

Evaluating the Performance, Reliability and Safety of Lithium-Ion Cells

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Since introduction of the first commercial lithium-ion battery by Sony in 1991, lithium-ion battery technology has steadily displaced more mature secondary battery chemistries in portable and autonomous devices. The rise in popularity of lithium-ion batteries is easily attributed to the strengths of the chemistry when compared to other rechargeable systems. Relative to nickel-cadmium or nickel-metal hydride systems, lithium ion cells have higher energy density, a lower self discharge rate and do not exhibit cycling related voltage depression (the so-called “memory effect”). Because of these and other performance advantages, lithium-ion batteries are increasingly considered for use in robotic applications.

Unlike the portable consumer electronics industry, where high unit volumes can justify the design and manufacturing of custom batteries, the robotics industry must often utilize standard, off-the-shelf batteries for specific applications. Even when the production of custom batteries is justified, few battery manufacturers appreciate the level of quality and reliability that is required by the robotics industry. Additionally, evolution of lithium-ion battery technology over the past 20 years has introduced alternate materials and designs exhibiting varied performance characteristics that serve niche needs of the growing market. Choosing and validating the correct cell design, specific cell chemistry and proper interfacing of the lithium-ion power supply to the application have become critical engineering tasks in the design cycle of robotics platforms.

Leveraging over 15 years of lithium-ion battery failure analysis experience, Exponent has developed a suite of analytical screening techniques specifically aimed at streamlining the lithium-ion battery selection and screening process for our clients. One such technique is a cell cross-sectioning protocol that allows the use of reflected light microscopy, scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) to critically evaluate the active material quality and purity, design, and construction of lithium-ion battery cells.

Figure 1 is a scanning electron microscope image of a typical lithium-ion cell showing one anode and cathode repeat unit. Active anode and cathode material particulate are deposited on metallic current collectors and are isolated from each other by a polymeric separator membrane. In a properly designed cell, operated within its specified range, this general morphology is maintained over the useful life of the cell.

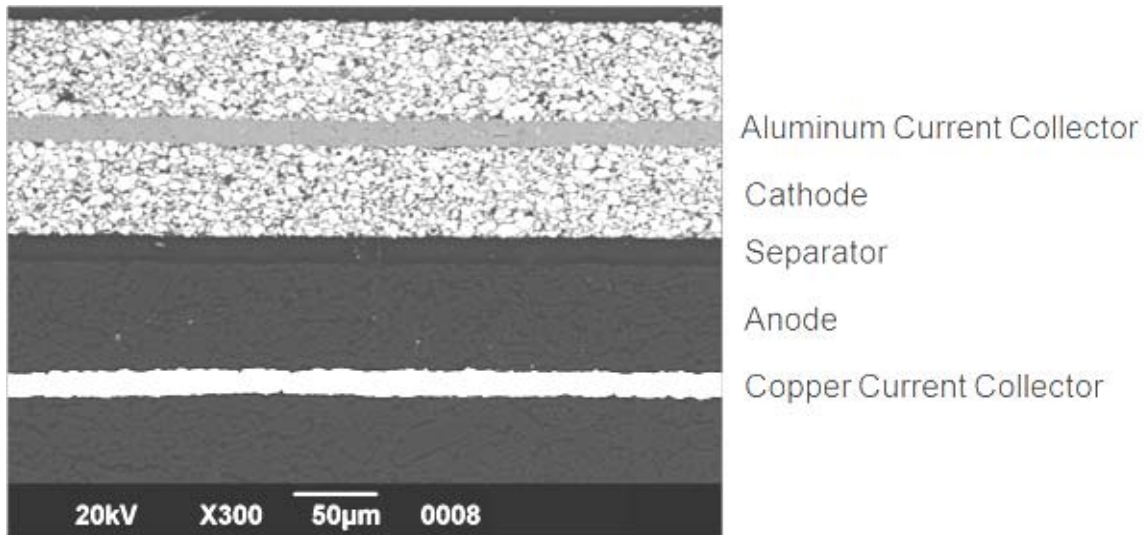


Figure 1. Backscattered scanning electron microscope image of an uncycled lithium ion cell showing one anode/cathode repeat unit

