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Battery Inspection Using Short Wave Infrared (SWIR) Imaging

By: SWIR VISION SYSTEMS

Introduction:

As lithium-ion battery technology plays a central role in the race toward mobile electrification, improved inspection capabilities are needed to help drive down cost, increase energy densities, and improve overall safety and reliability. Short Wave Infrared (SWIR) imaging is enabling new capabilities for lithium-ion battery inspection aimed at addressing these needs. In this application note, we explore how high resolution, wide field-of-view, and extended SWIR cameras have been put to work to overcome important lithium-ion battery inspection challenges to meet increasingly demanding performance and quality specifications.

Lithium-Ion Batteries:

Lithium-Ion battery cells come in many shapes and sizes and at their core, consist of anode, cathode, and polymer separator layers that are either rolled or stacked into cells before being impregnated with an electrolyte solution and then encapsulated to suit the final application. During the assembly process, machine vision systems are used to measure and inspect various aspects of the assembly process. One interesting feature of the polymer separator layers common to most lithium-ion batteries, is that their optical transparency increases at higher wavelengths, well beyond the visible spectrum where SWIR sensing is designed to operate.

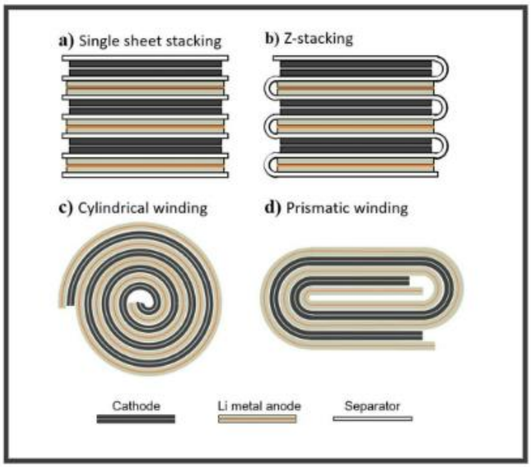

Figure 1. Schematic showing four typical types of Li metal batteries manufacturing processes. (a) Single sheet stacking; (b) Z-stacking; (c) cylindrical winding and (d) prismatic winding.

Colloidal Quantum Dot (CQD) SWIR sensors, pioneered by SWIR Vision Systems, deliver hyper-spectral image sensing at a cost per pixel well below industry norms by virtue of a patented CQD semiconductor technology, which leverages standard CMOS arrays to achieve the world's highest resolution, full HD, SWIR imaging camera. Resolution and cost/pixel are important considerations for lithium-ion battery manufacturers to maximize optical ROI while maintaining the necessary per/pixel resolution (i.e. um/pixel).

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In Figure 2, a SWIR camera integrated into a front-side illuminated battery inspection system captures SWIR photons reflected off the sample and provides an enhanced level of subsurface detail. The flexibility of this inspection setup, using Acuros® CQD® high resolution SWIR cameras, frees tool designers to exceed key specifications especially when it comes to:

1. **Detection Performance**: improved visibility through separator material layers
2. **Thermal Management**: no need to contend with sample heating/cooling impacts on the measurement
3. **Inspection Throughput**: acquisition speeds dictated by industry standard GigE acquisition standards
4. **Total System Cost**: Full-HD 1920 x 1080 CQD SWIR cameras enable fewer cameras to be deployed per system

