Lithium Rechargeable Solid Electrolyte Battery Market 2017

Ver. 1

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The Need to Renew Lithium Rechargeable Battery Technology

Lithium Batteries are Power Sources of Choice for many applications

- **Present Li-Ion technology (150-272 Wh/kg, 400-775 Wh/l – (4.45v cells in mass production) - not satisfy the power needed by E-Mobility and other applications.**

- **Improvement in Energy Density, cost reduction, safety enhancement , higher charging/discharging rates and cycle life required!!!**

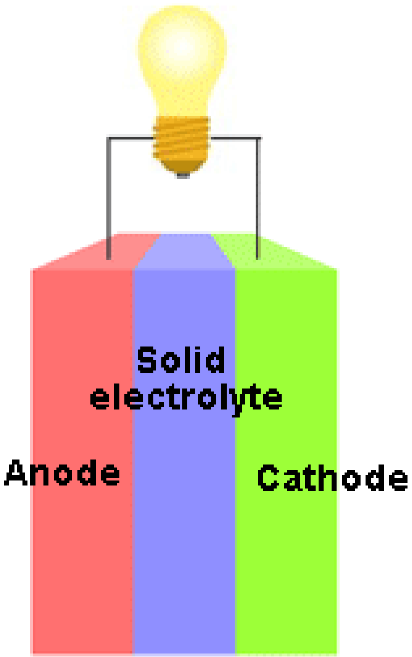
The Potential Technologies for Energy Storage Break Through

- Lithium Sulfur
- Lithium Metal
- Li-Ion with Silicon Nano-structure anode
- High voltage lithium rechargeable (4.35-5v)
- Lithium Air
- Solid Electrolyte batteries

What are Solid Electrolyte Cells?

- Lithium rechargeable using a dry polymer /ceramics electrolyte in a solid state cell in which a dry polymer electrolyte is sandwiched between a lithium metal film and a metal film

- By dissolving lithium, not into a liquid electrolyte but into a really thin dry polymer (plastic), a high-power battery is realized that is light, and yet durable



What are the difference versus Li-Polymer Cells

- Gel polymer electrolyte – still flammable, poor mechanical property – reasonable conductivity (10^3 S/cm @ RT)

- Include small sort of liquid/humidity – Not totally dry!!

- Some pouch “Li-Po” cells also include liquid electrolyte – Not even gel.

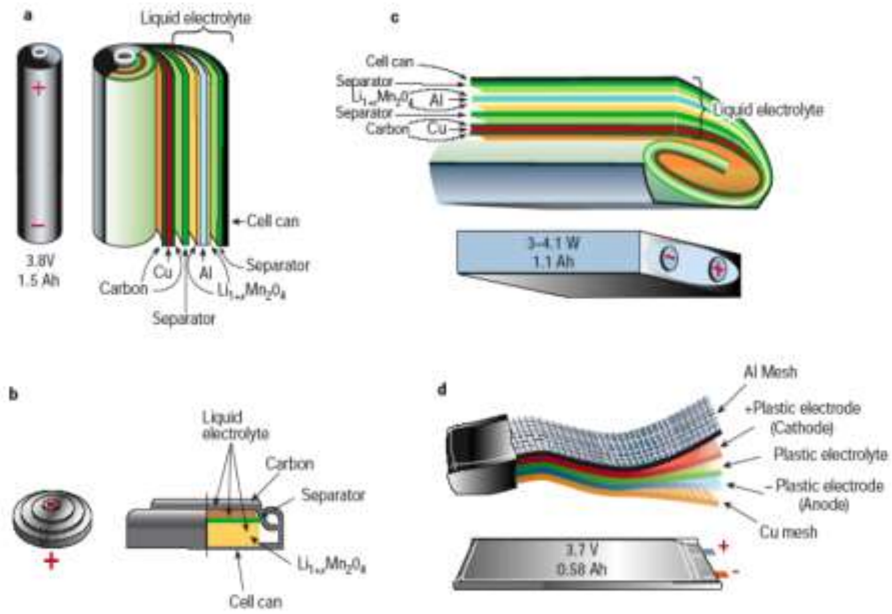
1998 – Sony first commercial Li-Po cells

Li-Po Fire

Solid Electrolyte Cells

- **The laminate construction of such cells offer flexibility of shape and size, which is advantageous for portable power source applications**
- **However, at the present time, the conductivity of these batteries is very low at room temperature, compared with those of liquid electrolytes: these batteries are normally operated in the 60-120ºC range**

