White Paper

Introduction to Lithium Polymer Battery Technology

Contents

Small, variable power packs

Lightweight, flat, powerful, long-lasting. And astonishingly variable in design and capacity. These are the advantages that set lithium polymer batteries apart. They stand out from other types of lithium batteries in a whole range of other factors. They are also a recommended alternative to conventional lithium-ion batteries in countless applications. In small, flat, mobile devices in particular they can guarantee a constant energy supply. This white paper provides an introduction to lithium polymer battery technology. It contains some important information on the design of housings and on how to handle these energy accumulators.

I. History of the lithium battery

Rechargeable batteries have been in existence for over 150 years. The first was the lead battery. This was followed by the nickel-cadmium battery. Major developments began to be made during the 1990s. Nickel-cadmium technology began to be replaced by nickel metal designs.

The functional principle of electrode-chemical systems for use in batteries continued to occupy minds in science and industry. New principles for the reversible storage of ions for the purpose of energy storage were developed during the 1970s at the Technical University of Munich. Electrodes based on lithium (Li) compounds ultimately proved to be effective and promising.

In 1980 a decisive step was made at the University of Oxford towards a lithium-ion battery. A lithium-cobalt dioxide compound was developed as the material for the positive electrode. Rechargeable batteries based on lithium turned out to offer a three-times greater voltage per cell (3.6 V) over earlier technologies. This means, for example, that only one cell is required for the GSM chip in a mobile telephone. Li systems are significantly lighter than their predecessors.

The first commercially available Li-ion battery was brought out by the Sony company of Japan in 1991. It was used to power a video camera and in notebooks.

In the following years mobile communications reached the mass market and acted as the driver for the use of smaller cells with high power density. At first, mobile telephone manufacturers used nickel metal hydride (NiMH) batteries for power storage. They were heavier than today’s solutions, but at the time they were the newest technology.

One of the first mobile telephones to use Li-ion batteries was the Siemens S4 (Fig. 1). This model came onto the market in the mid-1990s. The manufacturer fitted it with two cylindrical cells in 18650 format. Soon after this, mobile telephones with prismatic Li-ion cells came onto the market. Manufacturers included Asahi, Toshiba and Varta.

In 1999, with the TS28s, Ericsson introduced one of the first mobile telephones with lithium-polymer (LiPo) cells to the market (Fig. 1). At the time the unit was very small and sensationally flat.

After this milestone, Li-polymer battery technology began to be marketed in earnest. It enabled extremely flat batteries to be used. This had consequences for the design of the device. These could be designed thinner than devices that used Li-ion batteries or round cells, which alone require 10 to 18 mm of diameter.

Fig. 1. Trendsetters for mass use of Li-battery technology: Siemens S4 (left), Ericsson TS28s (right). Images: manufacturer photos

Today, use of Li-ion and Li-polymer batteries represents a mass market. They provide the energy storage for billions of electronic devices, smartphones, wearables and many other items of mobile and stationary equipment. Li-polymer cells were what made ultra-lightweight, thin notebooks, tablets and smartphones possible in the first place. According to market forecasts, sales of Li-based batteries will grow by some 15% each year until 2024.

No practicable alternative to Li-ion and Li-polymer batteries is currently known to science. It is intended that replacement materials can be found for the electrodes in future, since the metals used up to now (cobalt, etc.) are finite.

II. Properties and distinguishing criteria

The principle of operation and construction of Li-polymer batteries are identical to those of Li-ion batteries. These batteries operate on the principle of deintercalation and intercalation of lithium ions from positive electrode materials to negative electrode materials.

The sandwich-like cells (Fig. 2) consist of a graphite electrode (negative), a lithium metal oxide electrode (positive), and a separator layer. The lithium metal oxide is based on manganese, nickel or cobalt oxide compounds or a mixture of them.

In certain cells with a lower voltage level, iron phosphate is used as an alternative in the form of Li-iron phosphate cells. The composition affects the properties of the battery and varies by manufacturer and quality grade.

