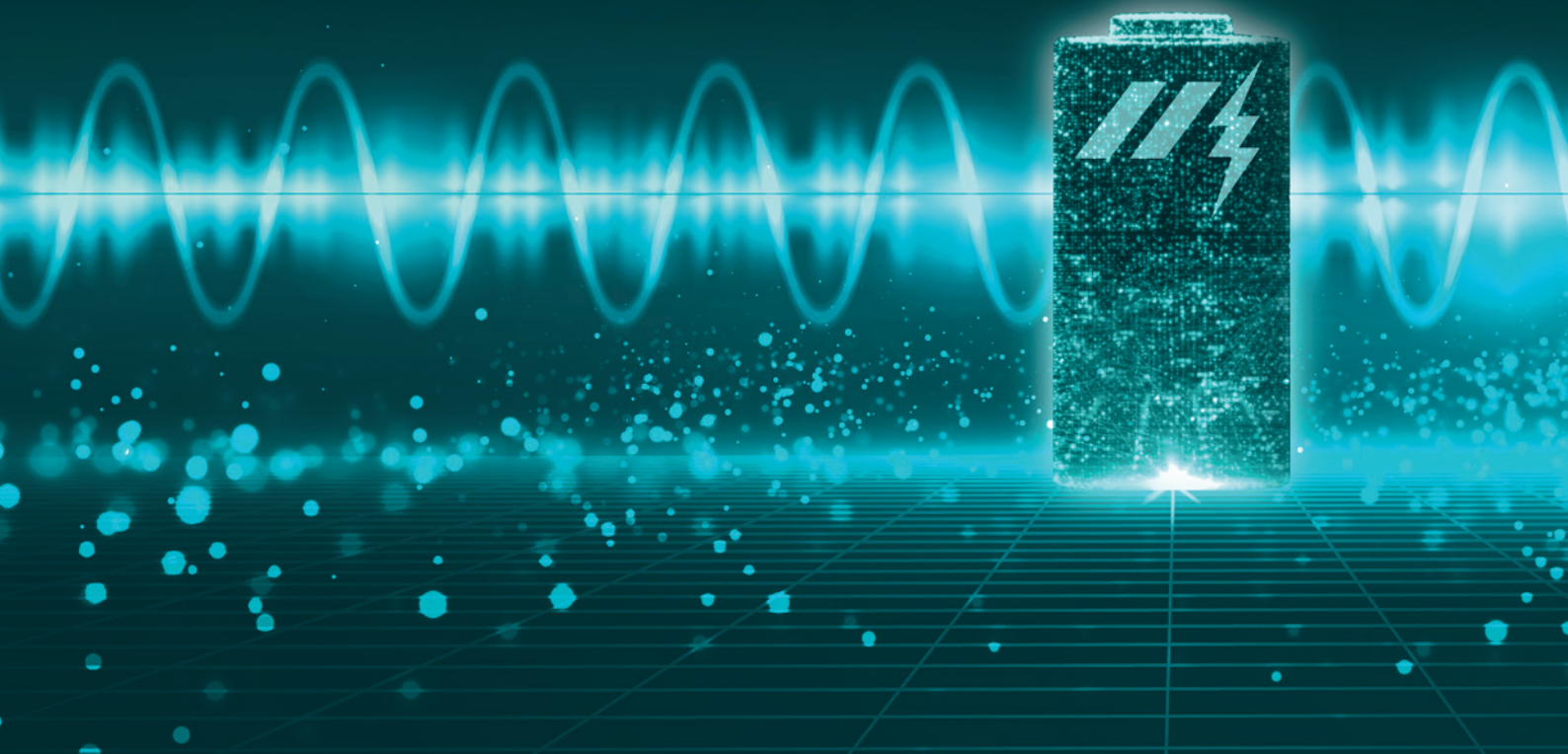




**Malvern
Panalytical**
a spectris company

Online process control solutions

Battery manufacturing and recycling



Industry 4.0 solutions for sustainable battery manufacturing

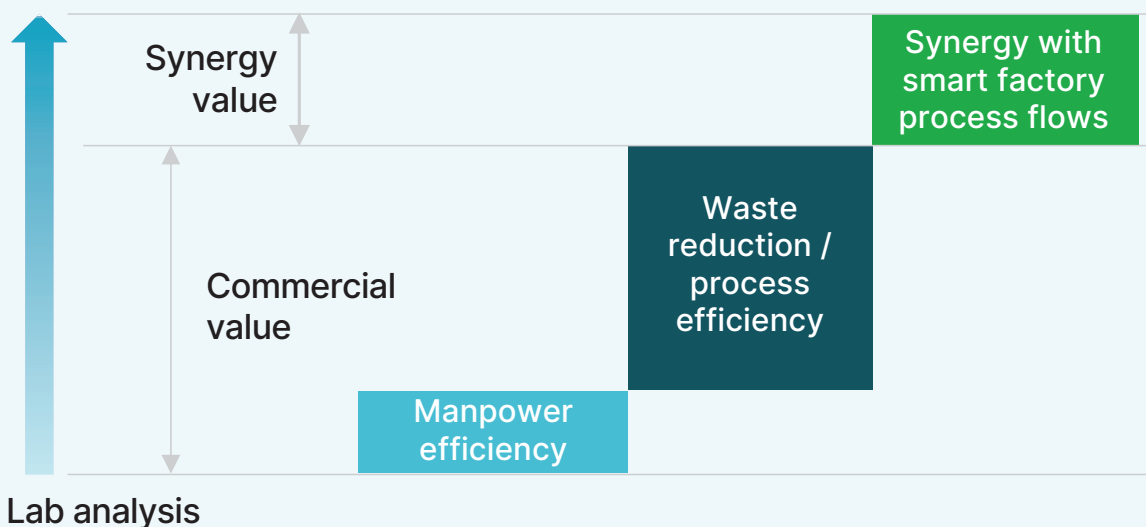
Driven by the electric vehicles, battery manufacturing has seen unprecedented growth in recent years, and this growth is likely to continue over the next decade. At the same time, the price of battery packs continues to fall, forcing manufacturers to innovate at every stage of production to minimize waste and maintain consistent quality. The same goes for the battery recycling, which needs to be profitable despite the price volatility of key minerals such as lithium (Li) and nickel (Ni).

This is where process automation analytical solutions enabling Industry 4.0 smart factory process flow can greatly help. Malvern Panalytical offers a range of online solutions that span the entire battery manufacturing value chain:

- Particle size analysis in precursor and electrode materials production
- Elemental composition analysis of liquid precursor materials during production and recycling
- Elemental composition analysis of electrode coatings
- Orientation index of graphite-coated electrodes
- Elemental composition analysis of black mass for recycling



Online analysis



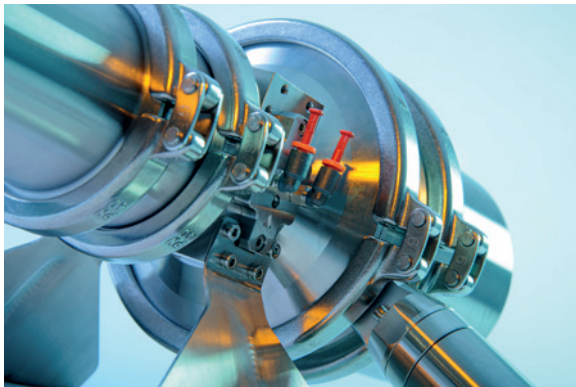
Potential gains with online monitoring in the process control.

Insitec

Online particle size analyzer for battery precursors and electrode materials

Insitec Wet

Insitec Wet: Engineered to withstand harsh chemical environments, Insitec Wet particle size analyzers use laser diffraction technology to measure particles in the 0.1 to 1000 μm size range in emulsions, suspensions, and slurries. Insitec Wet can be configured for virtually any wet particulate process, including battery recycling, and delivers continuous, automated, real-time results 24/7.