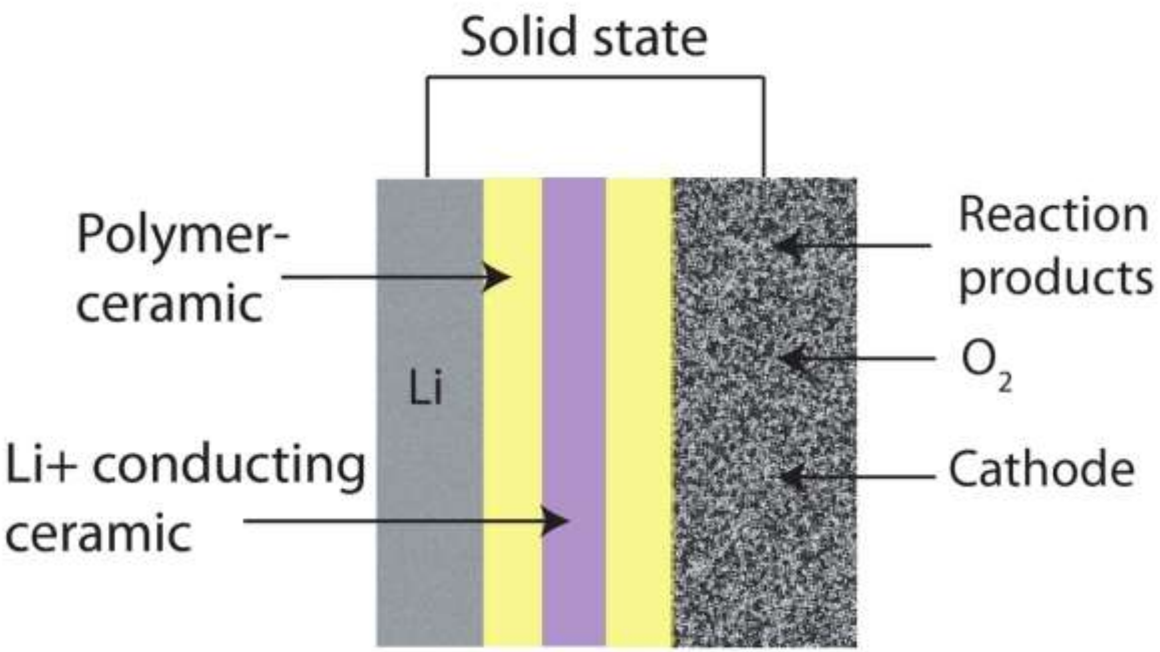
1. The solid-polymer, Li-ion battery--with its excellent combination of safe operation, more flexible packaging, and high performance--is the next step in the evolution of mobile power.

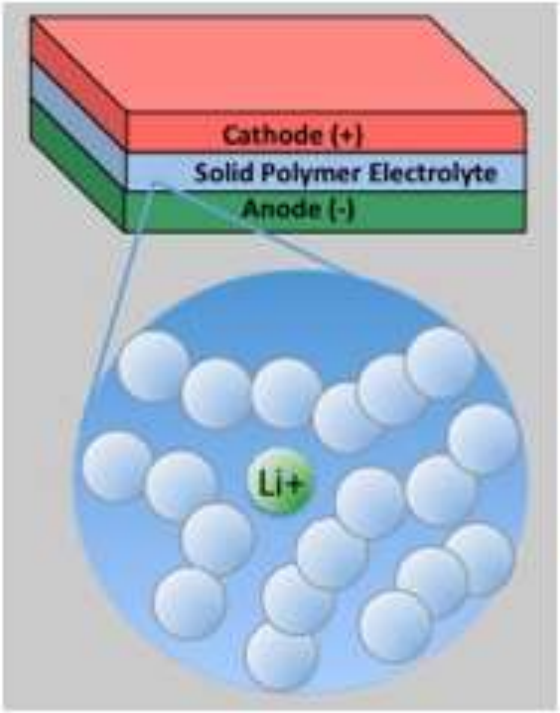


Current Packaging

Solid Electrolyte Types?