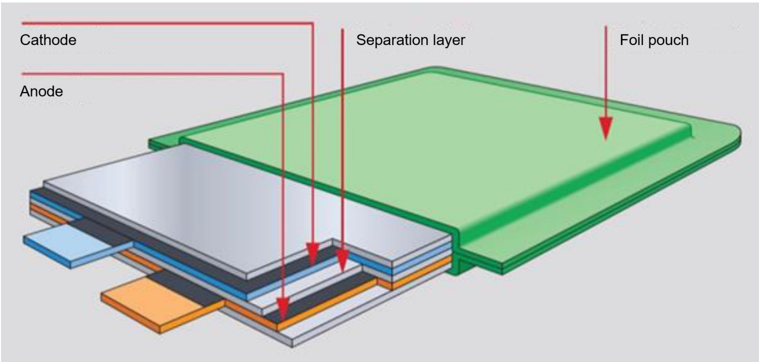

Fig. 2. Basic construction of Li-ion cells. Diagram: © University of Siegen

Significant criteria that distinguish Li-polymer batteries from other types of cell:

- **Li-ion cells** have a fixed housing in stainless steel or aluminum. The housing is usually cylindrical in form ('round cells'). Rectangular shapes are, however, also available.

  Disadvantages: relatively high tool costs for housing manufacture; restricted dimensions.

  Advantages: robust, mechanically strong housing, making the battery difficult to damage. A laser welding process seals the cells.

  Li-polymer cells, also known as soft or pouch cells, have a thin and somewhat 'soft' housing – like a pouch – made from deep-drawn aluminum foil. The mostly prismatic housing can be produced more easily and cheaply than the hard cases of Li-ion cells. The other components, in wafer-thin layer foils (< 100 µm) can also be mass-produced at relatively low cost.

  The cells are lightweight, thin and can be made in a wide range of shapes and sizes. Both large formats and heights of less than 1 mm can be achieved. The cells do, however, require careful mechanical handling.

The housing foil is coated on both sides with plastic. Inside: polyolefins, resistant to the cell components. Outside: polyamide, resistant to the outer environment. This waterproof laminate is welded and surrounds the cell comprising cathode, anode, and separator.

The execution of the deflector in the area of the terrace was a critical point. An additional foil welded to the deflector increases the sealing in this area of the welding of the ‘housing’.

- **Electrode set:** In Li-polymer batteries the electrode set comprises a carbon-based substance (graphite+additives) pasted onto a metallic substrate. The cathode consists of three-dimensional, lithiated cobalt oxides or nickel/manganese/cobalt (NMC) mixed oxides, also pasted onto a metallic substrate.

  Deflectors are present on both electrodes. They are wound around the core together with the separator, normally a three-layered polyolefin. The core generally consists of a flat pin in order to create the rectangular winding. The winding sits in the bottom of the pouch foil, which is partly folded and laid over the winding. The seal is created by welding the foil.

- **Design:** An advantage is the almost limitless range of sizes and formats thanks to the lack of a rigid steel housing and the compact construction. In particular, the possibility of designing very flat cells sets Li-polymer battery technology apart. Such batteries can be thinner than 1 mm.

  This results in significant design freedom for the end product. Individual dimensions can be realized even for small batch sizes, while the space reserved for the battery can be used to its full potential.

- **Energy density:** The energy density of these cells is higher than that of other types. Relative to their overall weight, Li-polymer cells have a slightly higher energy density than Li-ion cells. Like Li-ion batteries, they can be easily connected in parallel to allow higher capacities.

- **Self-discharge:** A further advantage of LiPo cells is their relatively low rate of self-discharge. They should nevertheless be protected from overcharging, deep discharge and extreme temperatures.

- **Approval:** The spread of Li-polymer cells on the market confirms the advantages and acceptance of this technology. Many of the cells on the market are certified to UL 1642. Before a particular cell is used, it should be verified whether it has a UL approval and whether the manufacturer has the tools required for production.

