

## Microscopy, Microtechnology & Image Analysis

### Unlocking the future of renewable energy

Kate Vanderburgh, Thermo Fisher Scientific

The global effort to combat climate change requires expanding renewable energy technologies. To optimise solar cells, batteries and hydrogen fuel cells, precise control over material structures at the micro and nanoscale is essential. Electron microscopy (EM) enables researchers to analyse material structures with unmatched detail. Here, Kate Vanderburgh, Senior Product Specialist at Thermo Fisher Scientific, explains how EM techniques are driving innovation and advancing sustainable energy solutions.

A successful global shift toward renewable energy hinges on improving the performance and durability of technologies like solar cells, batteries and hydrogen fuel cells. These technologies depend on advanced materials such as thin films, composite electrodes and nanostructured catalysts. Even minor changes at the atomic or nanoscale level can have a profound impact on efficiency and longevity.

For instance, improving solar panel efficiency requires enhancing light absorption and minimising energy loss at material interfaces. In lithium-ion batteries, which are essential for renewable energy storage, extending lifespan involves stabilising electrode structures and preventing unwanted phase transformations. Meanwhile, in hydrogen fuel cells, optimising the structure of catalysts can reduce the need for expensive materials such as platinum, making fuel cells more cost-effective.

To achieve these breakthroughs, researchers need a detailed understanding of how the structure, composition and morphology of materials influence their performance. Electron microscopy offers unparalleled insight by revealing atomic and nanoscale details that conventional optical techniques cannot capture.

#### Understanding the nanoscale world of materials

EM provides researchers with a powerful tool to study materials at the atomic scale. Unlike traditional light microscopes, EM uses electron beams to capture incredibly detailed images, allowing scientists to see and understand the fine structure of materials at the nanometer scale. This is crucial in renewable energy research, where even the smallest adjustments to materials can have a significant impact on technology efficiency.

Materials in renewable energy devices are often complex, requiring precise engineering to maximise their functionality. The performance of a solar cell, for example, depends not just on the composition of the materials used but, on the way, they are structured on the nanoscale. Defects, grain boundaries and interfaces within the materials can drastically reduce performance, making it essential to analyse these structures in detail.

Through electron microscopy, researchers can investigate the microstructure of solar cells, batteries, and fuel cells. They can pinpoint issues such as cracks in thin films, dendrites in battery electrodes and irregularities in catalyst surfaces, all of which could limit performance and lifespan. By identifying these issues, scientists can design more efficient, durable and cost-effective energy technologies.

#### Exploring techniques

EM encompasses a range of techniques that provide unique insights into material properties, enabling targeted research and development in renewable energy. Each technique offers distinct capabilities, allowing researchers to explore different aspects of material behaviour at the micro and nanoscale.

Scanning Electron Microscopy (SEM) is one of the most widely used techniques in materials research. It scans a focused electron beam across the surface of a sample to produce high-resolution images that reveal surface structures and topography. This is particularly useful in solar cell research, where surface texture plays a crucial role in determining the material's light absorption capabilities.

In photovoltaic research, SEM helps analyse the microstructure of thin films and interfaces that influence light absorption and electrical conductivity. By visualising surface defects, grain boundaries and texture, SEM provides critical insights for

optimising material properties in solar cells, energy storage systems and other renewable energy technologies.

For a deeper understanding of internal structures and atomic arrangements, researchers can turn to Transmission Electron Microscopy (TEM) and Scanning Transmission Electron Microscopy (STEM).

These techniques are essential for visualising features that influence the performance of lithium-ion batteries, supercapacitors and fuel cells - such as grain boundaries, phase interfaces and atomic defects. TEM transmits electrons through an ultra-thin sample to generate high-resolution images of internal structures, while STEM combines this capability with analytical tools to provide detailed imaging and chemical information.

To complement structural analysis, Energy Dispersive X-ray Spectroscopy (EDS) is often carried out alongside SEM or TEM to provide elemental analysis by detecting characteristic X-rays emitted when an electron beam interacts with the sample. EDS helps identify the distribution of elements like silicon in solar cells or lithium-ion battery electrodes, providing further insight into how the material's composition affects its performance.

Developing high-efficiency, long-lasting renewable energy technologies depends on a deep understanding of material properties at the micro and nanoscale. However, conventional analysis methods often rely on multiple instruments and complex workflows, leading to inefficiencies and longer development cycles. This creates a need for technology that integrates SEM and EDS analysis.

#### Advancing analysis

Integrating real-time structural and compositional analysis into a single workflow simplifies material characterisation by eliminating the need to switch between instruments or imaging conditions. This efficiency allows researchers to analyse materials faster and more effectively.

In renewable energy technologies, even small improvements in material efficiency, stability and cost can greatly impact the scalability and success of energy systems. The ability to quickly assess and optimise material properties is crucial for advancing renewable energy research. By providing faster feedback loops and reducing data acquisition time, this integrated solution streamlines the development of more efficient and cost-effective materials for solar cells, lithium-ion batteries and hydrogen fuel cells.

In solar photovoltaics, small tweaks to the materials used can lead to better energy capture, longer lifespan and higher durability, making these systems more reliable and affordable for large-scale adoption.

In a recent study, researchers used Thermo Fisher's Apreo ChemiSEM, which integrates SEM and EDS analysis, to examine the surface and internal structures of Ag/Zn Si photovoltaic material. Their analysis revealed how variations in elemental distribution affect the material's overall performance, providing critical insights for optimising photovoltaic technology.

