



Using Lithium Polymer Batteries In Portable Devices

INTRODUCTION

Lithium polymer batteries have become common in single-cell consumer applications like cell phones and MP3 players, but industrial and commercial applications are now putting them to good use as well. The thin and custom shaped cells are now used in large, complex packs. This white paper is an overview of the advantages, disadvantages and guidelines for using Lithium polymer based battery packs. It looks at Lithium polymer cells versus metal-cased cylindrical and prismatic Li-ion cells and gives a brief description of battery pack construction considerations.

Both the Lithium-ion (Li-ion) and Sealed Lead Acid (SLA) battery markets are expected to grow over the next several years. Applications with high voltage and capacity requirements are adopting Li-ion technology because of its many advantages- especially the high energy density, small size and low weight that this technology provides. Historically, SLA batteries have had a few superior technical traits, in addition to their extremely low cost, that have kept them leading the majority of the overall battery market. However, recent innovations in Li-ion chemistry has made it extremely competitive in markets that are weight sensitive and inconvenienced by SLA's need for frequent maintenance. Many devices have required batteries for power back-up and these are primed for direct Li-ion replacement of SLA. In the medical market alone, these applications include infusion pumps, ventilators, wheelchairs and workstation carts. This paper will outline the technical and business considerations involved in converting an existing product from SLA to Li-ion.

USING LITHIUM POLYMER BATTERIES IN PORTABLE DEVICES

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HISTORY OF RECHARGEABLE CELLS

Sealed Lead Acid (SLA) and NiCd batteries used to be the only options for portable equipment. While these chemistries still have the advantage of lower cost and large operating temperature ranges, their low energy density requires big, heavy packs. Lithium ion (Li-ion) battery systems are a good option for lower weight, higher energy density or aggregate voltage, or greater number of duty



cycles. Each chemistry has unique characteristics that affect how it performs in a particular portable device. The specific characteristics in terms of voltage, cycles, load current, energy density, charge time, and discharge rates, must be understood in order to specify an appropriate cell for an application.

Li-ion cells come in three basic form factors: cylindrical, prismatic (rectangular brick shape) and the flat Lithium polymer cells. The most commonly used Li-ion cell is the cylindrical 18650 cell. Several million cells per month are manufactured. They are used in most notebook computer applications. The 18650 offers the lowest cost per watt hour. 18 refers to the cell diameter in millimeters and 65-zero means that it's 65 mm long.

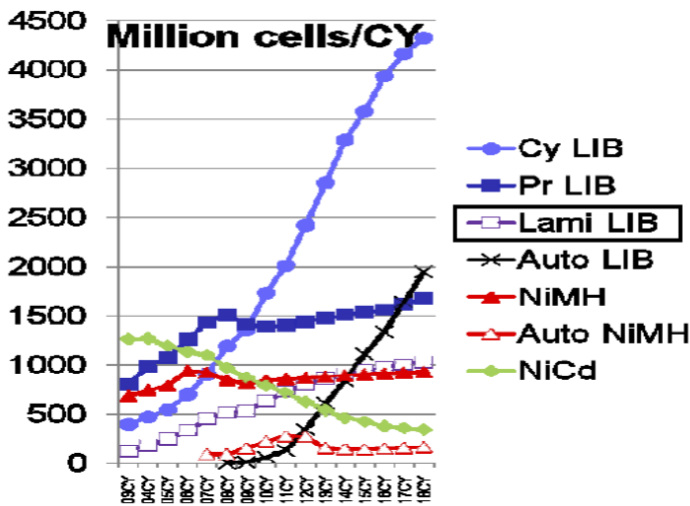
Prismatic or brick shaped cells are often cost effective and are available in a myriad of sizes. They also come in



a variety of heights ranging from about 4 mm to about 12 mm. The most common size is the 50 mm length and 34mm width foot print.

Lithium polymer cells, sometimes called laminate cells, are available in custom footprint size. They can be very thin or quite large depending on their intended use.