III. Production steps

The manufacture of Li-polymer cells can be divided into about ten steps (Fig. 3). Additional to these are quality checks and inspection processes.

- First, the electrode materials are mixed and prepared (material mixing).
- The mixture is pasted onto metallic substrates (coating).
- This is followed by drying, calendaring and slitting. Calendaring means rolling the material out to the desired thickness.
- The slitting process brings the electrode bands to their planned final dimension.
- Deflectors are attached to both electrodes (electrode assembly).
- They are wound around the core together with the separator, usually a three-layered polyolefin (winding). The core consists generally of a flat pin.
- The winding is placed in the cavity of a foil, which is partly folded and laid over the winding. The foil is welded to seal the sides.

These processes can be carried out in a normal atmosphere. The subsequent steps place higher demands on the production system.

- The packed winding must be dried in a vacuum under complete exclusion of moisture.
- Next is the injection of the electrolyte with the conductive salt, the degassing and the sealing of the cell.
- Since the cells are manufactured in a discharged state, they must now be formed and activated. The first charging takes place at this stage (electrical activation).
- The process is completed with tests of voltage over time (in which cells with short circuits are removed), capacity, quality and safety (x-ray full inspection and packaging inspection).

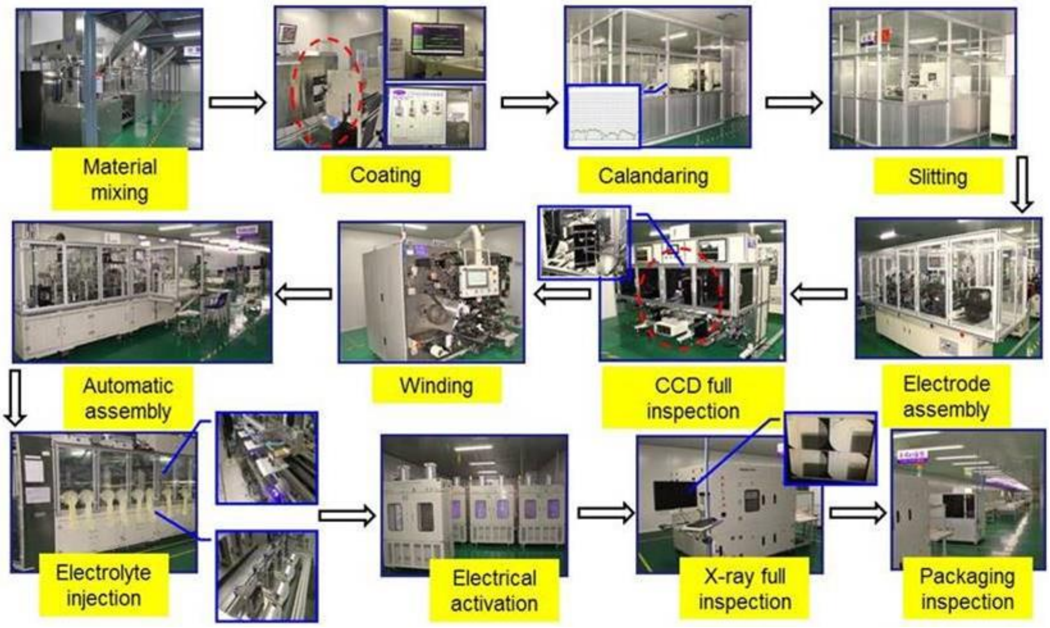

Fig. 3. Process steps in the manufacture of Li-polymer cells. Images and diagram: Jauch

IV. Chemical principles

During the first charge at the activation/formation stage, lithium from the cathode passes through the electrolytes and is stored in the graphite-based anode (intercalated). This action expands the gaps between layers and the cell thickness increases.

The discharge of the cell reverses this process; the cell thickness decreases again. The conductive salt most frequently used for the organic electrolyte medium is lithium hexafluorophosphate (LiPF6).