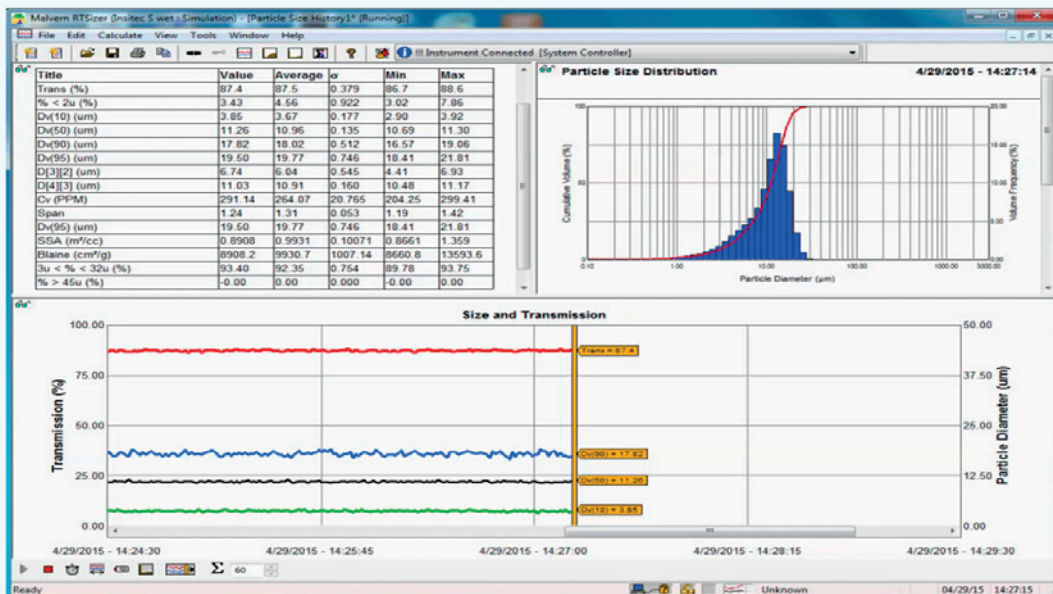


Insitec Dry

Insitec Dry: Engineered to withstand the rigors of the process environment, Insitec Dry particle size analyzers use laser diffraction technology to measure particles in the 0.5 to 2500 μm size range. Insitec Dry can be configured for virtually any dry particulate process, delivering real-time monitoring and enabling process optimization and Industry 4.0 control.

