Soteria Architecture Cell Materials

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Abstract: *Lithium ion batteries have utilized a layered construction with metal foil current collectors and poly separators for quite some time. In the presence of any defect which causes a short between the layers large currents will be delivered to the defect from the cell and any external cells in parallel via the solid metal conductors. The heat generated causes the separator to shrink and enlarge the short while the current collectors continue to be good conductors in the presence of the generated heat. This can lead to thermal runaway with temperatures rapidly rising until the flammability point of various cell materials is exceeded. Substantial safety and performance benefits can be achieved by using separators that do not shrink under high temperatures, and current collectors that break their conductivity under these conditions.*

Keywords: Current Conductor; Fuse; Safety; Light Weight; Energy Density.

Introduction

Traditional Lithium-ion cells use solid metal foils for current collectors and plastic separators as components of the basic cell sandwich structure. The metals are excellent at delivering current and are typically made of aluminum on the cathode side and copper on the anode side. Both metals have high melting temperatures with aluminum around 660 degrees C and copper close to 1085 degrees C. Current 1st generation separators exhibit significant shrinkage around 130 degrees C and 2nd generation (ceramic coated) separators add about 45 degrees C to this, maintaining their dimensions until around 175 degrees C.

The combination of the materials in a cell lead to a positive feedback loop under certain failure conditions. When an interlayer short develops, the solid metal conductors deliver higher than normal cell operational currents to the location of the short causing rapid heating of the immediate area around the defect. The quick rise in temperature causes significant shrinkage of the separator whose effect is to bring more of the positive and negative parts of cell into contact. This temperature rise is not sufficient to degrade the solid metal conductors, so they continue to efficiently delivery whatever current is available into the defect area. This forms a rapid positive feedback system that can see temperatures quickly rise past separator shutdown regions to the ignition point of the materials the cell is composed of and a thermal runaway is initiated. The elements are shown in the following diagram:

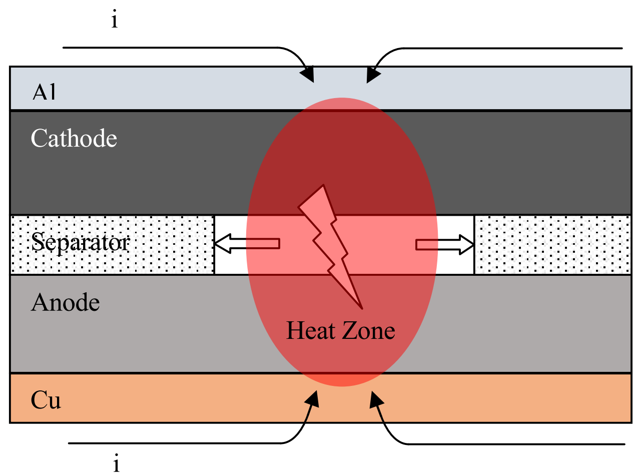

Figure 1. Defect in traditional cell architecture leading to thermal runaway

Note that i, the current delivered into the defect, can include not just the capacity of the cell but also any cells that are in parallel to the failing cell unless isolation is employed between parallel cells at the pack level. The short or defect (represented by the lightning bolt in the figure) can be any low impedance path through the separator between any of the materials of the cell but is most troublesome when conduction is made to one of the metal current collectors.

Possible latent defects include metal debris in the active materials and burrs in the foils that pass the hi pot test at manufacturing time but become active later. Damage to the cell in the form of a cell penetration by a conductive element, such as the well know nail penetration test also cause a similar positive feedback loop.

The Soteria Architecture

Soteria architecture cells are cells made with 3rd generation non-woven separators and metallized film current collectors. The combination of the two result in a cell architecture that breaks the positive feedback loop associated with thermal runaways. Each element contributes to the safety while also providing benefits to the energy density of the cell as the materials weigh less than those they replace. Safety is improved to the point where cell operation after catastrophic shorting is possible and demonstrated.

3rd Generation Separators

3rd generation separators exhibit much lower shrinkage to much higher temperatures than 1st and 2nd generation separators, as seen in figure 2.

