Portable Power Considerations for Medical Device Design

Many medical devices are moving from simple back-up power to true portability. This creates challenges unique to medical devices and adds new advances in battery technology that can enhance and differentiate portable medical products.

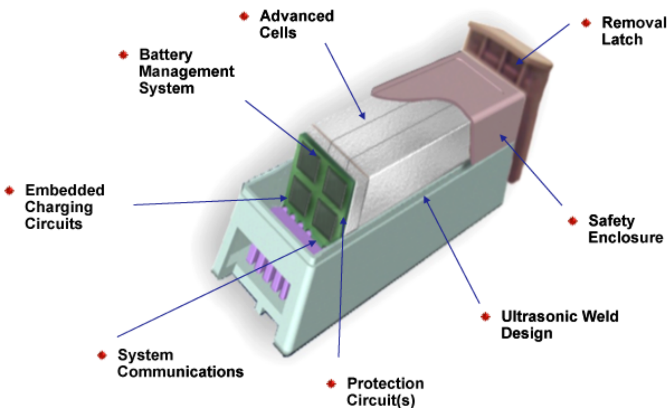
This white paper will look at the following advances in portable battery technology and the special considerations for medical device applications:

- Lithium Ion (Li-ion) chemistries' advantages over older technology
- Fuel gauging accuracy
- Unique form factors using Li-Polymer
- Use of Lithium Iron Phosphate for high current and Sealed Lead Acid (SLA) replacement
- Sterilization of Li-ion for surgical equipment

Micro Power Electronics specializes in the design and manufacture of lithium battery packs and chargers for mission-critical applications, such as medical equipment. As a technology integrator, we choose the best components for a given set of design constraints and usage models and design each custom battery pack from the ground up.

ADOPTION OF LI-ION CELLS

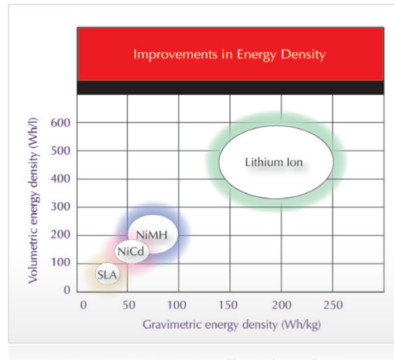
As shown in the figure below, battery packs are no longer a simple configuration of cells. They are carefully engineered products with many safety features.



The main components of a battery pack include:

1. Battery cells, the primary energy source
2. Printed circuit board, the intelligence of the system, which contains:
   - The fuel gauge which calculates remaining cell capacity
   - Protection circuitry
   - Thermal sensors used to monitor internal pack temperature
   - LEDs that indicate pack or cell status
   - A serial data communications bus that provides the status of the pack to the host equipment
3. The custom plastic enclosure, typically produced in an injection mold
4. External contacts, the physical electrical interface with the host equipment
5. Insulation, used to absorb external shock and retain the positioning of internal components

Measured by size and weight, Li-ion cells store and deliver more energy than other rechargeable batteries, as seen in the figure below.



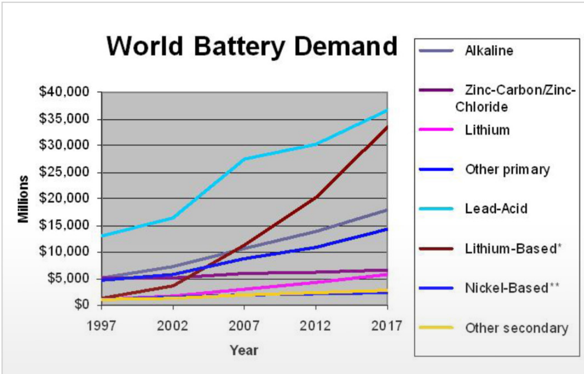
The energy density, measured both volumetrically and gravimetrically at nominal conditions, is up to almost 500 watt-hours per liter, and 200 watt-hours per gram.

As indicated by the size of the Li-ion bubble, there are a wider variety of Li-ion cell capabilities than other chemistries. Many have been developed to deal with varying usage and environmental factors such as exposure to high or low temperatures, high drain rates, etc.