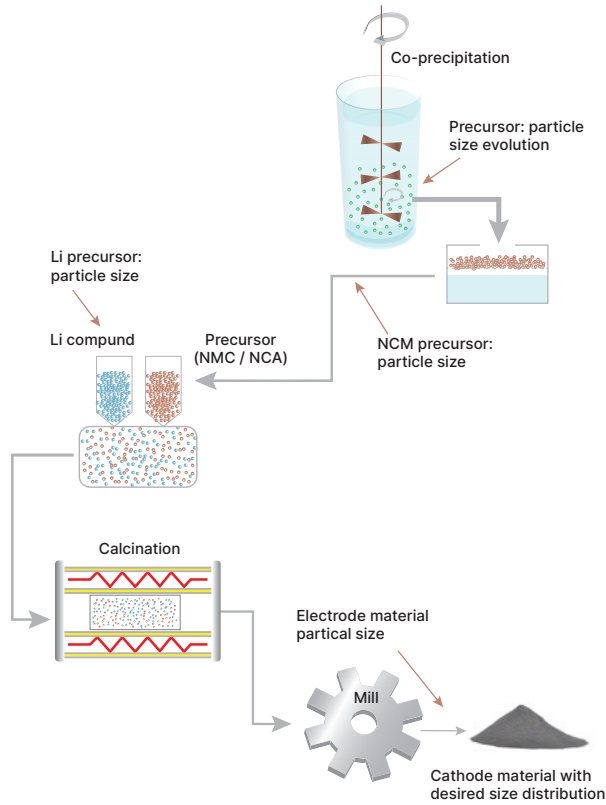


Monitoring trends in particle size with Insitec Wet



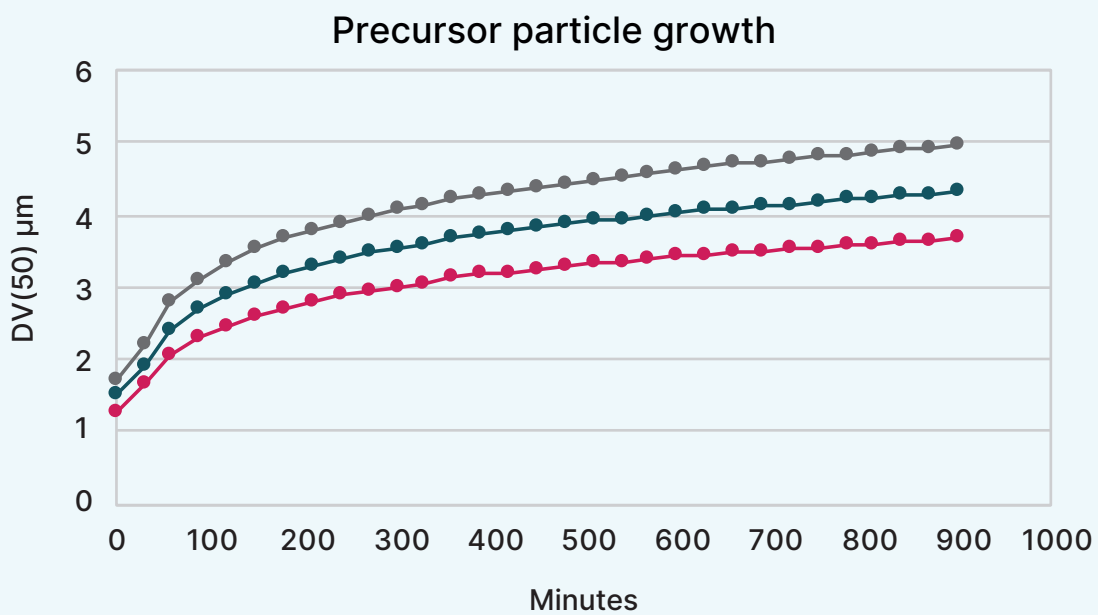
Insitec

Online particle size control to minimize process waste



Typical manufacturing process for NCM cathode material. **Online particle size analysis with Insitec** can be used to monitor and control the following process stages:

- Nucleation and growth of particles in the reactor tank to produce NCM hydroxide precursor
- Sieving / grinding of Li precursors (LiOH, LiCO₃)
- Control of the classifier mill to achieve the correct particle size distribution of cathode and anode materials



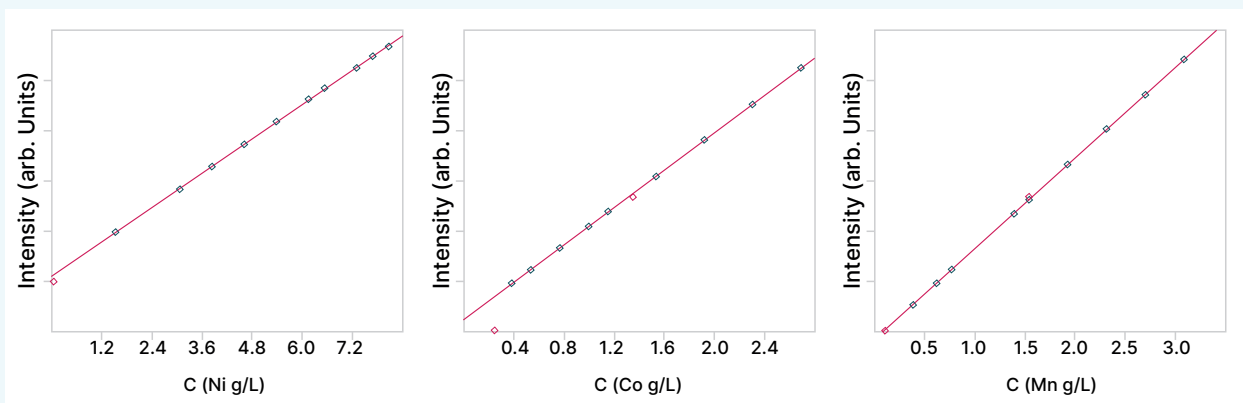
Growth of cathode precursor particles in the reactor tank under different growth conditions, as measured with online laser diffraction over time.