The expansion of the cells (up to 10%) during the cycles must be allowed for in the design of the battery compartment.

The following illustration (Fig. 4) shows the chemical mechanism within the cells in Li-polymer battery technology.

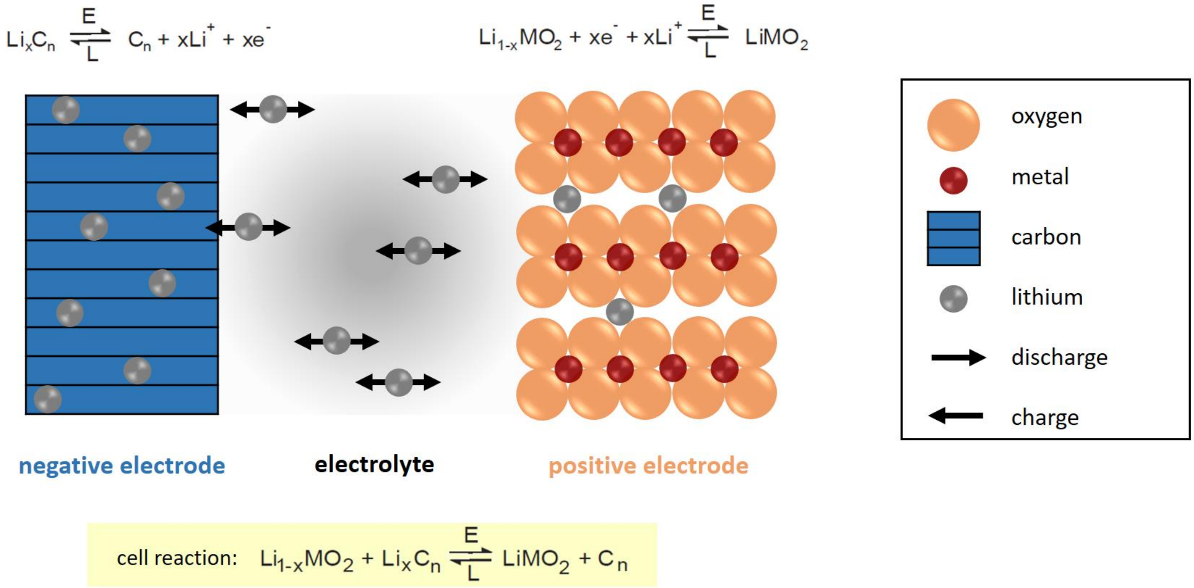

Fig. 4. Chemical processes in Li-polymer cells. Diagram: Jauch

V. Electrical data

Some benchmark data for ‘standard’ Li-polymer cells:

- Voltage level: 3.6 to 3.7 V (average voltage at 50% discharge depth/0.2 C).
- Charging: Constant I / constant V, maximum charging voltage 4.2 V, for special cells up to 4.35/4.4 V, max. charging current 1 C, for larger cells 0.5 C.
- Discharge: min. voltage 3.0 V, currents up to 1 C (in some cases 2 C).
- Temperature range: Charge: 0°C to +45°C, with reduced currents below 15°C. Discharge: -20°C to +60°C with suitably reduced voltage levels and capacities at low temperatures.
- Cycles: Charge/discharge at 0.5C/0.5C, 80% residual capacity after 500 cycles.

Other market-relevant parameters:

- Power density: up to several kilowatts per kilogram
- Energy density: up to approx. 200 Wh/kg
- The capacity range varies between a few mAh to over 10 Ah depending on the design and desired performance.

