Clevertronics
Emergency Lighting Innovation

Emergency Lighting Discussion Paper

Lithium battery technologies compared for the Emergency Lighting application

With emergency escape lighting, the quality and performance of the battery is critical, both from a life-safety and a maintenance cost viewpoint.

With the release of the Clevertronics L10 Optimum range in 2012 and LP Lithium

Premium in 2014, and with many different Lithium battery technologies already in widespread use, this discussion is simply aimed at highlighting:

1. There are many different Lithium based battery chemistries.

2. Each has different performance characteristics and relative strengths and weaknesses depending on the specific battery chemistry.

When it comes to advances in battery technology, Lithium based battery chemistries dominate the headlines. The last 10 years have seen dramatic performance advances that include smaller batteries that supply more power and last longer. Every year we see mobile computing, smart phones and other devices become more powerful and at the same time thinner and lighter, and Lithium based battery technologies are now the power-plant of choice for almost every device we use day to day.

So how do the "Lithium" batteries that we use for our laptops, watches, phones and latest personal flying devices differ from each other, and how does the LiFePO4

Lithium Iron Phosphate (LFP) technology used in the Clevertronics LP range and

Lithium Nanophosphate (LNP) used in the L10 range compare?

Primary (non-rechargeable) and Secondary (rechargeable)

Lithium Batteries Lithium batteries are non-rechargeable (primary) batteries that have lithium metal or lithium compounds as an anode. They stand apart from other batteries in their high charge density and long life. The button style batteries commonly used in watches are an example of this type.

Lithium batteries find application in many long-life, critical devices, such as artificial pacemakers and other implantable electronic medical devices. These devices use specialised lithium-iodide batteries designed to last 15 or more years. And for other, less critical applications such as in toys, the lithium battery may actually outlast the device.

By comparison lithium-ion batteries are rechargeable (secondary) batteries in which lithium ions move between the anode and the cathode, using an intercalated lithium compound as the electrode material instead of the metallic lithium used in primary lithium batteries.

There are many different Lithium Ion chemistries. Mobile phones and laptops for example use what is commonly called a Lithium Polymer (or LiPo) battery, while the standard Lithium Iron Phosphate (LFP) battery used by the Clevertronics LP range and Lithium Nanophosphate (LNP) chemistry used in the L10 range fall within the LiFePO4 family. Although they all feature different chemistries and different characteristics as a result, all belong to the Lithium Ion (rechargeable Lithium) battery category.

This discussion is focused more on comparing LFP and LNP batteries with other common Lithium Ion battery technologies, since we are interested in the rechargeable technologies that may be applicable to emergency lighting. For an indication of the wide range of different Lithium Ion chemistries used,

Appendix A includes a table listing many of the Lithium Ion battery types.

General comparison with NiCd and NiMH

In a general comparison with Nickel Cadmium (NiCd) and Nickel Metal Hydride (NiMH), Lithium Ion batteries have the advantages of higher energy density, no memory effect, higher cycle counts and longer calendar life. And LFP and LNP battery technology in particular is far less toxic and damaging to the environment. But just as performance, safety, environmental impact and toxicity characteristics differ between the two Nickel based batteries mentioned above, so to do they vary across Lithium Ion battery types.

Performance

When selecting the appropriate battery technology for emergency lighting, consideration must be given to three main areas:

1. Long term performance when on stand-by charge under elevated temperatures. This takes priority over maximum cycle counts for example, as the battery is typically not discharged frequently, but is often enclosed in a luminaire and exposed to elevated temperatures under constant charge.
2. As a life-safety product, reliability and safety under abuse conditions is paramount.
3. Environmental impact and human toxicity. After all, emergency lighting is almost the last industry left standing still using toxic NiCd and NiMH batteries and an alternative is long overdue.

Comparing LFP & LNP with other Lithium Ion

The Lithium Polymer "LiPo" battery commonly used in smart phones is typically a Lithium Cobalt Oxide (LiCoO2) battery. The advantage of this technology is its higher energy density when compared with LFP and LNP, meaning smaller batteries to deliver the same power. However, LFP and LNP batteries will lose their capacity at a slower rate compared with LiPo batteries, so that typically after around 12 months these batteries will have a higher energy density than the same size LiPo.

LFP and LNP batteries also have much higher cycle counts and better performance under a wider range of temperatures. For emergency lighting applications, the ability to maintain capacity over time at elevated temperatures is a major tick for these battery technologies.

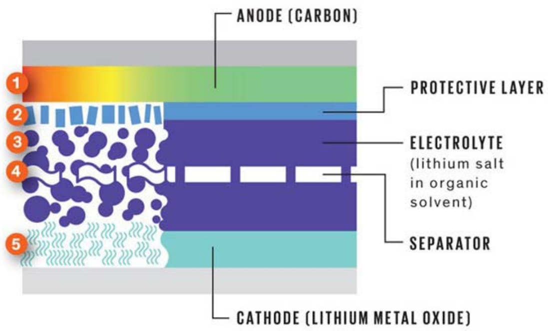
Safety

All the rechargeable battery types used in emergency lighting feature both circuit and battery protection, as do the countless products using rechargeable battery technology that we use and are exposed to every day. Overcharging, short circuit or exposure to extreme temperatures can lead to "thermal runaway" – a situation where there is an uncontrolled increase in temperature which can release energy which in turn further increases temperature. This energy release or exothermic reaction can be in the form of heat or in extreme cases fire or combustion.