Epsilon Xflow

Online elemental composition analysis of liquid precursors

Cathode active materials are commonly produced via co-precipitation from a solution containing metal sulfates (Ni, Co, and Mn sulfate for NCM-based active material). Online analysis of the elemental composition of the liquid precursor with the Epsilon Xflow enables fast and accurate control of the chemical composition of starting materials. Across the battery industry, heightened regulations and strict quality specifications are driving the need for continuous process flow monitoring. The Epsilon Xflow delivers real-time data insights, enabling you to manage your production processes more efficiently and reduce your operational costs.

- Simultaneous multi-element liquid precursor analysis in battery CAM manufacturing and battery recycling
- Real-time results
- Leading EDXRF technology for fast measurement with high repeatability and accuracy



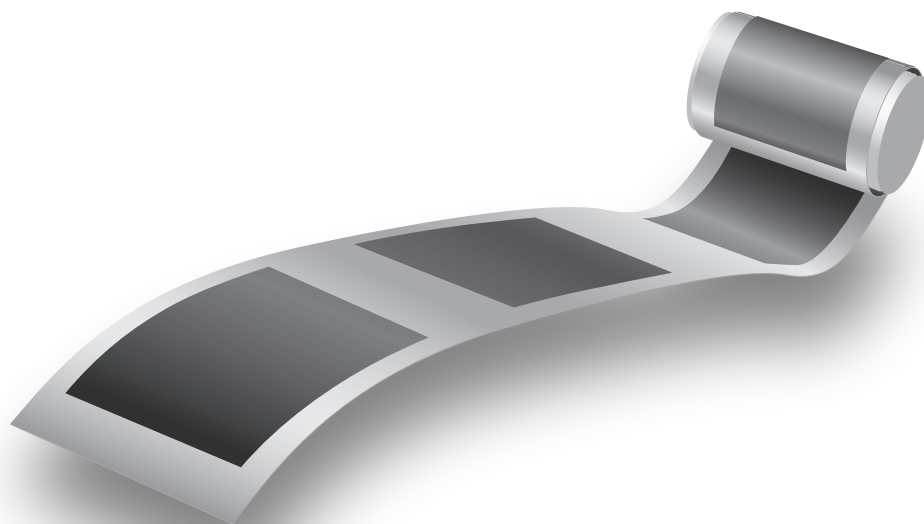
Ni, Co, and Mn calibration on liquid precursor samples using EDXRF.

Epsilon Xline

In-line elemental composition analysis of electrode coatings

By integrating our advanced Epsilon 4 technology with in-line functionality, this tool offers real-time material monitoring and up-to-the-minute process control for both ultrasonic spray coating and roll-to-roll (R2R) coating processes.

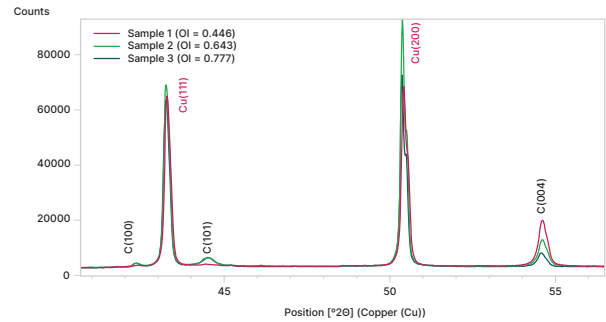
- **Continuous monitoring of R2R coating processes:** real-time analyses eliminates the need for sampling, thus avoiding disruptions to the coating process.
- **Precise measurement:** a patented robotic arm with an ultra-fast Silicon Drift Detector provides optimal distance control over the production line for accurate measurements at high coating speeds.
- **Seamless integration into production processes:** Epsilon Xline supports standard communication protocols, making it easy to adopt and integrate into existing production setups.
- **Comprehensive element analysis:** the instrument can measure all elements of interest, including impurities and dopants down to parts per million (ppm) level
- **Precision measurement of thin layers:** it uses proven software for single as well as multi-layer webs
- **Versatile use:** suitable for patch, continuous, or multi-lane coating processes, the Epsilon Xline offers multiple scanning options to optimize coating homogeneity for a consistent quality product
- **Wide roll width compatibility:** Epsilon Xline accommodates a wide range of roll widths, enhancing manufacturing flexibility to meet the increasing product differentiation in the fuel cell industry