- **Dry polymer electrolyte – Low ionic conductivity (10^5-10^4 S/cm @ RT)**
- **Inorganic or ceramic solid electrolyte**

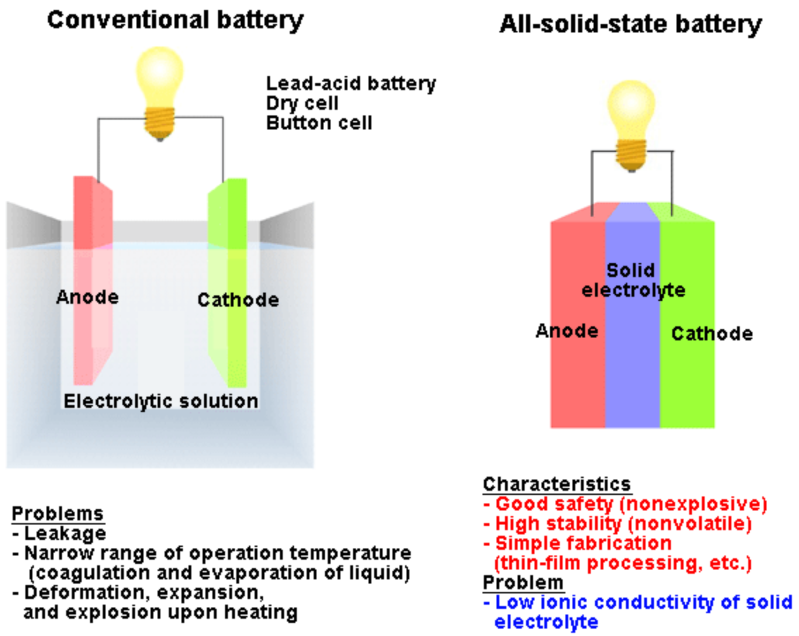




Solid polymer electrolytes for lithium-ion batteries

Solid Electrolyte Batteries Advantages

- Higher energy density than Li-Ion
- Safety – no flammable electrolyte (Ceramic, Dry Polymer)
- No electrolyte leakages
- Can fit any casing shape (soft packaging)
- Cells can be made as thin as 0.1 mm or about one-tenth the thickness of the thinnest prismatic liquid Li-ion cells
- Low potentially manufacturing cost
- Excellent cycling stability
- Excellent shelf life



Solid Electrolyte Batteries Limitations

- **Power limited by electrolyte low ionic conductivity**
- **High temperature working operating temperatures**
- **High interfacial resistance**
- **As with other Li-ion batteries, require individual cell monitoring**
- **Costly manufacturing process when using vapor deposition process**

More research is needed!!!

Solid Electrolyte Batteries Development Status?

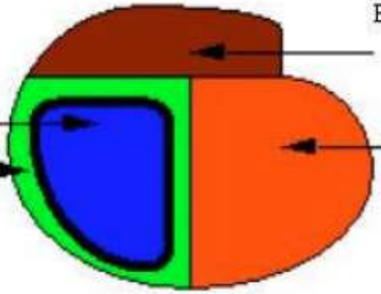
- **Research is being aimed at increasing conductivity through the use of plasticizers and new polymers.**

- **The development of "Polymer-In-Salt" materials, in which super ionic glass electrolytes are mixed with small quantities of the polymers, has been suggested.**

- **Dissolution of the polymer into these melt-glass-electrolytes produces a rubbery version of a glassy electrolyte with a thousand-fold increase in lithium ion mobility.**

Solid State Batteries for Implants

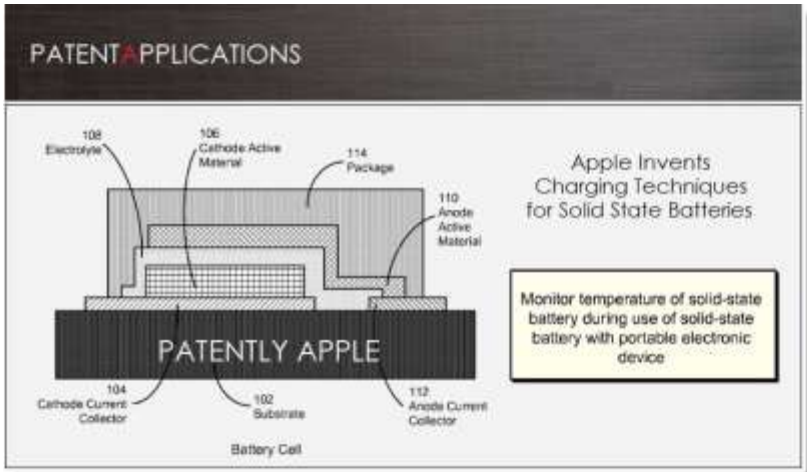
Solid state enables new applications



1. Open Circuit Voltage: 2.8 Volt
2. Control Circuit minimal voltage: 2.2 Volt
3. Control Circuit current drain: **10 µA**
4. EOL battery resistance: **10 k Ohms**
5. C_{hold}: 10 µF
6. Oscillator frequency: 167 Hz
7. Duty Cycle; 16.7 %
8. Ah rating: 2 Ah (typical rating)
9. Reliability: 99.6% probability of survival beyond 8 years
10. Failure Rate: 0.005 % failures/month