The graph shows the market growth predicted over the next decade for various types of rechargeable cells (including automotive Li-ion batteries). All of the Li-ion cells are overtaking the Ni cells in almost every market. The cylindrical and automotive batteries are predicted to have astronomical growth. Lithium polymer batteries, shown in violet, are predicted to become quite common with manufacturers producing 1 billion cells per year by the end of this decade.



MARKET DIFFERENTIATION WITH LITHIUM POLYMER

The primary advantage of Lithium polymer batteries is the variety of form factors available. Manufacturers of blue tooth devices were the first to recognize the advantage of Lithium polymer batteries. The availability of very thin batteries enabled the Motorola Razr phone to have great market success. Apple created a thin notebook which differentiated it in the highly commoditized notebook market.



The illustration above is one of the first medical products to make use of the thin Lithium polymer form factor, a digital x-ray plate that is thin enough to fit in conventional film x-ray cassettes.

HISTORY OF LITHIUM BATTERIES

At one time a polymer battery had a solid polymer electrolyte such as Polyethylene oxide and a salt, but no liquid electrolyte. Cells using these solid polymer electrolytes typically had lithium metal anodes which become unstable during cycling. The other problem with these solid polymers is that they have poor conductivity at room temperature; batteries using them can only function at elevated temperature, such as 80°C. These two factors prevented any mass commercialization of that technology.

In the 90's, Bellcore Labs came up with a Li-ion battery that used a cast porous polymer film to bind the electrodes together as well as electrically insulating them from each other. Liquid electrolyte was added and then gelled to bind it into the polymer matrix to some degree. Many companies tried and failed to commercialize this process, although some aspects of it are used in Lithium polymer cells today.

Today's Lithium polymer cells have a different design. Their defining feature is a flexible, foil-type (polymer laminate) exterior. They still contain organic solvent. There are a wide array of different technologies used to produce these batteries - some have liquid electrolytes, some are gelled by inclusion of polymers in the electrolyte, some have the layers laminated together and others may be have their electrodes stacked rather than wound. The chemistry is the same as Li-ion. Basically, it is a Li-ion battery in a soft pack.

DIFFERENCES BETWEEN LITHIUM POLYMER AND OTHER LI-ION CELL COMPONENTS

Lithium ions move from the negative electrode to the positive electrode during discharge and reversely when charged. The three primary functional components of a Li-ion battery are the anode, cathode, and electrolyte, for each of which a variety of materials are used. Commercially, the most popular material for the anode is graphite, but some manufacturers use coke. The cathode is generally one of three materials: a layered oxide (such as lithium cobalt oxide), one based on a polyanion (such as lithium iron phosphate), or a spinel (such as manganese).

Means of Electrode Separation:

Li-ion cylindrical and prismatic cells use a discrete porous polymer membrane – usually polyethylene (PE) which is placed between the electrodes. Once assembled, the cell is backfilled with electrolyte solution.

Lithium polymer uses a PE, polypropylene (PP), or PP/PE separator. Some Lithium polymers use polymer gel containing the electrolyte solution which is coated onto the electrode surface. The structure may then be laminated before packaging.

Construction:

- Li-ion cylindrical and prismatic material layers are rolled (like a jelly roll).
- Lithium polymer can either be rolled or stacked like a deck of cards.