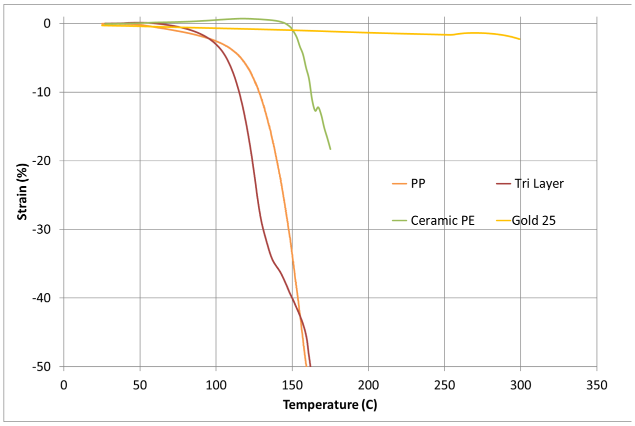

Figure 2. Shrinkage vs. Temperature in 1st, 2nd, and 3rd Generation Separators

Of note is that the ceramic coated separator extends the performance of plastic separators 45 degrees C or so, but when they reach a critical temperature, their strain slope is similar to the non-coated plastic. The non-woven 3rd generation separators exhibit very little shrinkage up to 300 degrees C and beyond and provide a much larger temperature margin to a shorted cell. Figure 3 shows post nail penetration separator differences between a Gen3 and Gen 2 separator.

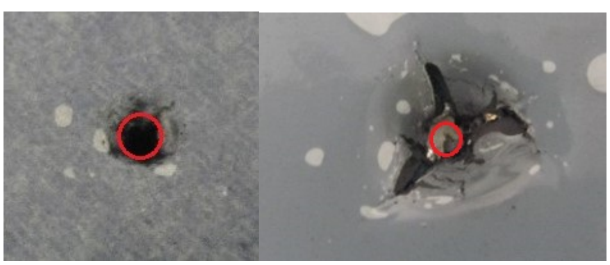

Figure 3. Post Nail Penetration Gen 3 (left) Gen 2 (right) Separators

The red circles designate the approximate size of the nail. Note the Gen2 separator has pulled away from the mechanical puncture area and also split as a result of the heating introduced into the short area no doubt enhanced by the extra area of the exposed electrodes.

The temperature stability of 3rd generation separators prevents one component of the thermal runaway positive feedback cycle, the enlarging of the shorted area due to heating. This is one pillar of the safety realized with Soteria architecture cells.

Metallized Film Current Collectors

The other pillar responsible for the safety is the use of metallized film current collectors. These are replacements for the copper and aluminum foils currently used. The metallized film consists of a substrate, like polyester, that is coated with a thin metal on both sides. This provides a electrical conductor capable of carrying the normal operating currents of the cell without any heating. However, when the current density is exceeded due to a shorting defect, the conductor disintegrates and breaks the conduction path from the rest of the cell.

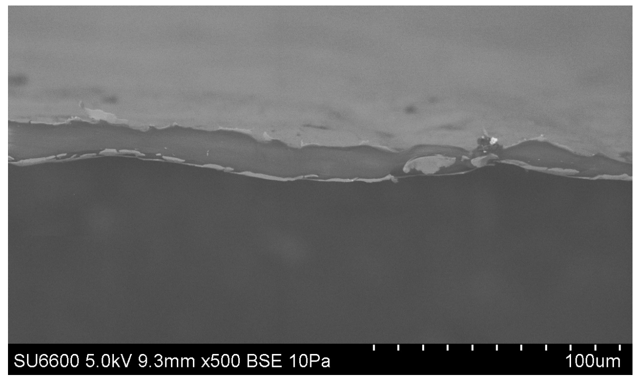

Figure 4. Scanninng Electron Microscope Photo of Metallized Film conductor

Both the thickness of the metal coating and the thickness and composition of the substrate are engineered quantities to adopt to the applications requirements. For our first cell builds, we have chosen 10um thick polyester substrate coated with 500nm of aluminum on each side for the cathode current collector and 700nm of copper on the same substrate for the anode. The thickness of metal on both sides is on the order of 1/10 the metal used in equivalent solid foil current collectors.

The effect of the thin metal coupled with the polyester substrate is to become a fuse when current density exceeds designed limits. There are two methods that act in concert to achieve this. First, when the temperature rise due to the increased current density reaches around 100 degrees C, the polyester begins to shrink. Next, as the heating continues, the metal coating exceeds its ability to carry current and disintegrates. The effect is that the conductor breaks where current density exceeds set levels. Increasing the metal thickness will move the current density limit up while decreasing the thickness will reduce the limit.