Lithium iodine battery for cardiac pacemaker

Apple Invents Charging Techniques for Solid State Batteries



IMPRINT energy

Apple's invention provides a system that manages use of a solid-state battery in portable electronic devices. During operation, the system monitors a temperature of the solid-state battery during use of the solid-state battery with the portable electronic device. Next, the system modifies a charging technique for the solid-state battery based on the monitored temperature to increase a capacity or a cycle life of the solid-state battery. To modify the charging technique based on the monitored temperature, the system may increase a charge rate of the solid-state battery if the temperature exceeds a first temperature threshold (e.g., 25.degree. Celsius). On the other hand, the system may maintain the charge rate of the solid-state battery if the temperature does not exceed the first temperature threshold. In some embodiments, the system further increases the charge rate of the solid-state battery if the temperature exceeds a second temperature threshold such as 45.degree. Celsius. In some embodiments, increasing the charge rate of the solid-state battery involves at least one of increasing a charge current of the solid-state battery, and increasing a charge voltage of the solid-state battery. Apple states that the new solid state batteries will apply to such devices as the iPhone, iPad, iPod, MacBooks and more. This would be ideal for bendable and/or wearable computers.

The LMP Battery

- Based on extruded films
  - All solid design
  - No liquid electrolyte
- High discharge power
- Environment friendly:
  - No solvent
  - Highly recycle or reuse
- Operating temperatures -20 to 60 C
  - Internal temperature 60-80 C

Samsung SDI Flexible Solid Electrolyte Pouch Cells

- Presented at Interbatt Korea, Seoul 10/2013
- Higher energy Density than Li-Po
- Safer – No leaks – No flammable electrolyte
- Expected commercially on 2015

Samsung SDI Flexible Solid Electrolyte Pouch Cells

Cymbet

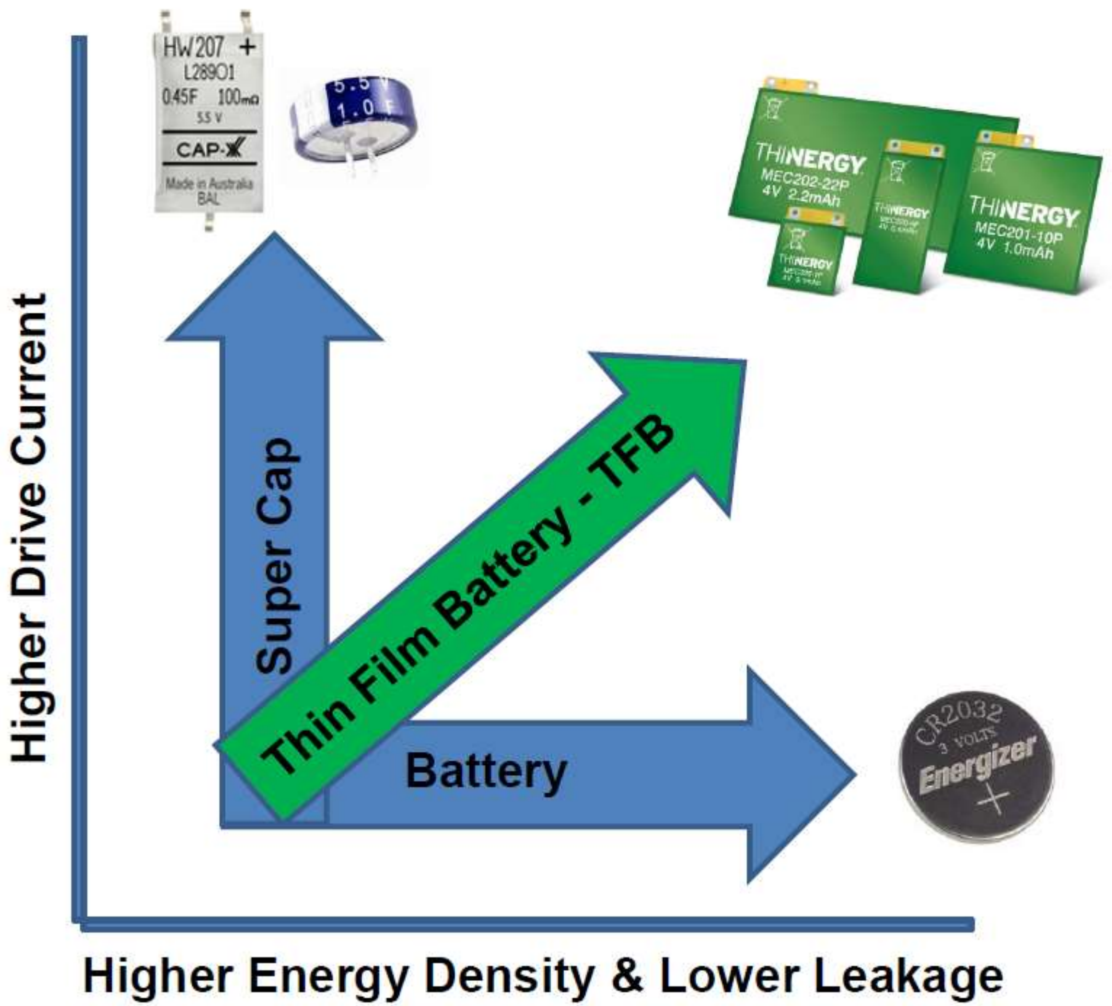
- Cymbet EnerChip™ thin film rechargeable solid-state smart batteries (SSB)