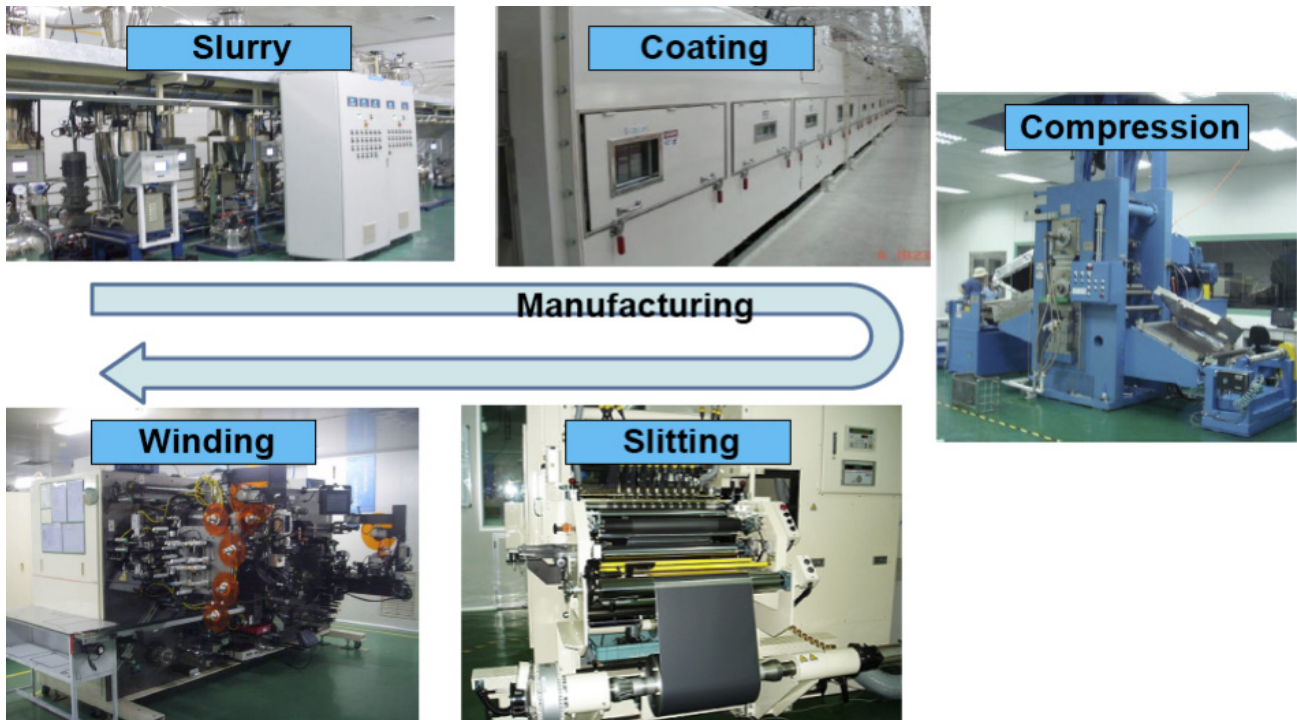
Packaging:

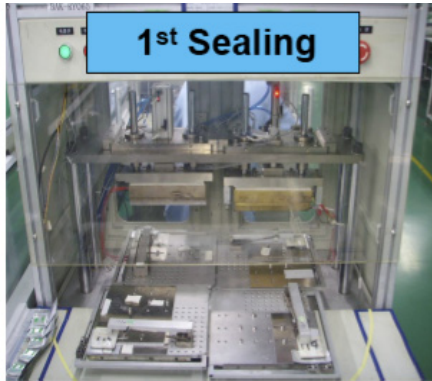
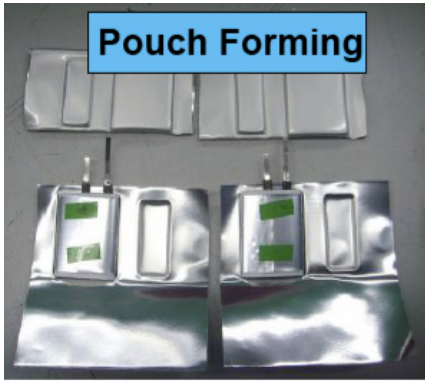
- Li-ion cylindrical and prismatic cells are packaged in metal cans.
- Lithium polymer is packaged in a flexible “coffee bag” material.