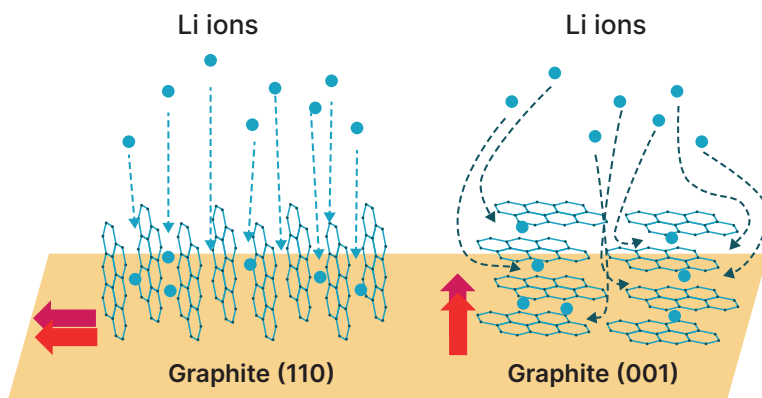
Online XRD

Controlling the orientation index in graphite electrode coatings

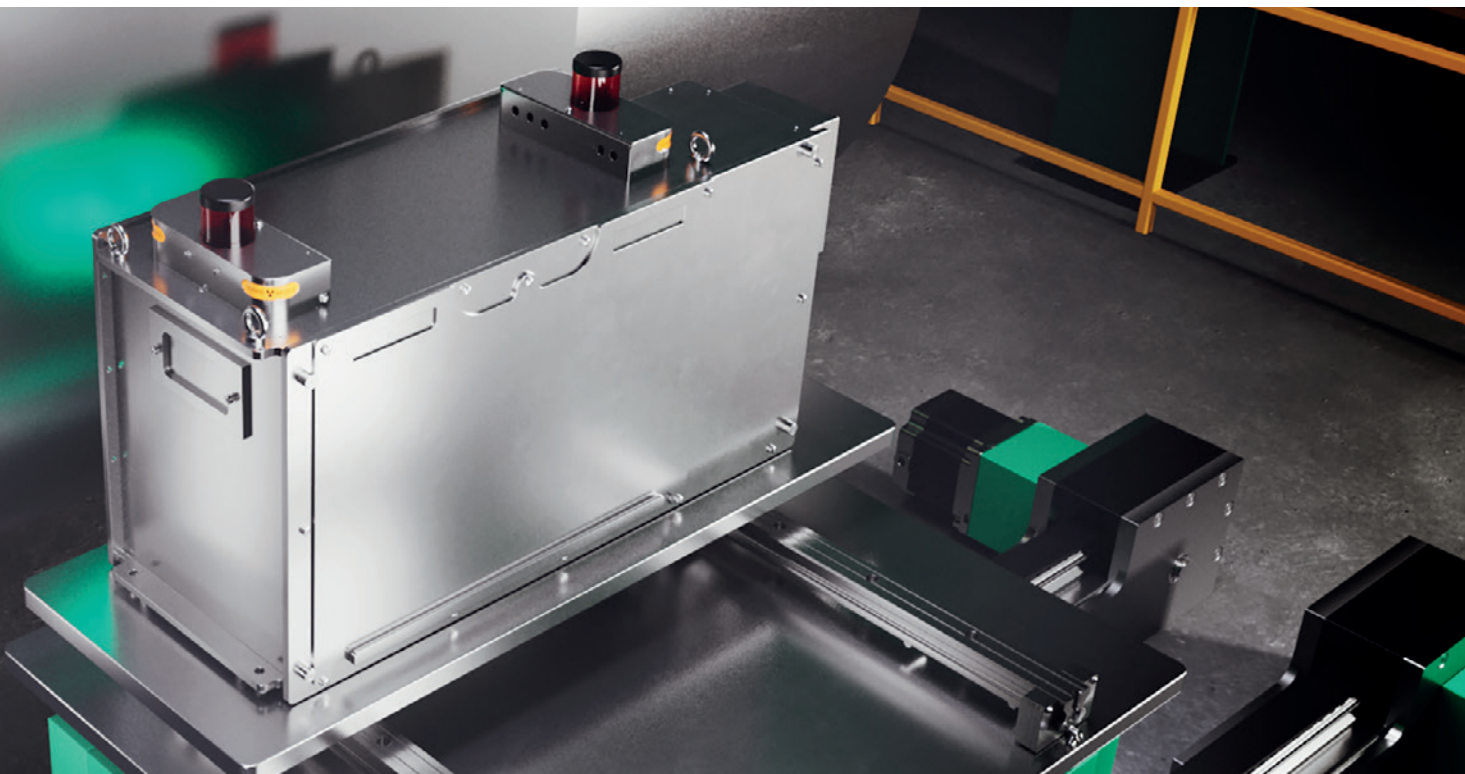
The **orientation index** is a highly significant parameter in coated graphite layers. The orientation of graphite particles can vary depending on the coating process. Orientations such as 110 and 100, where the c-axis of the graphite aligns with the plane of the current collector, significantly enhance electronic and ionic conductivity compared to the 001 orientation, where the c-axis is out-of-plane to the current collector. **Online XRD** can be used to monitor the orientation index in real time.