- Packaged as a Surface Mount Technology (SMT) component, the EnerChip provides energy storage in a convenient form factor.

- Cymbet's EnerChip SSBs are well suited for applications where battery backup power is needed to maintain the settings of microcontroller memories, real-time-clocks and SRAM during power loss or power failures.

Infinite Power Solutions

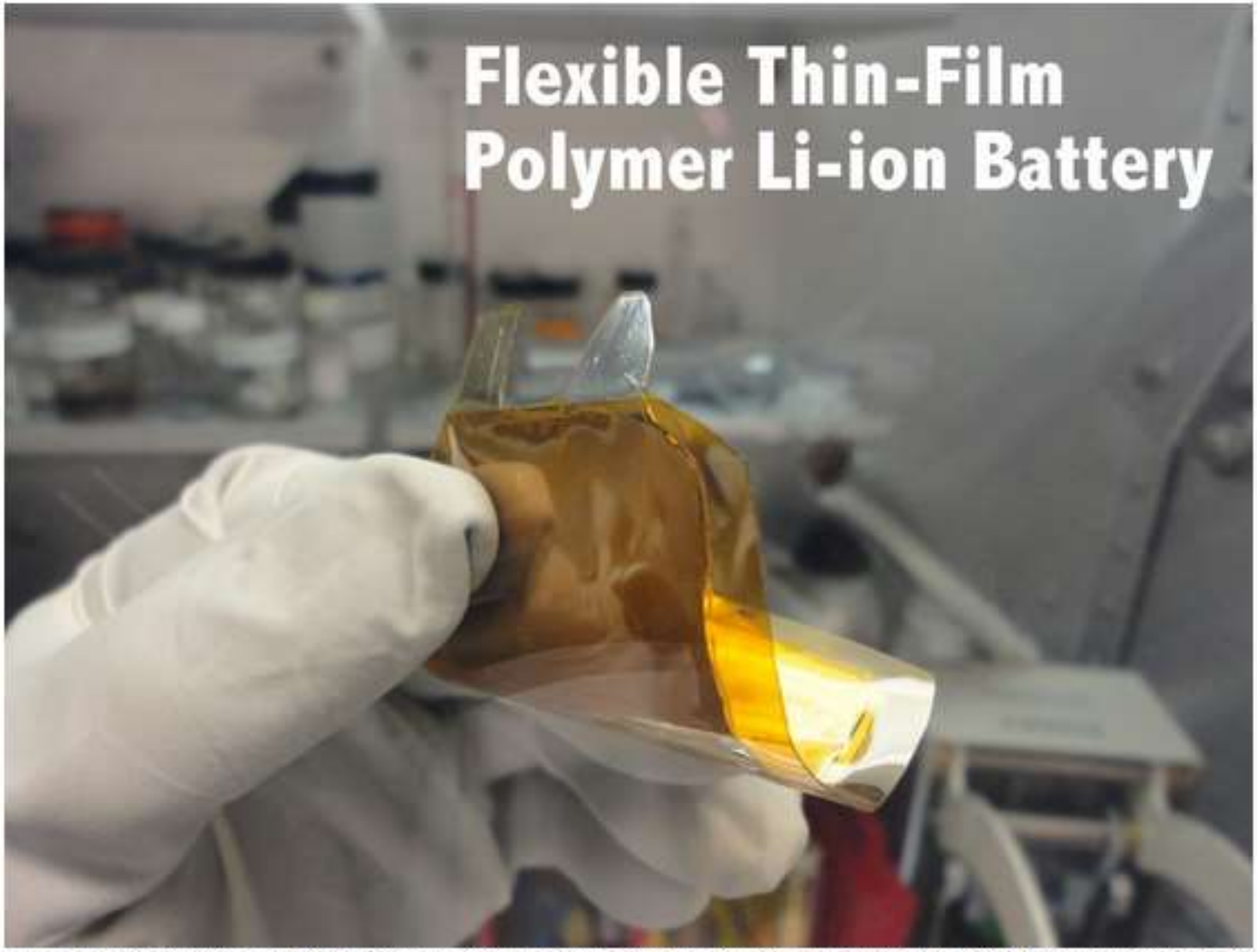
Thin Film Batteries, Supercaps and Coin Cells