LITHIUM POLYMER MANUFACTURING PROCESS

Because the chemistry and internal structure is the same as for conventional Li-ion cells, the front end of the manufacturing process is essentially unchanged. All of the same automated high-throughput equipment can be used. This helps to control costs and maintain product quality and consistency. With lithium iron phosphate is that unchecked trickle charge will overcharge the cells.

The first step is making slurry; the electrode powders are mixed with binders and dispersed like a paint in either water or solvent.





Next the slurries are coated at very high precision onto the foils to make rolls of the two electrodes: anode and cathode.

The electrodes are then compressed at high force to get as much material as possible into the cell in order to maximize cell capacity.

These wide rolls of compressed electrodes are then slit into several spools with the correct width for the cell being made.

Then the winder process welds on the tabs, applies several pieces of insulating tape and winds up the electrodes with interposing separators to make a jellyroll. Another way to make Lithium polymer cells is by cutting out rectangular sheets of electrodes and stacking them, with separator layers in between. In that case a punching and stacking machine is required instead of a winder.

Where the process diverges is with assembly; Lithium polymer assembly tends to be semi-automatic giving it the advantage of faster and less expensive conversion to new cell sizes versus the highly automated cylindrical cell process which makes changing sizes very expensive and

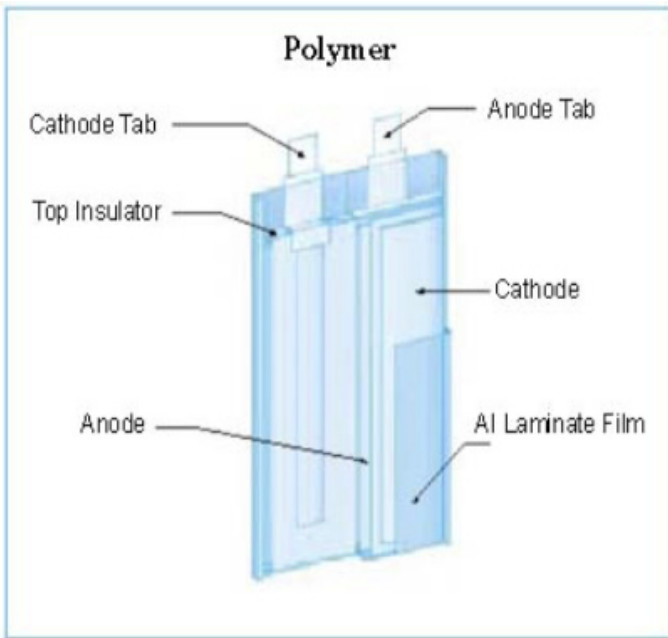
time-consuming. Polymer assembly lines can also be fully automated, but then lose some of the size flexibility.

The first step of assembly is forming pouches for the cells. The laminated packaging material is typically about 100 micrometers thick, consisting of 5-7 layers with differing functions. In the middle of the laminate is an aluminum layer that serves as a moisture barrier, the same function as in food packaging. Since Li-ion cells will react with moisture, this layer is vital for long life in the battery.

Once the pouches are formed, the jelly rolls or decks are inserted and then heat sealed, leaving an opening for electrolyte filling. The electrolyte is then filled and the opening to the package is sealed.