Upon initial inspection of the sample, differences in material structure and compositional contrast were observed across the surface. However, it was unclear whether these variations stemmed from topographical differences or compositional heterogeneity.

Using an integrated solution allowed the researchers to deconvolute these differences in real-time using advanced imaging techniques, without the need to change imaging conditions or switch detectors. This streamlined workflow enabled faster identification of key material properties, accelerating the development of more efficient solar energy materials. *Figure 1* illustrates an image of the Ag/Zn Si photovoltaic surface, providing initial clues to material heterogeneity.

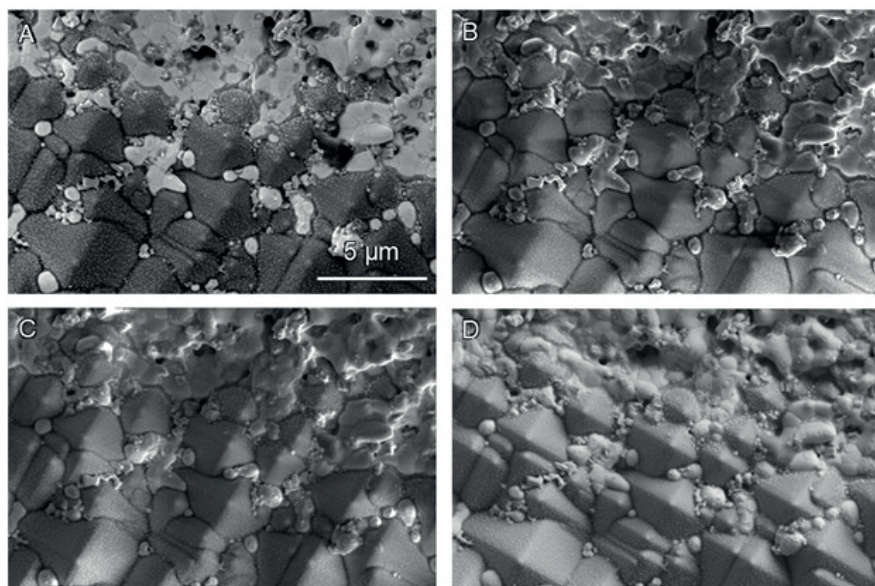


Figure 1: Apreo ChemiSEM SEM images of Ag/Zn Si photovoltaic surface taken with detector A) T1, B) T2, C) T3, D) ETD.

With the ability to map the distribution of specific elements, such as silver, zinc and silicon, researchers gained valuable insights into how the spatial arrangement of these elements affects the material's overall performance. Figure 2 provides individual quantitative elemental maps showing the distribution of these elements across the sample, helping the team identify regions where compositional inhomogeneities could impact device efficiency. These findings contribute to the advancement of high-performance photovoltaic materials, supporting the broader goal of enhancing renewable energy technology.

This integrated solution is also useful in driving the growth of other core elements of renewable technology. In lithium-ion batteries, real-time analysis of battery electrodes helps researchers optimise electrode structures to improve charge retention, reduce charging

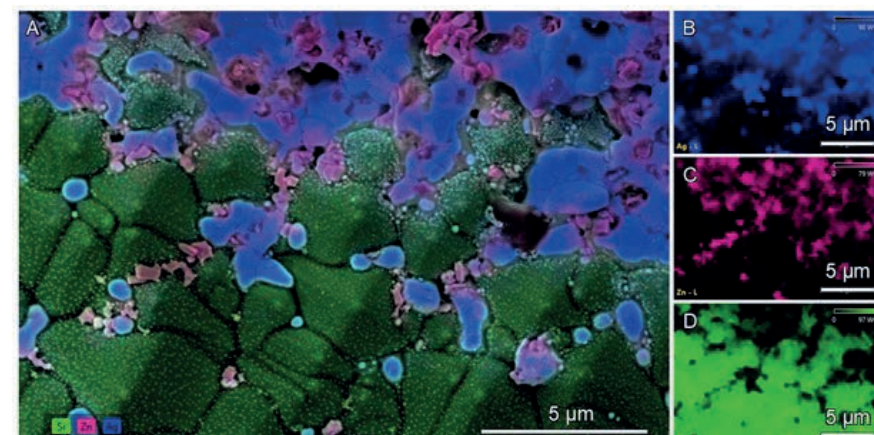


Figure 2: A) ChemiSEM image of a Ag/Zn Si photovoltaic surface showing B) silver (blue), C) zinc (pink), and D) silicon (green).

times and enhance safety. By directly linking material composition to performance, this approach accelerates the development of high-efficiency, long-lasting batteries essential for renewable energy storage.

Furthermore, in hydrogen fuel cells, integrated SEM and EDS analysis helps refine catalyst materials by mapping the distribution of precious metals like platinum or identifying cost-effective alternatives. Optimising these materials enhances reaction efficiency, lowers costs and supports the widespread adoption of hydrogen fuel cells as a sustainable energy solution.

The transition to renewable energy depends on optimising materials at the nanoscale. Traditional EM techniques have long been crucial for analysing material structure and composition. However, integrated SEM and EDS solutions could drive the next wave of material innovation by providing real-time, detailed insights that streamline material discovery. By reducing development cycles, these advanced tools enable breakthroughs that enhance efficiency, durability and cost-effectiveness - paving the way for a more sustainable and accessible clean energy future.