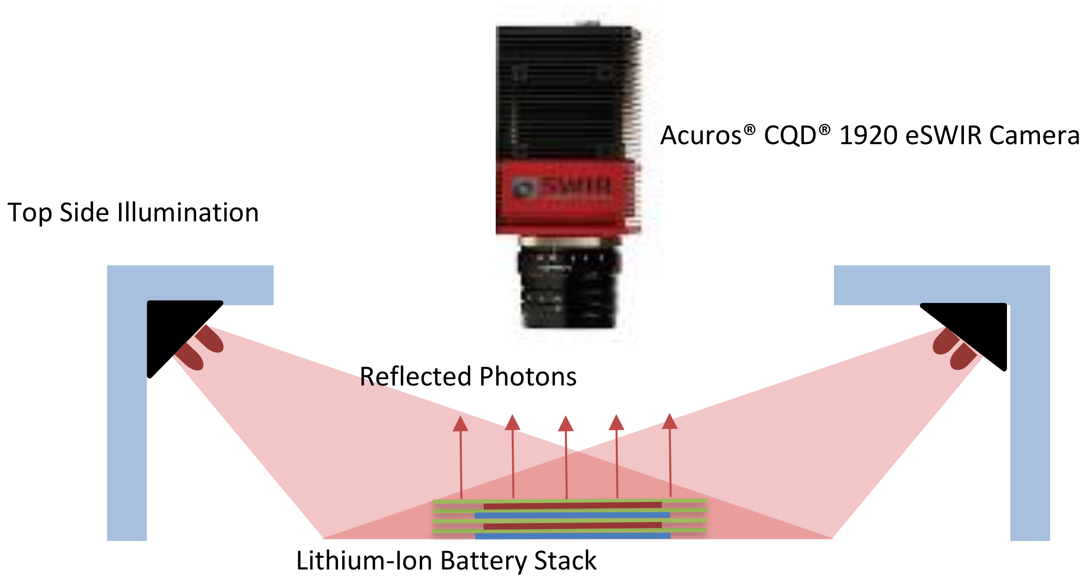

Figure 2. Typical battery inspection setup showing a "stacked" type cell with alternating Anode/Cathode (blue & red) layers with polymer separator (green) between each interface. Incident SWIR radiation illuminates the sample and the light reflected back to the SWIR image sensor provides detail regarding the subsurface layers covered by the separator.

Applications:

<u>Edge Detection:</u> One area where SWIR battery inspection promises to improve upon legacy solutions, is battery capacity (typically measured in Amp-hr) which is proportional to the amount of overlapping electrode area achieved during assembly. Since visible imaging solutions are limited in their ability to

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see through the separator layer materials, underlying edges of electrodes can be obscured thus preventing accurate edge identification and alignment. Even small alignment errors (on the order of 100um or less) can have meaningful impacts when considering how these alignment errors are compounded across the entire electrode and between each of the layers. The enhanced contrast and superior FOV of SWIR Vision's Acuros CQD SWIR cameras provide the necessary alignment accuracy of inter-layer electrodes leading directly to more available energy storage capacity and longer battery lifetimes.

In Figure 3, provides a comparison of visible and SWIR images demonstrating the enhanced contrast achieved using Acuros CQD SWIR cameras. In practice, alignment of electrode layers depends on accurate detection of the previously positioned electrode layers which are hidden beneath the polymer separator once it is laid down. Increasing the contrast of this underlying edge transition enables edge detection algorithms to function with precision. Achieving this contrast is one thing but doing so in a full HD (2.1MP) format, is something only SWIR Vision System's has been able to deliver to the market.

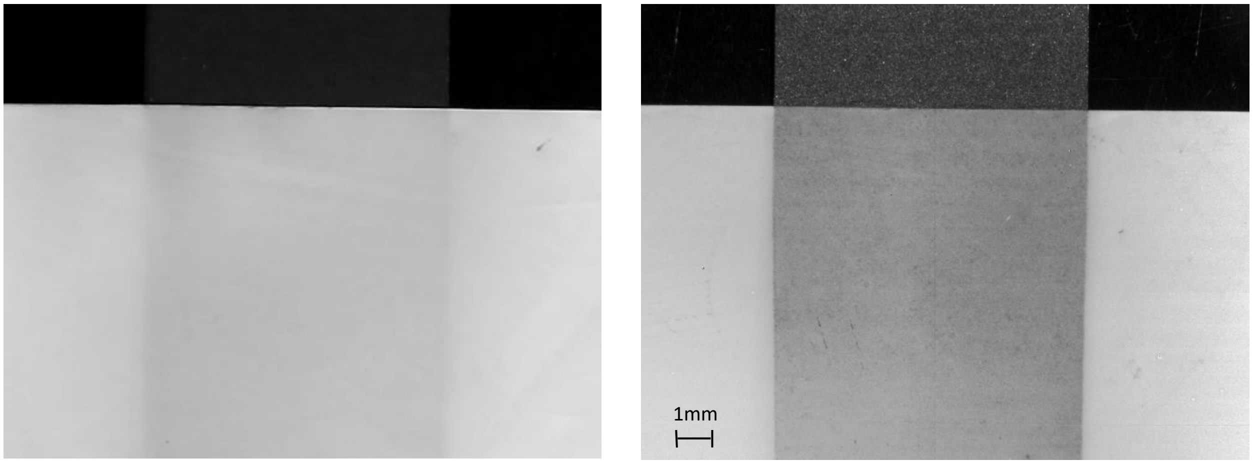

Figure 3. Visible (left) and SWIR (right) images of lithium-ion anode layer as viewed through a polymer separator. Because the polymer separator material is more transmissive in the SWIR spectrum, the anode edge is clearly visible in the SWIR image on the right versus the faint shadow detected by visible image on the left.

Particle Inspection:

Particle contamination is another challenge facing lithium ion battery manufactuers. Several high profile incidents of battery fires and explosions have been triggered by minute particles which managed to become lodged between the electrode-seperator interfaces. If left undetected, these particles can gradually impinge through the separator layer eventually producing a short-circuit followed thermal runaway and finally, combustion. One of the primary sources of particle contamination in cell produciton, is generated during the electrode cutting step where the anode and cathode electrode layers must be cut

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to size before subsequent rolling or stacking processes. During this cutting process, lithium, carbon, and other electrode coating material fragments have a tendency to delaminate from the edge. Metal shavings and other airborn particles can also pose a risk to cell reliability. For the sake of this example, we will focus on lithium/carbon particulate which can be especially challenging to detect given the particle sizes of interest (down to sub-10um) and the fact that they are inherently camoulfaged by their background.