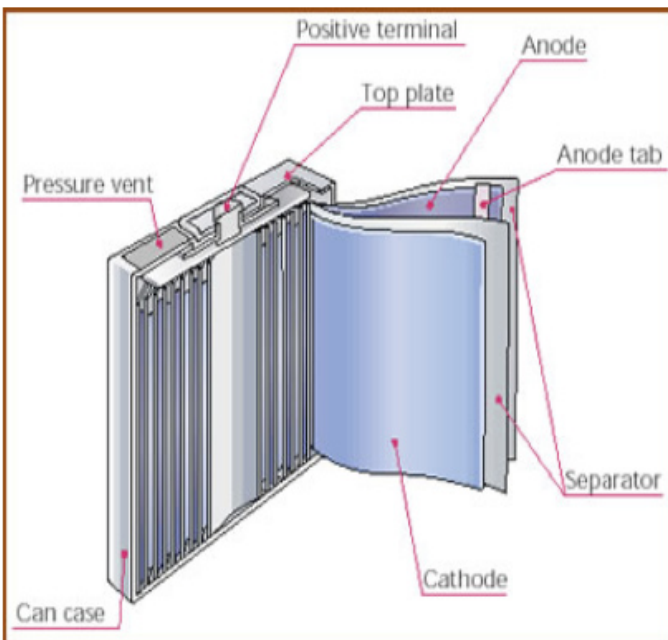
Next is an x-ray check to make sure that the electrodes are properly aligned before sending the cells to formation.

The formation process is the first charge, a proprietary method that contributes to stability of the cell performance. There are two compartments in the pouches, one for the jellyroll and the other is a pocket to accept the gasses produced during the formation cycle. After formation, these gas pockets are sealed off from the cell and removed.



Finally, the cells are tested in order to remove substandard cells, and the good cells are sorted for capacity and charged up to ~50% state of charge for shipping.

A Li-ion prismatic with a metal can and jelly roll is on the left. The thin layered polymer is on the right. Another feature to note is that the prismatic cell has a pressure vent with the terminals on the metal can. The positive and negative terminals on the polymer cell are tabs protruding from the cell.



ADVANTAGES OF LITHIUM POLYMER BATTERIES

They can be made very thin, down to around half a millimeter. However, much of the space is wasted by the packaging at the bottom of this range so cells typically range from 2 to 6.5mm thick.

The length and width can be made quite large. Cell capacities can range anywhere from 50mAh for a small cell such as for a Bluetooth headset, up to 10Ah or more for an electric vehicle battery.

The lack of a metal can allows more flexibility to change sizes per customer requirement. This flexibility exists for several reasons. First from a components supply standpoint, the laminate material is just slit to different widths rather than requiring a can supplier to produce new tooling to manufacture some new can size. Also the heat sealing process is easily modified compared to crimping for cylindrical cells. For prismatic cells, laser welding can also be easily adapted, but large, flat aspect ratios are problematic for assembly.

Typically turnaround times are less than 90 days from customer request to UL qualified samples.

DISADVANTAGES OF LITHIUM POLYMER BATTERIES

Their flexibility does come at a small cost premium. Lithium polymer cells are more expensive per watt hour



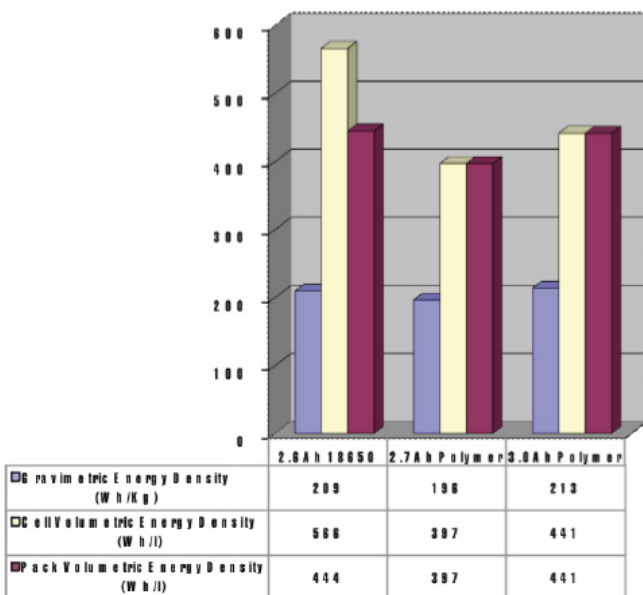
compared to other types of Li-ion cells for several reasons. The high quality laminate material and the special tabs that allow sealing against the bag are expensive. Secondly, the lower speed of manufacturing increases both labor and overhead costs. Finally, while lower production runs allow for size flexibility, it results in lower yields and higher prototyping costs.

