Advancing Next-Generation Battery Evaluation

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NEXT-GENERATION LITHIUM-ION BATTERIES are poised to have great impact on power storage and improved performance in several industries, from mobile phones to automotive to satellites.

According to MarketWatch, the global lithium-ion (Li-ion) battery market is expected to exceed more than $77 billion by 2024, growing at a CAGR of more than 11%. Major drivers include:

- Improved designs for higher efficiencies and longer lifespan;
- Continued growth in consumer electronics;
- Increasing shift toward sustainable, clean fuel in the automotive industry.

The report added that awareness of new designs and their capabilities remains a restraint on growth. This demand is driving significant R&D into alternative lithium-ion chemistries and storage technologies. For example, graphene is a highly conductive, lightweight and easy-to-manufacture material being tested as an electrode material. Recent European research describes a composite material of tin oxide nanoparticles enriched with antimony, attached to a base layer of graphene. Lithium-ion cells using this material for its electrodes can increase energy density by up to three times and reduce charging time.

And, in November 2017, the Samsung Advanced Institute of Technology developed a battery material called “graphene ball” that enables a 45% increase in capacity, and a charging speed five times faster than standard lithium-ion batteries. “In theory, a battery based on the graphene ball material requires only 12 minutes to fully charge,” the company stated. The battery can also maintain a highly stable 60°C temperature, particularly key for electric vehicles.

Together with PC-based software and purpose-built cells for inspecting and evaluating battery cross-sections, the new ECCS (electro-chemical reaction visualizing confocal microscope system) from Lasertec, Yokohama, Japan, and San Jose, Calif., is making such new battery developments possible. In a confocal system, a light beam is scanned on the sample surface and reflected light is detected through a pinhole (or a slit) set at the imaging surface in the microscope’s optical system. “Confocal” means focusing occurs both on the sample surface and imaging surface, and only the light in focus is detected selectively. Out-of-focus light from the sample surface barely goes through a pinhole (or slit) and only the part in focus on the surface is very clearly observed. This confers a large depth of field to the image.

The ECCS (electro-chemical reaction visualizing confocal microscope system) from Lasertec. (All photos provided by Lasertec)

“Seeing reveals many things,” said Dennis Fenn, district sales manager for Nikon Metrology Inc., Brighton, Mich., a Lasertec distribution partner. “In lithium-ion batteries, whether they are to be used for watches or spacecraft, there are many development goals: greater reliability, longer life, shorter charging time and higher energy density. This means there are a number of different ways for developing new materials and battery production methods.”

Danger Ahead!

There are a few givens. By design, Li-ion batteries are dangerous. They contain volatile chemicals with relatively thin membranes keeping them separated. If this barrier becomes worn and is breached, the electrodes can come in contact and the battery will short-circuit. Moreover, the batteries are filled with flammable electrolyte that can combust when hot. Not only is there risk of fire, but the liquid can also burn your skin.

"Unlike most mature technology encompassing the past 25 years, when it comes to Li-Ion batteries they can still be volatile, even after all this time," Fenn added. "That is because we expect more from our batteries every day—faster charge times, longer life and smaller form factors."

Lasertec white light confocal optics bring a number of advantages to battery evaluation: high resolution, the ability to detect true colors (high chromatic separation) and, with purpose-built battery-testing fixtures, the ability to visualize and measure battery chemical reactions while charging and discharging in-situ.

Proprietary battery-testing fixtures for the ECCS include anode and cathode connectors and electrode holders that can contain active materials for both. Specially designed software makes many kinds of analysis functions possible. This includes making videos to visualize chemical reactions during charging/discharging, linking the images to charge/discharge curves, expansion/contraction analysis, color analysis and more.

"For example, battery developers can see graphite color changes—blue to gold as the battery is charged and gold to blue as it is discharged," Fenn added. Capturing such color changes makes correlation and state of change (SOC) analyses possible.

Fixing the Dendrite Problem

Dendrites are particular hazards that can develop in batteries. As ions are exchanged between the anode and cathode over several charge and discharge cycles, lithium electrodes will sometimes grow dendrites that can expand through the electrolyte that separates the anode and cathode. These dendrites can reduce the battery's capacity, shorten its life or even start fires as the dendrites heat up. Dendrites were found in the batteries related to the Boeing 787 battery fires that happened in 2014, for example.

However, according to a 2018 article on arstechnica.com, researchers from Rensselaer Polytechnic Institute, Troy, N.Y., have proposed a way to ameliorate dendrite growth. By applying a high-current pulse to a lithium-metal anode, the researchers were able to produce heat that wasn't enough to melt the lithium metal but was enough to encourage "extensive surface migration" of the lithium atoms. That essentially "healed" the lithium-metal anode of newly growing dendrites, which smoothed out the surface of the lithium anode again.

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Such local heating gives flux and flow to lithium, triggering extensive surface diffusion, which smooths the dendrites. The self-heating is at safe levels, below any danger of electrolyte breakdown or thermal damage to the separator. Researchers then tested the batteries to see if healing the dendrites expanded their life. Cells that had received smaller current density pulses shorted in about 500 hours "because of the dendritic projections" that grew on the lithium electrodes. The cells that had been pulsed with current densities above 9 mA/cm^2 "showed no indication of electrical shorting even after 2,000 hours."

These are the types of findings that color observation, anode and cathode testing on a variety of materials, and powerful software and data analysis tools on confocal microscopy systems are making possible, taking hours to complete instead of the days needed with older technology. As a result, new battery developments can move from R&D labs to production and onto the road or into space much faster than ever before.