The L10 and LP ranges feature three levels of battery protection circuitry: intelligent over-voltage protection during charge; under-voltage protection during discharge; and "capped current" over-current protection during charge. One important advantage of LFP and LNP over other lithium ion chemistries is thermal and chemical stability. The cathode material is intrinsically safer than the LiCoO2 used in mobile phones and laptops, and is used in hybrid-electric vehicles and large capacity battery applications where safety is critical.

Thermal Runaway in a Lithium-Ion Battery

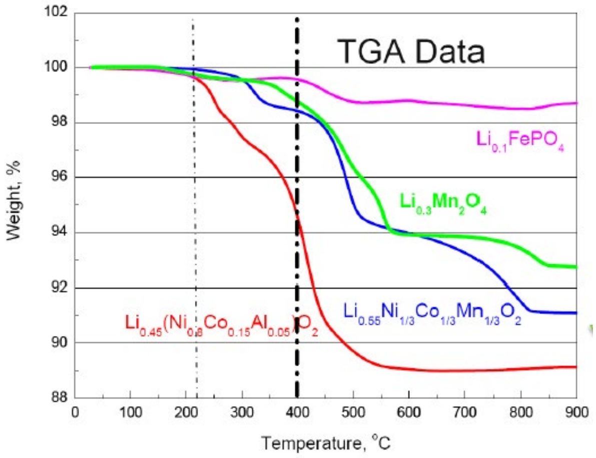
1. Heating starts.
2. Protective layer breaks down.
3. Electrolyte breaks down into flammable gases.
4. Separator melts, possibly causing a short circuit.
5. Cathode breaks down, generating oxygen.



Thermal runaway in a LiCoO2 Lithium battery

Again, different Lithium battery chemistries will react very differently under "abuse conditions" like over-charging, short circuit, physical damage to the cell and exposure to extreme high temperatures or fire. The non-rechargeable Lithium button batteries used in toys and pacemakers tend to have the most violent (and spectacular) reaction due to the use of Lithium metal rather than a Lithium compound within the battery. Short circuiting a Lithium button battery can lead to excessive discharge, over-heating of the battery, rupture and even explosion.

The re-chargeable Lithium LiPo (LiCoO2) batteries used in mobile phones when shortcircuited, overheated, or overcharged can suffer thermal runaway and cell rupture, which in some cases can lead to combustion. Under these conditions, oxygen loss in LiPo cells can lead to exothermic reactions which can in turn lead to ignition. A quick search on You Tube will reveal dozens of "torture tests" of LiPo batteries – from driving nails into them to short circuit them, massive overcharging on unprotected cells, exposing them to extreme heat welding flames and even shooting them with a shotgun! The results can be mildly entertaining with cells releasing smoke and sometimes catching fire or combusting. However, with multiple circuit and other protection this is extremely unlikely to occur with your laptop or phone charging next to your bed at night!



Oxygen loss under abuse conditions for different Lithium battery chemistries.

In comparison, LFP and LNP batteries do not suffer energetic thermal runaway when overcharged, short circuited or exposed to extreme heat. When under abuse conditions, due to the stronger chemical bonds in the cathode material there is little or no oxygen release, resulting in a highly resilient battery cell. Fortunately, due to this resilience a search of You Tube for the same torture tests on these batteries will not yield extreme results.

Appendix A: Lithium Ion Battery Chemistries

(Table from Wikipedia December 2013)

Positive Electrode

Technology	Researchers	Target application	Date	Benefit
Manganese spinel (LMO)	Lucky Goldstar Chemical,[58] NEC, Samsung,[24] Hitachi,[59] Nissan/AESC,[60] EnerDel[61]	Hybrid electric vehicle, cell phone, laptop	1996	durability, cost
Lithium iron phosphate	University of Texas/Hydro-Québec,[62] Phostech Lithium Inc., Valence Technology, A123Systems/MIT[63][64]	Segway Personal Transporter, power tools, aviation products, automotive hybrid systems, PHEV conversions	1996	moderate density (2 A·h outputs 70 amperes) operating temperature >60 °C (140 °F)
Lithium nickel manganese cobalt (NMC)	Imara Corporation, Nissan Motor,[65][66] Microvast Inc.		2008	density, output, safety
Lithium Manganese Oxide/NMC	Sony, Sanyo[67]			power, safety (although limited durability)
Lithium iron fluorophosphate	University of Waterloo[68]		2007	durability, cost (replace Liwith Na or Na/Li)
5% Vanadium-doped lithium iron phosphate olivine	Binghamton University[69]		2008	output
Lithium purpurin	Arava Leela Mohana Reddy Rice University[70]		2012	Organic material, low production cost 90 milliamp hours per gram after 50 charge/discharge cycles
Lithium manganese dioxide on porous tin	University of Illinois at Urbana-Champaign[71]	automotive, electronics	2013	energy density, power, fast charge using microstructured porous tin
Air	IBM, Polyplus[72]	automotive	2012	Energy density: up to 10,000 mAh per gram of positive electrode material. Rechargeable.
Air	University of Dayton Research Institute[73][74]	automotive	2009	density, safety
Water	Polyplus Corporation[75][76]	marine	2012	Energy density: 1300 w·h/kg Non-rechargeable. Solid lithium positive electrode. Solid electrolyte. Reduced selfdischarge.