The soft packaging on polymer cells is easily punctured and has more swelling than metal cans.

Another disadvantage of a Lithium polymer cell compared to a cylindrical cell is less volumetric energy density. This is because cylindrical cells do not bulge due to their extremely strong shape, so very high electrode densities can be used. Also the selection of materials is easier because small amounts of gas produced by a cylindrical cell have no effect on its performance or shape. The same is not true of Lithium polymer cells. However, this disadvantage in energy density can be overcome by the advantage in packing density. In addition to the lost space between cells, cylindrical cells are a fixed size, mostly 18mm diameter, so they may not be able to make use of all the space available in an application.

IMPROVED PACKING EFFICIENCY

Per the chart below, a single 2.7Ah 624199 Lithium polymer cell has similar Wh/kg (blue) to a 2.6Ah 18650 but

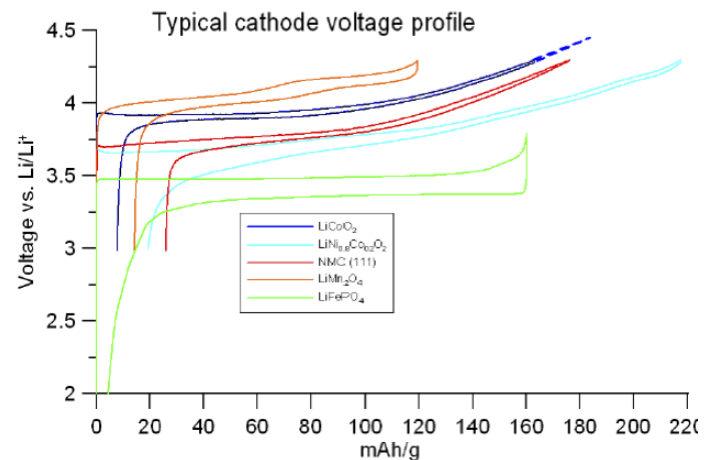


a lower Wh/l. But when looking at the Wh/l when 18650s are packed into a rectangular box, they are pretty close. Later this year the capacity in this size will increase to 3Ah for Lithium polymer cells, bringing the pack energy density up to the equivalent of a 2.6Ah 18650.

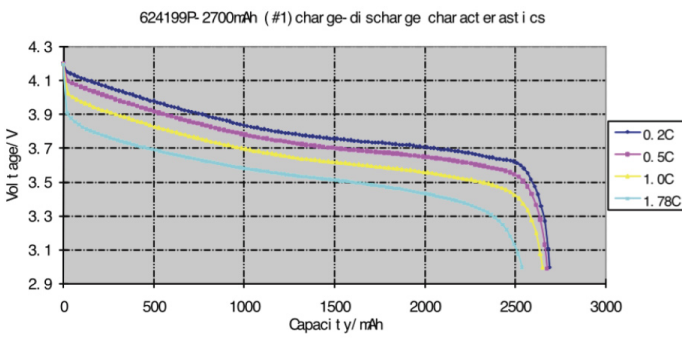
VOLTAGE PERFORMANCE CHARACTERISTICS

The OCV profile does not depend on the packaging but on the active materials inside. Below are the voltage curves of all of the cathode materials used in Li-ion batteries. From highest to lowest voltage, these are Manganese Spinel, Cobalt Oxide (CO), Nickel Manganese Cobalt (NMC), and Iron Phosphate. The vast majority of Li-ion cells, including Lithium polymer cells, are CO, NMC or a blend of the two so the voltage ranges should be the same from 3V on the low end to 4.2V at the top of charge.