TFB = Best of Both

- **High Drive Current**
- **High Energy Density**
  - *50 X SuperCap*
- **Lowest Leakage**
  - *4,000 X < SuperCap*
- **Rechargeable/Long Life**
- **Superior Lifetime Energy**

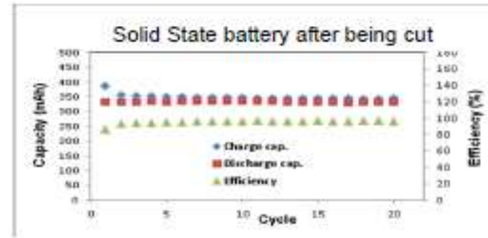
Solid Energy



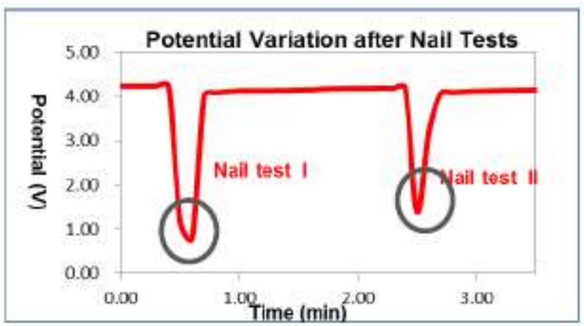
By using ionic liquids and thin films -- two cutting edge materials technologies, SolidEnergy reduces the limitations of lithium-polymer cells. [Image Source: MIT]

ATL – Solid State Batteries

ATL Solid State Battery—High Capacity



ATL's solid-state battery can be cycled normally after being cut



Solid state battery can "self-healed" after repeated nail tests.

