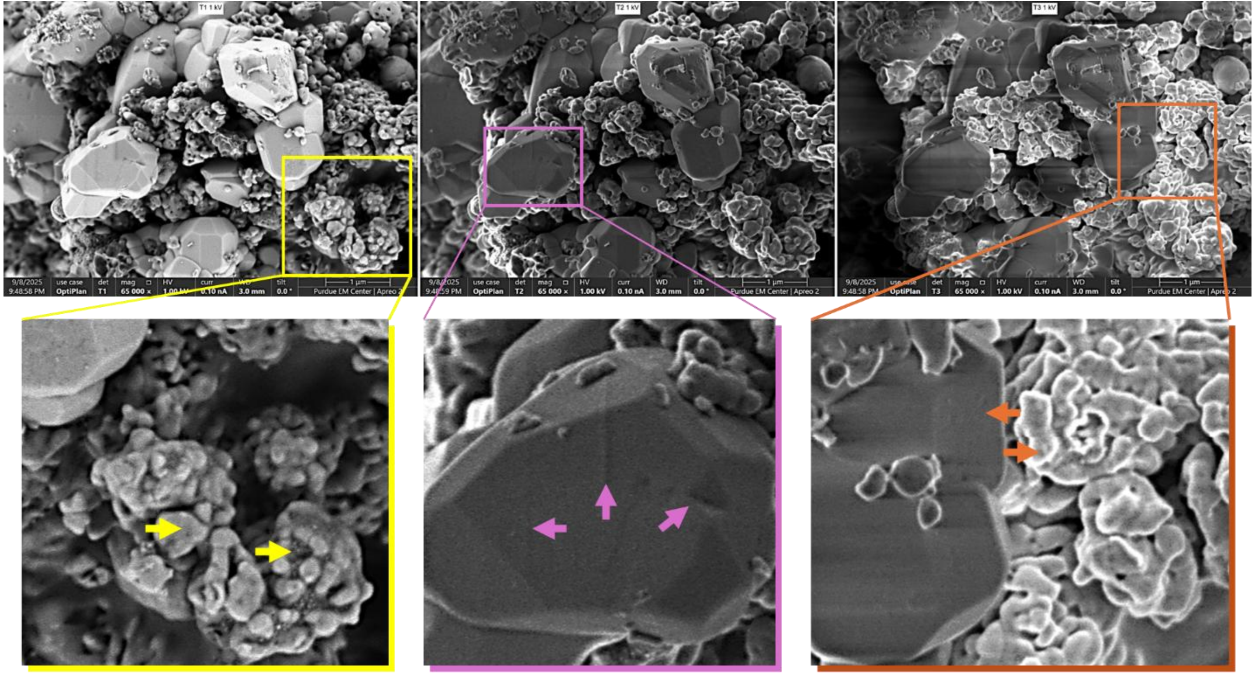

Figure 3. LiFePO4 cathode material imaged simultaneously with T1 (compositional contrast), T2 (topographic detail), and T3 (charge distribution). Arrows indicate: yellow—iron phosphate vs. carbon coating; pink—crystal defects and morphology; orange—charge differences between particles. 2 kV, 3 mm working distance, 65,000× magnification.

The images above demonstrate why this matters. These are LiFePO4 battery cathode particles captured simultaneously at 65,000x magnification, 3 mm working distance, using the three Trinity detectors (T1, T2, T3). Same location, same moment—but look at how different each image appears.

Each detector responds to physically different electron populations, revealing distinct information. Referring to Figure 3:

- **T1 (left)**: Compositional differences between phases. Yellow arrows show the brighter high iron phase cemented with a darker carbon phase.
- **T2 (middle)**: Surface topography and particle morphology. Pink arrows indicate the presence of subtle defects in the larger LiFePO4 crystals and crisp morphology, which is useful for identifying the equilibrium and growth shapes that are important to understand the formation of this material.
- **T3 (right)**: Surface charging and ultra-fine surface features. Orange arrows highlight the charge difference between the larger, more uniform, and conductive crystals and the smaller, less conductive particles.

This detector system is incredibly useful for delicate samples with small features that interact with surface charge.

Summary: Impact on Materials Characterization

I have only scratched the surface of what the Thermo Fisher Apreo S2 can do and look forward to learning more. What materials analysis challenges are you tackling? If multi-detector SEM could help, please contact me! Some examples to consider:

For Battery Researchers: Simultaneously evaluate active material distribution (T1), particle sintering and connectivity (T2), and coating quality (T3) without sample preparation or multiple scans.

For Failure Analysis: Distinguish whether a surface anomaly is contamination (compositional), physical damage (topographic), or charging from insulating buildup (T3 contrast).

For Polymer Scientists: Achieve compositional contrast at voltages that won't damage your samples (White paper example: clear differentiation of HDPE/COC blend at 500V).

For Geological or Cement/Concrete Analysis: Map mineral phases (T1), grain boundaries and texture (T2), and surface weathering or alteration (T3) in a single acquisition.

For Quality Control: Rapid, non-destructive assessment of coating uniformity, contamination, and structural defects without extensive sample preparation.

About the Analysis: The featured SEM images were all collected on the Thermo Fisher Apreo S2 FEG-SEM in the Purdue Electron Microscopy Center (RRID:SCR_022687).

About Cubic Labs LLC

We provide advanced materials characterization services using state-of-the-art XRD, XRF, and SEM-EDX instrumentation at Purdue University. With an MS in Physics and 22 years of experience in energy and environmental research, we bring deep expertise to complex analytical challenges in battery materials, geological samples, failure analysis, and environmental contamination.

Our approach emphasizes consultation over routine testing—we help you understand what measurements will answer your questions, then execute those analyses with transparent, cost-effective pricing.

Services include:

- Multi-detector SEM imaging and EDX elemental analysis
- Phase ID and quantification using powder X-ray diffraction (XRD)
- Absolute elemental concentrations using X-ray fluorescence spectroscopy (XRF)

- True Density by Helium Gas Pycnometer
- Expert data analysis and visualization for images, including computed tomography
- Equipment design, prototyping, and repair

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