In Figure 5, a test strip that is 4 squares long is subject to steady state current with temperature and failure point monitored. A 10um film with 0.5um aluminum on both sides is compared to an equivalent 17um aluminum foil

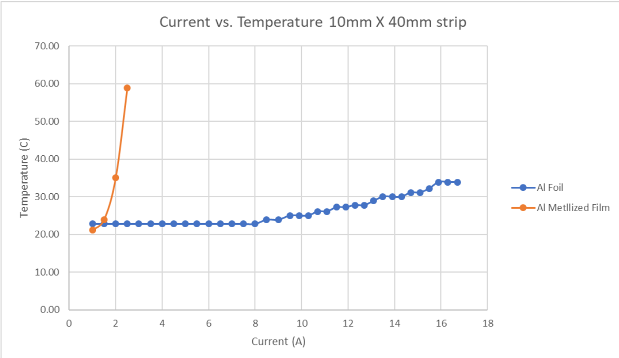

Figure 5. Metaillized Aluminum Film (.5um/10um/.5um vs. Foil (17um) Current Characteristics

Note that the film quickly heats and fails around the 2A point, while the foil exhibits minor heating and no failure up to 17A where the test was discontinued. This is steady state performance. Transient response is even better. In a test simulating a short forming in an active cell, the energy pulse necessary to blow the conductor is on the order of 4uJ for a sharpened point short on aluminum film and 40uj on copper film.

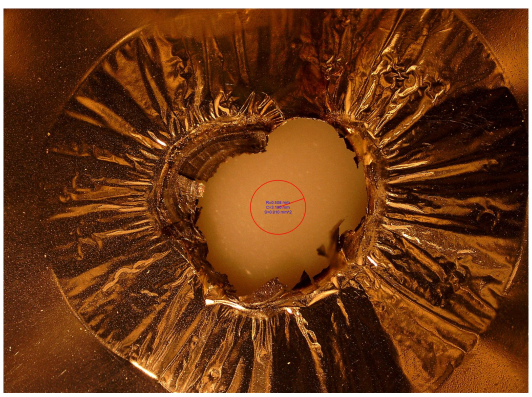

Figure 6. Metaillized Aluminum Film Point Short Area

Cell Testing

Cells using combinations of Soteria metallized current collectors in all combinations were built and tested. The cells were hand coated NMC pouch cells of ~500mah capacity with low rate (C/5) electrodes. Control cells using conventional foils for current collectors were built in the same batch to serve as a comparison. Cells all performed similarly in electrical testing with a few exceptions.

The DC impedance of the Soteria cells was a surprise given that the metallized foil conductors exhibit roughly 25 times the impedance of the solid foils. In Figure 7, we see the average DC impedance of each of the cell combinations with the control cells (both conductors solid foil) being the highest.

In figure 8, we see the 48 hour self discharge curves of all the cell build combinations, with the control cells being the most discharged at the end of the test period.

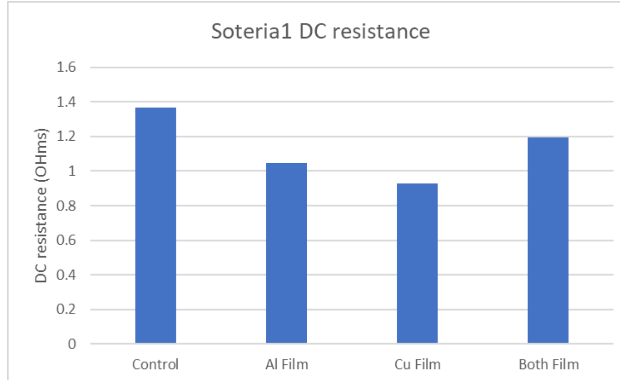

Figure 7. 48 hour Self Discharge Curves

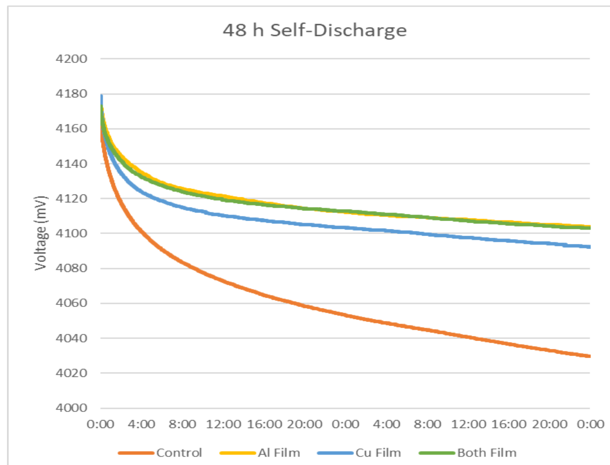

Figure 8 . 48 hour Self Discharge Curves

Cell Abuse Testing

Cells were subjected to nail penetration testing in the fully charged state. Recall that the subject cells are capable of C/5 rates due to their hand coated manufacturing. In figure 9, we see the voltage at the terminals of a control cell and a Soteria cell in response to a 3mm nail being driven completely through the cells.