To demonstrate the effectiveness of SWIR imaging to detect particle contamination, a side by side comparison was made. For the comparison, an 'Extended SWIR' camera was used to capture photons all the way out to 2um in the SWIR spectrum, thus taking full advantage of the separator transmissivity profile. Figure provides the comparison between visible and eSWIR images acquired both with and without an overlaying polymer separator. In the visible image (top), there are no particles detected as the separator is virtually opaque to the spectral response of the camera. In the case of the eSWIR image, higher wavelength photons are able to penetrate the separator layer and provide details regarding the sublayer contamination. The particle sizes in this demonstration were on the order of 50-100um. One of the key benefits of SWIR Vision's 1920x1080 focal plane array technology is that even much smaller particle sizes can still be detected while still maintaining large imaging FOVs.

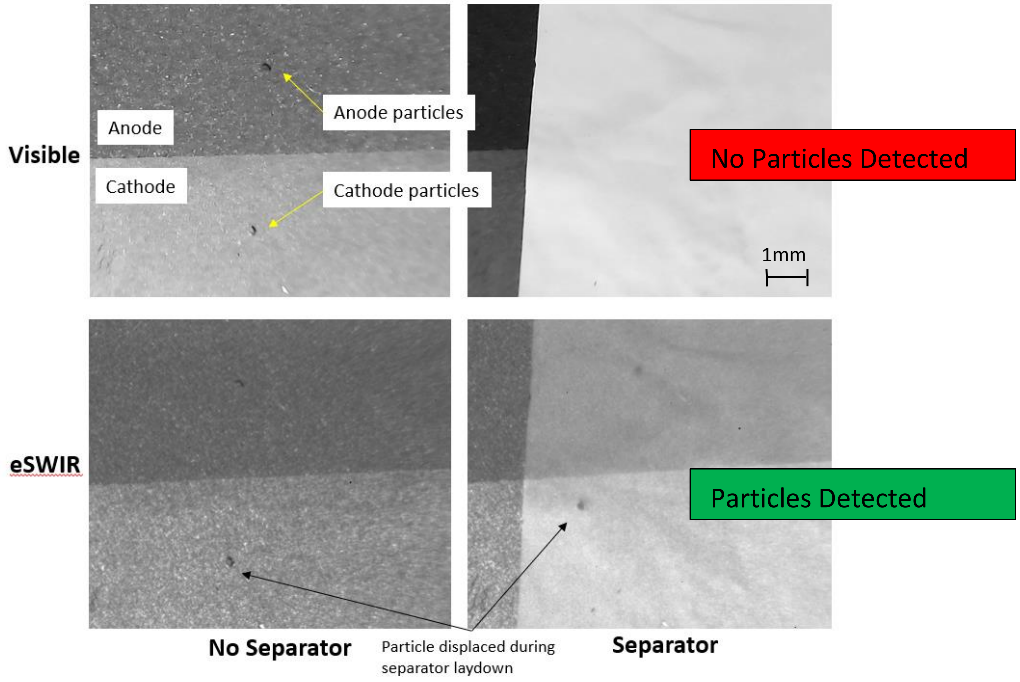

Figure 4. Visible (top) and SWIR (bottom) images of delaminated particulate generated from the electrode coating during the cutting process as seen without (left) and with (right) a polymer separator overlay. Particle sizes range from 50-100um and are shown on their corresponding Anode/Cathode backgrounds to simulate the most challenging detection scenario.

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Conclusion:

Lithium-ion battery inspection is poised to make significant impacts in the push toward mobile electrification. SWIR image sensors have been around for a while and many machine vision engineers are familiar with the benefits and limitations of traditional InGaAs image sensors. But now, higher resolution, wide field-of-view, extended SWIR, and low total system cost CQD SWIR sensors, pioneered by SWIR Vision Systems, are uniquely positioned to address many of the key challenges facing lithium-ion battery inspection.

For more information, please contact SWIR Vision Systems at sales@swirvisionsystems.com or by calling +1 (919) 248-0032.

Figure 1 Source: wu, Bingbin & Yang, Yang & Liu, Dianying & Niu, Chaojiang & Gross, Mark & Seymour, Lorraine & Lee, Hongkyung & le, Phung & Vo, Thanh & Deng, Zhiqun & Dufek, Eric & Whittingham, M. & Liu, William & Xiao, Jie. (2019). Good Practices for Rechargeable Lithium Metal Batteries. Journal of The Electrochemical Society. 166. A4141-A4149. 10.1149/2.0691916jes. 361-8970.