In testing cells using different usage profiles, Micro Power has found that battery cell performance varies widely, even between cells with identical performance at nominal conditions.

The trend is towards a much greater use of Li-ion as the chemistry of choice. Applications with high voltage and capacity requirements are adopting Lithium-ion technology because of its many advantages:

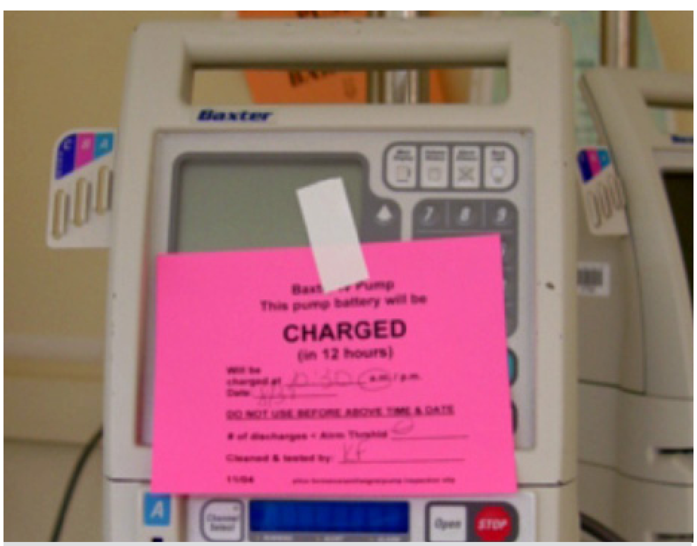
- Good cycle life
- High energy density—both smaller size and lower weight
- No loss of capacity when recharged after long periods of storage



As market data from Fredonia shows in the figure above, Sealed Lead Acid (light blue) is the biggest battery market today and in the near future; however, Li-ion (brown) has already overtaken the Nickel market and is predicted to be almost as big as the SLA market by 2017. Li-ion is by far the biggest growth market.

FUEL GAUGING ACCURACY

Older battery fuel gauges used either a simple voltage monitor, which is not accurate for Li-ion chemistry, or coulomb counting/current monitors, which require frequent learn cycles. This picture depicts an infusion pump as it is used in the Mayo Clinic, today. This infusion pump uses substandard SLA chemistry and older gas gauge technology.



One of the most prestigious medical facilities in the world is resorting to paper signs to indicate battery status.

The capacity and runtime predictions of the newest fuel gauge technology are 99% accurate without the inconvenience of learn cycles.

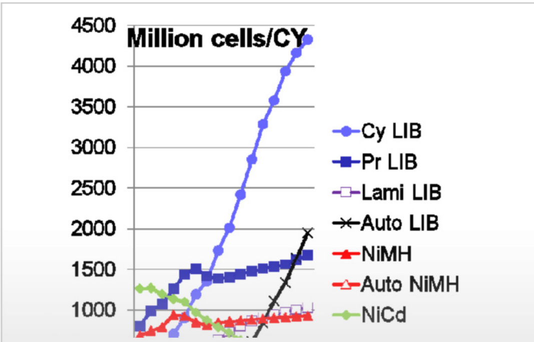
The new fuel gauges gain accuracy by combine advantages of voltage and current based methods and they consider load and environment information including average power usage, recent power usage and the temperature profile. Battery-related information is also used including open circuit voltage, full charge capacity, resistance and starting depth of discharge. The new gas gauges use a current integration based method under main load (i.e. coulomb counting) and a simplified DC-model in case of constant current or a step-wise calculation in case of constant power. They use a voltage based method where no load or stand-by load is applied to battery to determine starting state-of-charge and no-load capacity. They update impedance at every cycle using voltage and current information and calculate remaining runtime at given average load using both open circuit voltage and impedance information.

This solves the problem of remaining runtime calculations for patient critical medical battery applications.

USE OF LI-POLYMER CELLS IN MEDICAL APPLICATIONS

Li-ion cells come in three basic form factors; cylindrical, prismatic (rectangular brick shape) and the flat, Li-Polymer cells.