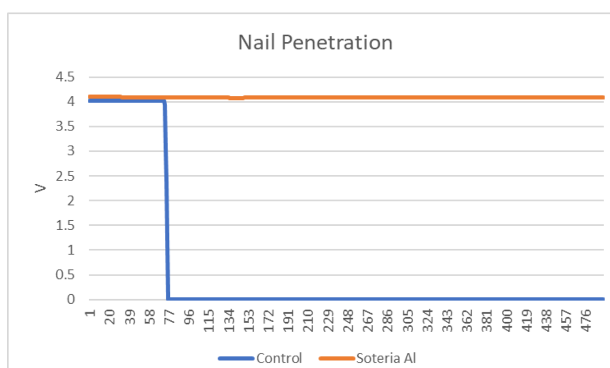

Figure 9. Nail Penetration Test voltages

The control cell immediately goes to 0 volts and begins heating, as shown in Figure 10, left. The Soteria cell exhibits no detectable change in its terminal voltage, and remained at room temperature throughout the duration of the test as seen in Figure 10, right below.

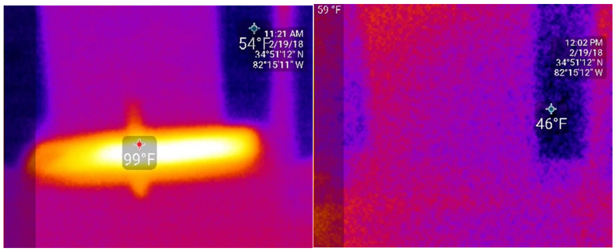

Figure 10. Control Cell (left) and Soteria (right) Thermal Image of Nail Penetration Test

The Soteria cell functioned as a cell during and after the nail penetration test. The cell, with the nail still embedded, was still functional and delivering power, of course at a reduced level, and eventually, due to electrolyte loss stopped functioning.

Material Data

Soteria cell materials are production friendly on current roll to roll cell manufacturing equipment. Dreamweaver Gold separator has been used in production environments successfully. Both copper and aluminum coated films have been built into cells and will be used in a series of cell builds that progressively prove out more elements of the production process.

Film Property	10 um Soteria Aluminum	10 um Soteria Copper
Thickness (um)	10	11
Metal Coating Thickness(nm)	500	700
Weight (g/m^2)	16	29
Tensile strength (N/mm^2)	160	>150
Elongation (%)	>50	>50
Resistance, double sided (mΩ/□)	26	11

Figure 11. Soteria Metallized Foil Material Data

Note that the 10um Soteria aluminum film has very similar tensile strength to 15um thick aluminum foil, typically quoted at 150N/mm^2. This similarity in strength with better elasticity yields similar coating and handling properties on roll to roll coating equipment.

Basic Membrane Property	Unit of Measure	USABC Requirements	Dreamweaver Gold™ 20
Thickness (12.6 psi)	µm	<25	22
Thickness (25 psi)	µm	<25	21
Gurley (JIS)	seconds		300
Porosity	%		37%
Pore Size	µm	<1.0	0.4
TD Shrinkage @ 280 C/1 Hour	%		1
MD Shrinkage @ 280 C/1 Hour	%		2
TD Strength	Kgf/cm^2		500
MD Strength	Kgf/cm^2	>70	800
Young's Modulus	Kgf/cm^2	>5,000	15,000
Melt Integrity	C	>200	500
Puncture Strength	gf	>300	
Moisture Content	%	<0.0005	6%

Figure 12. Dreamweaver Gold 20 Material Data

Both materials are lighter than the materials they replace while being dimensionally similar which results in an energy density increase at the cell level. Depending on the characteristics of the cell, energy densities can increase 10-20%.

Summary

Soteria architecture cells are built with existing manufacturing infrastructure friendly materials that replace currently used separators and foils. The result is a safer, lighter cell. Current cells that adopt the architecture can expect increased energy density due to lighter weight and a new level of safety that extends to the possibility of operation after damage.