Negative Electrode

Technology	Researchers	Target application	Date	Benefit
Lithium-titanate battery (LT)	Altairnano, Microvast Inc.	automotive (Phoenix Motorcars), electrical grid (PJM Interconnection Regional Transmission Organization control area,[77] United States Department of Defense[78]), bus (Proterra)	2008	output, charging time, durability (safety, operating temperature −50–70 °C (−58–158 °F))[79]
Lithium vanadium oxide	Samsung/Subaru.[80]	automotive	2007	density[81]
Cobalt oxide nanowires from genetically modified virus	MIT		2006	density, thickness[82]
Three dimensional (3D) porous particles composed of curved 2D nanolayers	Georgia Institute of Technology	high energy batteries for electronics and electrical vehicles	2011	high efficiency, rapid lowcost synthesis[83]
Iron-phosphate nanowires from genetically modified virus	MIT		2009	density, thickness, selfassembly [84][85][86]
Silicon/titanium dioxide composite nanowires from genetically modified tobacco virus	University of Maryland	explosive detection sensors, biomimetic structures, water-repellent surfaces, micro/ nanoscale heat pipes	2010	density, low charge time[87]
Silicon whisker on carbon nanofiber composite	Junqing Ma, Physical sciences, Inc.	portable electronics, electrical vehicles, electrical grid	2009	high capacity, good cycle life, fast rate, low charge time[88]
Silicon nanowires on stainless steel	Stanford University	wireless sensors networks	2007	circumvents swelling[89][90] (shift from negative to positive electrode limited) but safety issue remains (wire cracking)
Silicon oxide coated doublewalled silicon nanotubes	Yi Cui/Stanford University[91][92]	automotive and electronics	2012	
Silicon nanotubes (or silicon nanospheres) confined within rigid carbon outer shells	Georgia Institute of Technology, MSE, NanoTech Yushin's group[93]	stable high energy batteries for cell phones, laptops, netbooks, radios, sensors and electrical vehicles	2010	ultra high Coulombic Efficiency and outstanding SEI stability[94]
Silicon nanopowder in a conductive polymer binder	Lawrence Berkeley National Laboratory[95]	automotive and electronics	2011	Compatible with commercial Si, good cycling characteristics
Silicon oxycarbide-coated carbon nanotubes	G Singh/Kansas State University[96]	automotive	2013	~99.6 % average coulombic efficiency; Negative electrode active weight (1.0 mg/cm2), Thickness (~125 micrometers)
Electro-plated tin		consumer electronics	2012	Reduced cost. 3x capacity vs conventional Li-ion
Solid-state plated copper antimonide nanowire	Prieto battery[92]	consumer electronics	2012	Reduced charging time from reduced positive/negative electrode gap. Increased energy density.
Boron doped silicon nanoparticles	University of Southern California Chongwu Zhou[97][98]	various	2012	ten minute charging time. Scalable construction.
Hard carbon	Energ2[99]	consumer electronics	2013	greater storage capacity
Silicon/conducting polymer hydrogel	Stanford University[100][101]	various	2013	10x energy density of carbon without destruction caused by 400% negative electrode expansion under charge
Nanomatrix structure	Amprius[102]	Smartphones, providing 1850 mA·h capacity	2013	uses silicon and other electrochemicals. Energy density

Negative Electrode (continued)

Technology	Researchers	Target application	Date	Benefit
Carbon-encased silicon nanoparticles	Stanford[103]	various	2013	commercially available Si nanoparticles sealed inside conformal, self-supporting carbon shells, with rationally designed void space between particles and shell. The space allows Si particles to expand without breaking the outer carbon shell, stabilizing the SEI on the shell surface. Coulombic efficiency of 99.84%.
Lithium/titanium/oxide	Ener1/Delphi[61]		2006	durability, safety (limited density)
Fe 3O 4-plated copper nanorods	Université Paul Sabatier/Université Picardie Jules Verne[104][105]		2006	density
Nanophosphate	A123 Systems[106][107][108]	automotive	2012	Operation at high and low ambient temperature
Nickel/Tin on porous nickel	University of Illinois at Urbana-Champaign[109][110]	automotive, electronics	2013	energy density and power using microstructured metal as the substrate for thin film Nickel/Tin. These are assembled as threedimensional bicontinuous interdigitated microelectrodes.
Manganese oxide nanowires produced by M13 virus	MIT[111]		2013	Energy density from increased surface produced by genetically-engineered M13 virus that produces a roughened surface.