The flexibility of dimensions, the high energy density and the electrical data have led to a diversity of cell designs. The following designs are particularly interesting for the market:

- Gel-polymer cells with improved cycle stability
- High-energy cells with charging voltages of 4.35/4.4 V
- High-temperature cells for (intermittent) use up to 80°C
- Low-temperature cells that can be discharged at temperatures down to -40°C
- High-current cells

VI. Notes on safe operation

Li-polymer cells must always be used in conjunction with protection electronics. Safe operation cannot be guaranteed if cells are used without such electronics (a protection circuit module, PCM). The PCM breaks the circuit under critical operating conditions outside the specified data range. This includes:

- Charging voltage above maximum value
- Discharge voltage below minimum value
- Excessive discharge current/short circuits

For safe operation, four safety levels should be observed (Fig. 5). This relates in particular to overcharging. The following diagram shows the levels. The first safety level must be observed in all cases. This concerns the maximum charging voltage of the charger. Only chargers that are designed for this battery chemistry should be used.

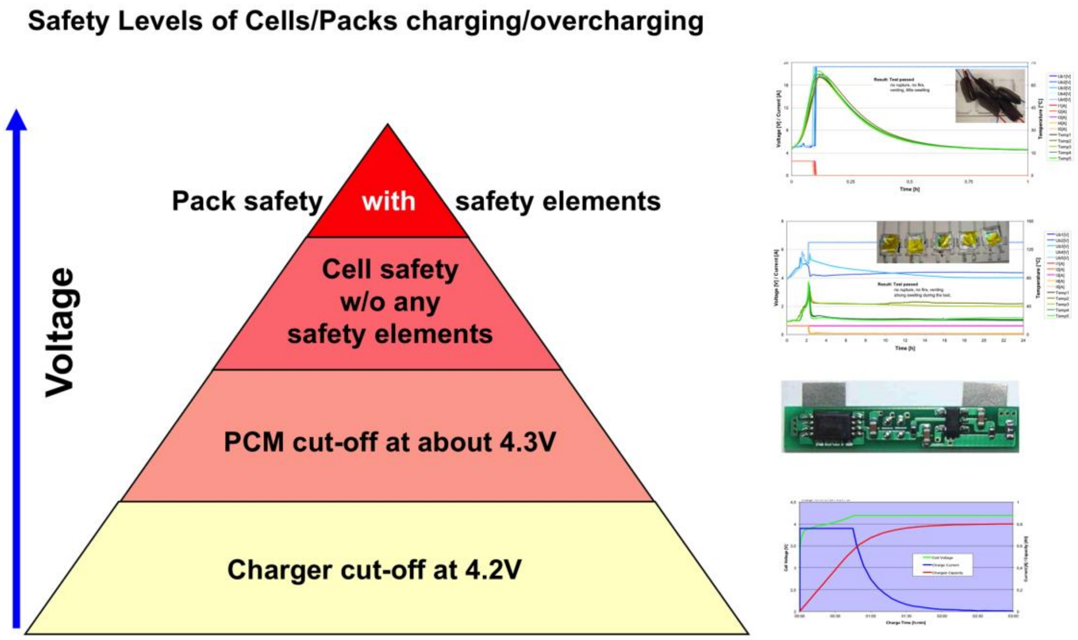

Fig. 5. The capacity of LiPo batteries can be increased flexibly. Diagram: Jauch

Further recommendations for safe operation and avoidance of failures:

- **Battery compartment**: Soft packs must only be used as permanently fixed batteries (customer non-replaceable). Removal or insertion poses a risk of damage to the foil housing.

  The battery compartment should be sufficiently large to allow insertion without physical damage and to allow for swelling. Sharp edges or ridges should be avoided.

  Metal components should be isolated from the battery by an insulation film. Isolation film should also be inserted between the PCB and components.

  For applications with high mechanical stresses (rotation, shock) the battery should be fixed in place. Movement of the components of the pack should be prevented.

- **Handling**: Li-polymer batteries are sensitive. They should be transported in rugged and secure trays. Generally, manufacturers supply the batteries in suitable trays that can be used right up to the infeed onto the production line.

Li-polymer batteries must not be placed on metal surfaces.

They must not be damaged by tools during insertion.

- **Other matters**: Short circuits, high storage temperatures and hotspots in the application that contact the battery should be avoided.

  Approval to UL 1642 should be obtained.