- **18650 Cylindrical** (18 millimeter cell diameter, 65 zero being 65mm long) are the most common Li-ion cell. Several million cells are manufactured per month. Predominant in the notebook computer markets, they have the lowest cost per watt hour.
- **Prismatic** or brick shaped cells are also fairly cost effective and available in many sizes; the most common is 50mm length and 34mm width with heights ranging from about 4mm to about 12mm.
- **Li-Polymer** cells (sometimes called laminate cells) are available in custom foot print size. They can be very thin or quite large depending on intended use.



As shown in this market graph for each type of Li-ion rechargeable cell and Ni based cells:

- All of the Li-ion cells are predicted to overtake the Ni cells in every market
- Cylindrical are predicted to have astronomical growth primarily because of the automotive market
- Li-Polymer batteries (Lami LIB in violet) are predicted to go from being a relative rarity to being quite common. Production is estimated at 1 billion cells per year by the end of this decade

The primary advantage of Li-Polymer batteries is the variety of form factors available. Manufacturers of blue tooth devices were the first to recognize the advantage of Li-Polymer batteries. Then the availability of very thin batteries created the Motorola Razr phone market success. Apple was the next company to recognize the appeal of very thin products. Most of the new Apple products use thin polymer batteries to differentiate themselves in the highly commoditized notebook market.

LI-POLYMER HAS SPECIFIC ADVANTAGES AND LIMITATIONS TO CONSIDER:

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 moderate volumes, any reasonable size can be produced
- Light weight - Simplified film packaging reduces weight
- Available as a thin form factor with high capacity (10+ Ah) or high current (50+ Amps) cells

In this picture, is one of the first and newest medical products to use the thin polymer form factor, a digital x-ray plate that is thin enough to fit in conventional film x-ray cassettes.

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)

IRON PHOSPHATE, HIGH RATE AND SLA REPLACEMENT

The electric vehicle market is very important for the battery industry because of the market size and the innovation in technology that is required. There are many more Sealed Lead Acid (SLA) applications that are ripe for the migration to Li-ion as well.

Many medical devices requiring high series or parallel battery cell counts benefit from lighter weight and smaller size batteries. Examples include:

- Infusion pumps
- Ventilators
- Wheelchairs
- Oxygen concentrators
- Medical carts

Iron Phosphate cells are designed for high rate and SLA replacement. There are a few features that make them easily designed into SLA replacement packs:

- 3.3 V cell voltage enables packs in 12 and 24 V increments
- They can use float charging, which makes them compatible with SLA chargers
- Their very long cycle life often yields lower total cost of ownership over the lifetime of a product
- High rate capability for charging and discharging are beneficial for many applications

Although energy density is higher than SLA, it is relatively low for Lithium chemistries. This chemistry also requires most of the battery management electronics to be customized.

Sealed Lead Acid (SLA) batteries have had a few advantages, in addition to their extremely low cost, that keep their market share high in the overall battery market. However, recent innovations in Li-ion chemistry have made them extremely competitive in the medical market which is weight sensitive and inconvenienced by SLA's need for frequent maintenance.

This photo shows a Lithium Iron Phosphate battery, IRONWORKS, which is designed to be a direct replacement for a U1 form factor SLA battery

STERILIZATION OF LI-ION FOR SURGICAL USE

Surgical equipment is quickly adopting battery technology because of the need to be untethered to maintain equipment sterility, and thus creating the need for equipment that can be sterilized with the battery pack.

Sterilization options for batteries include:

Rechargeable

- Autoclave (steam sterilization)
- Sterrad or Steris (Hydrogen Peroxide plasma)
- Aseptic Transfer

Non-rechargeable

- Gamma radiation
- Ethylene Oxide (ETO)

General Surgery is expected to follow the trend of Orthopedic tools toward battery power. The market for surgical equipment powered by batteries is expected to grow substantially in the next few years. The exact usage model for many procedures and technologies is still evolving.

SUMMARY

The use of batteries in devices, especially portable medical products, is continuing on a steep upward trend.

New forms of Lithium batteries are dominating the growth of battery markets, including Li-Polymer with its wide range of form factors such as very thin cells, and Lithium Iron Phosphate with its high power capabilities.

The ability to sterilize equipment with the battery intact is now available and continues to improve.