DISCHARGE RATE CAPABILITY OF LITHIUM POLYMER CELLS



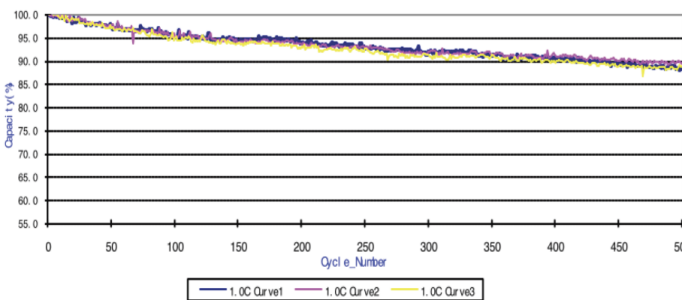
While Lithium polymer batteries using solid polymer electrolytes suffered from poor conductivity and gelled polymer cells had higher impedance due to the high viscosity of their electrolyte and lower ionic mobility, these issues can be overcome with cell design and the use of liquid electrolytes. Below is an example the discharge profiles of a 2.7Ah cell used for notebook PC applications, discharging at up to 4.8A or 1.78C, on par with 2.6Ah



18650 cells. Low temperature performance is also available. Lithium polymer cells are often an option as long as the correct cell is selected. a lower Wh/l. But when looking at the Wh/l when 18650s are packed into a rectangular box, they are pretty close. Later this year the capacity in this size will increase to 3Ah for Lithium polymer cells, bringing the pack energy density up to the equivalent of a 2.6Ah 18650.

LITHIUM POLYMER CYCLE LIFE

Both Lithium polymer and prismatic cells tend to have better cycle life than cylindrical cells because they are not so tightly constrained, allowing the electrodes to expand and contract more freely during cycling. Below is a graph of the 1C charge, 1C discharge cycle life of a 2.7Ah cell. It is still retaining 90% after 500 cycles. There are newer designs coming that achieve 95% after 500 cycles, and should exceed 1000 cycles.



SUMMARY OF ADVANTAGES AND LIMITATIONS OF LITHIUM POLYMER BATTERIES

Advantages:

- Very low profile — Batteries that resemble the profile of a credit card are available.
- Flexible form factor — Manufacturers are not bound by standard cell formats. With high enough volume, any reasonable size can be produced.
- Light weight – Gelled rather than liquid electrolytes enable simplified packaging.
- Available as thin form factor with high capacity (10+ Ah) or high current (50+ Amps) cells.

Limitations:

- Packaging is fragile and could compromise cycle life.
- Specialized tools are required for joining cells.
- More susceptible to swelling.
- Minor price premium over cylindrical cells (\$ / Watt-hr)

POLYMER CELL CONSIDERATIONS

Puncturing a cell is a much larger risk for a Lithium polymer cell compared to one in a steel or aluminum can. A punctured cell can cause an internal short circuit, which will cause the cell to get hot. Even if it does not short the cell, a leak may allow moisture in, eventually causing the cell to self-discharge and die. The cell may also swell from the reaction of the anode with moisture. Special care must be made in handling the cells and in the pack design so that there are no sharp objects that could come into contact with the cells.

Edge shorting is another often overlooked issue. The aluminum layer in the packaging is conducting so if it is exposed at the cut edges of the package, it can short out components that are put in contact with it. In addition, there are internal corrosion reactions in the cell that can occur if the tabs to the aluminum layer are shorted. This could happen if the tabs are bent over the edge of the

packaging. Again, careful handling and good pack design is required.

Over-discharge damage is an issue for all Li-ion cells but the resultant gassing in Lithium polymer cells is more obvious. When the cell voltage drops too low (~1.5V), reactions at the anode start to produce gas. As the voltage continues to drop under 1V, copper from the anode current collector starts to dissolve and will short out the cell. Over-discharge should be prevented by the BMU.

Overcharge is similar. Gassing occurs at the cathode as the electrolyte starts to decompose at high voltage (~4.6V). Cylindrical cells have integral pressure activated current interrupt devices (CIDs) to stop the overcharge when the gas pressure builds. Polymer cells do not have any CID. Although their swelling helps to prevent further overcharge by increasing the cell impedance, this should only be a final failsafe. An external thermal fuse is usually added for overcharge protection, in addition to the control by the charger and BMU.