Typical orientation index measurement using XRD.



Schematics of Li intercalation pathways for graphite 110 and 001 orientations. Red arrows show the direction of the c-axis. Graphite has poor ionic and electronic conductivity along the c-axis.





About Malvern Panalytical

We draw on the power of our analytical instruments and services to make the invisible visible and the impossible possible.

Through the chemical, physical and structural analysis of materials, our high precision analytical systems and top-notch services support our customers in creating a better world. We help them improve everything from the energies that power us and the materials we build with, to the medicines that cure us and the foods we enjoy.

We partner with many of the world's biggest companies, universities and research organizations. They value us not only for the power of our solutions, but also for the depth of our expertise, collaboration and integrity.

We are committed to Net Zero in our own operations by 2030 and in our total value chain by 2040. This is woven into the fabric of our business, and we help our employees and customers think about their part in creating a healthier, cleaner, and more productive world.

With over 2300 employees, we serve the world, and we are part of Spectris plc, the world-leading precision measurement group.

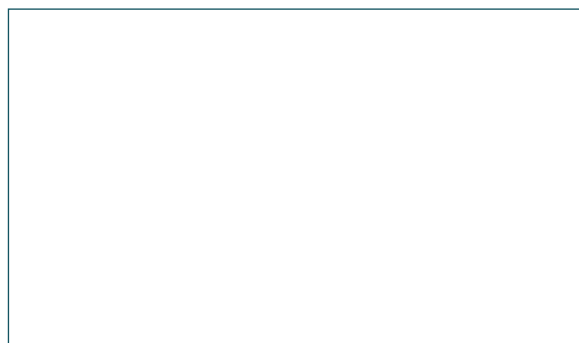
Malvern Panalytical. We're BIG on small™

Service & Support

Malvern Panalytical provides the global training, service and support you need to continuously drive your analytical processes at the highest level. We help you increase the return on your investment with us, and ensure that as your laboratory and analytical needs grow, we are there to support you.

Our worldwide team of specialists adds value to your business processes by ensuring applications expertise, rapid response and maximum instrument uptime.

- Local and remote support
- Full and flexible range of support agreements
- Compliance and validation support
- Onsite or classroom-based training courses
- e-Learning training courses and web seminars
- Sample and application consultancy



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