  Physically damaged batteries must not be used.

  To delay the aging process, it is recommended that batteries be stored at room temperature and half charged.

VII. Applications

Lithium polymer accumulators can be created in a wide range of sizes, shapes and power levels. Available shapes include cylindrical, prismatic, round, angled, curved, pentagonal and ultra-thin (Fig. 6).

Fig. 6. LiPo cells can be produced in a wide range of shapes. Images: Jauch

The flexibility of dimensions, the high energy density and electrical performance have driven the diversification of cell design. In particular, the possibility of using very flat cells offers device manufacturers an almost unprecedented level of design freedom.

Thanks to this variability, LiPo cells are particularly suited to small, flat, and mobile devices. Typical applications include smartphones, tablets and notebooks.

More recently, numerous wireless applications have also appeared (Fig. 7): smart watches, gadgets, toys, navigation and tracking devices, audio and VR systems, drones, measuring instruments, barcode scanners and devices for smart homes and the Internet of Things. A wide range of medical applications can also be exploited.

Lightweight, electrically driven vehicles can also be considered: hoverboards, e-bikes, solar vehicles, and even cars. Market analysts anticipate that the demand for Li-polymer batteries in the automotive sector will grow enormously as a result of the growing spread of electrically powered vehicles.

Summary: All electronic devices that frequently require power over longer periods can be powered by a lithium polymer battery. Where flexibility of shape is required, lithium polymer batteries offer the ideal solution.

Fig. 7. Lithium polymer batteries are suitable for use in a wide range of applications. Images: Shutterstock | Dmitry Kalinovsky ; Fotolia | autofocus67 ; Shutterstock | pixinoo ; Shutterstock | Alexey Boldin ; Fotolia | Eisenhans

VIII. Development and design

Battery suppliers such as Jauch support engineers, product designers and project managers by developing an optimized, product-specific solution for every application and every device. One advantage is that LiPo batteries can be easily adapted to individual plans. They can be designed and produced in the required quantity quickly, even in small series.

Often only a small amount of space is available for the design-in of a battery. In some circumstances the dimensions of the battery compartment is established before the first contact with the assembler is sought. In such a situation it is advantageous to have recourse to a wide repertoire of options. Jauch has a wide range of samples and tested shapes of lithium polymer batteries. This repertoire makes it possible to select suitable cells even at short notice – even in a highly advanced project phase.

Jauch develops, manufactures and tests battery packs for all areas of industry. The customer thus benefits from the decades of the company's experience. Jauch has been involved with mobile power supply systems since 1974.

Safety and function are our highest priority. For this reason, Jauch's experts accompany the development of cells for specific requirements from the outset. This enables them to ensure that all parameters, international certification, approvals and transportation regulations are complied with exactly.

Cells are manufactured in fully automated production facilities. All production sites are certified to ISO9001 and ISO14001 as standard, so compliance with international safety and environmental standards is guaranteed.

About the author:

Dr. Jürgen Heydecke is an acknowledged expert in his field with decades of experience at home and abroad. Throughout his working life he has been involved with different battery chemistries and he knows the requirements of the industry like few others. In 2009 he and his partner set up Batteries and Powersolutions GmbH (BAPS). Since the merger with Jauch Quartz GmbH in 2018, Jürgen Heydecke has acted as technical director of the newly-established Jauch Battery Solutions GmbH and also leads seminars at the Jauch Battery Academy.

Sources:

- Archive Heydecke, Jauch Quartz GmbH, Jauch Battery Solutions GmbH
- Akku.net, Batterieforum-Deutschland, Computerwoche, Fraunhofer ISI, Global Market Insights, Grand View Research, heise.de, ITWissen.info, Marketwatch.com, Nationale Plattform Elektromobilität, ResearchAndMarkets.com, Sparkfun.com, Süddeutsche Zeitung, Techchannel.de, Transparency Market Research, TU Munich, University of Siegen, University of Ulm, Wikipedia.org

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