An external short circuit can cause swelling due to heat and over-discharge. Cylindrical cells have an integral PTC (positive thermal coefficient), a device that expands and creates high impedance when it is heated or self-heats due to the high currents experienced during an external short circuit. Polymer cells do not have this integral PTC so an external PTC or thermal fuse can be added for shorting protection.

LITHIUM POLYMER PACK CONSTRUCTION CONSIDERATIONS

Battery packs made with Li-ion chemistries are not a simple configurations of cells. They are carefully engineered products with many safety features. The main components of a battery pack include the cells - the primary energy source, the printed circuit board - the intelligence of the system, the plastic enclosure, external contacts, and insulation. Only recently have commercial and industrial applications started using Lithium polymer. Here are some special guidelines for battery pack construction with Lithium polymer cells.

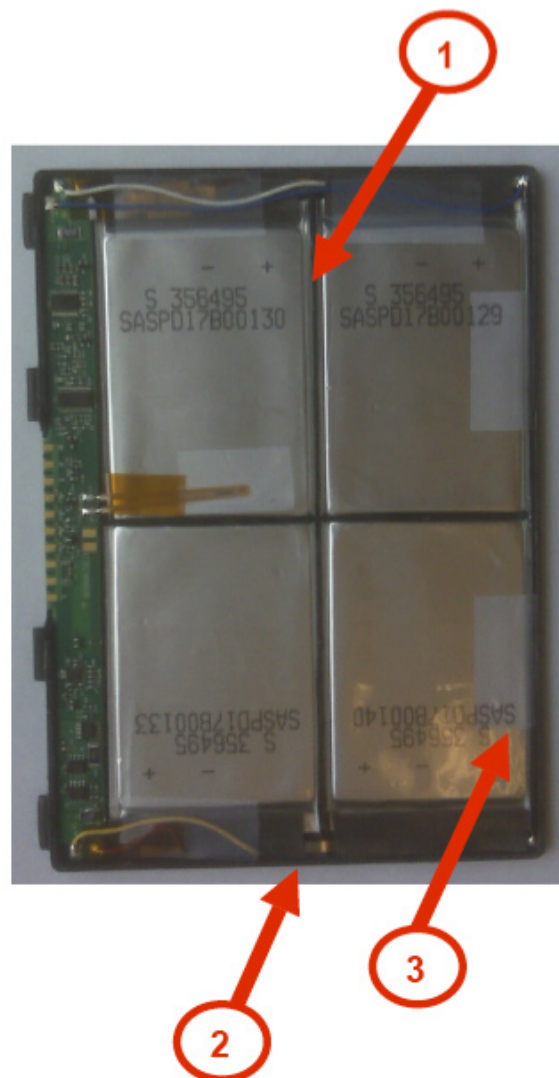
Mechanical Guidelines:

Since the cells are not rigid, ribbing (1) is put between cells to prevent crushing and twisting of the pack.

Resistance welding to the tabs (2) is recommended to prevent heat from soldering from melting the cell's packaging.

The cells need to be secured within the enclosure to prevent shifting during shock and vibration (3).

Stacking the cells prevents issues caused by cell swelling (up to 10% of cell thickness should be anticipated for Lithium polymer and li-ion prismatic cells). On the other hand, cell stacking should be avoided for high current applications because stacking creates thermal management issues.



Electrical Guidelines:

The thermistor(1) is a safety feature, which needs to be against the cell but away from areas most likely to swell.

External short circuit and over-temperature protection is required on the battery management circuit board (2) since there is no PTC or short circuit protection within the cell.

As in all Li-ion battery packs, cell matching is very important since voltage differences among cells affect the discharge and charge characteristics, significantly reducing cell capacity.