Improper cell design or operation of the cell outside of the manufacturer's specifications can produce failure modes that are readily identified and characterized by the cross-sectioning technique. One such example is shown in Figure 2, which shows a backscattered electron image of a prototype lithium-ion cell that was designed to satisfy the power and capacity needs of a specific application. Manufacturing and design flaws compounded to establish a condition during normal operation of the cell that caused severe over-discharge of the system.

Over-discharge of a lithium-ion battery cell results in the dissolution (electrochemical oxidation) of the copper negative electrode current collector. On the subsequent charge cycle, the dissolved copper re-deposits as metallic copper at other locations in the cell. In the SEM image on the left side of Figure 2, voids in the copper negative electrode current collector, formed by the dissolution of copper, are readily identified. The use of EDS with selectivity for copper (right image of Figure 2) confirms that metallic copper has been re-deposited at the surface of the negative electrode. The dashed red circle indicates a region where copper has re-deposited and formed a short-circuit between the negative and positive electrodes.

In this presentation, the impact of cell design, material selection and manufacturing quality on cell performance and safety will be considered. Analytical techniques developed to identify and quantify lithium-ion battery cell deficiencies, including computed tomography X-ray imaging, cell cross-sectioning, accelerating rate calorimetry and various electrochemical techniques, will be highlighted.

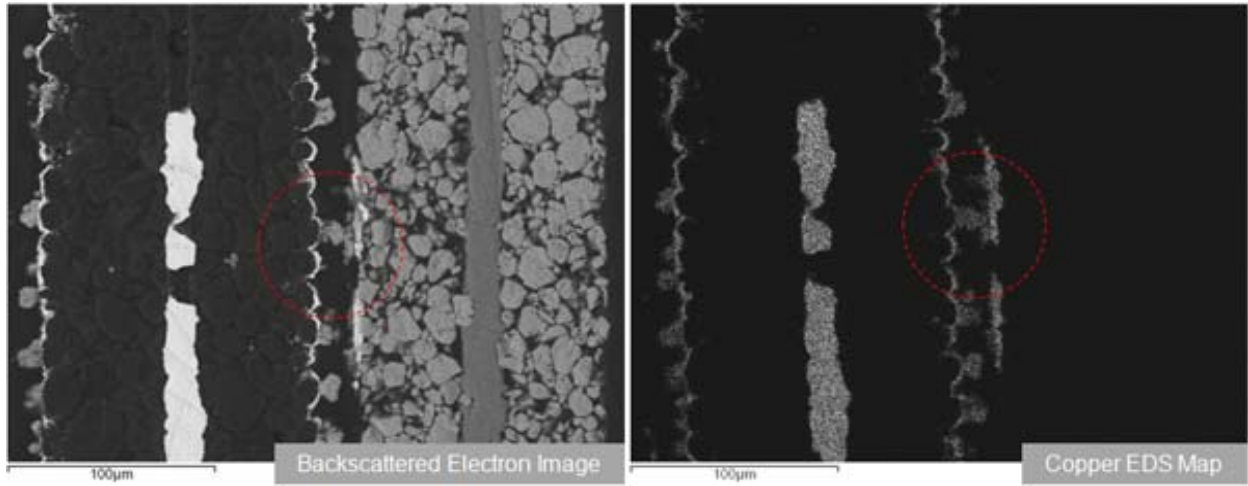


Figure 2. Backscattered scanning electron microscope image (left) and an EDS map (right) of the same region with selectivity for copper showing a short circuit comprised of copper between the negative and positive electrodes (dashed red circle). Bright pixels in the EDS map correspond to regions of high copper concentration.