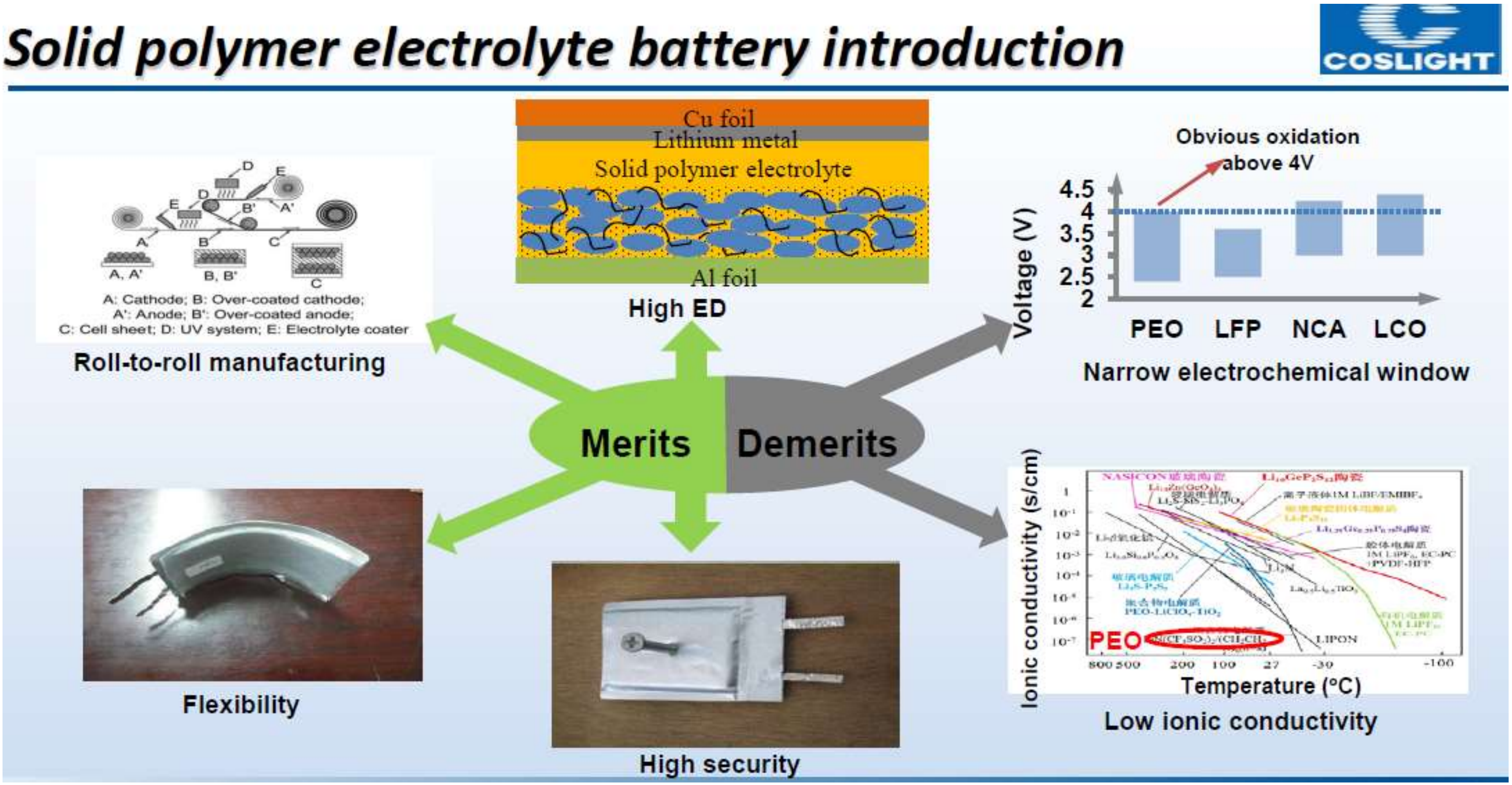
- **Nail Test**

Cell with liquid electrolyte after hot-box test.

Solid-state cell after hot-box test

- **Hot Box Test**

Coslight



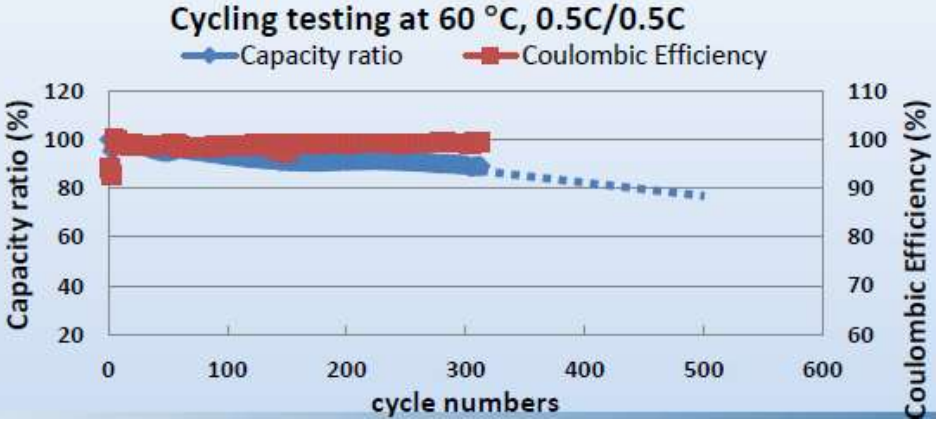
http://www.cncoslight.com/

COSLIGHT 光宇集团 COSLIGHT GROUP

Coslight work on polymer solid-state battery

LFP/SPE/Li pouch sample cell

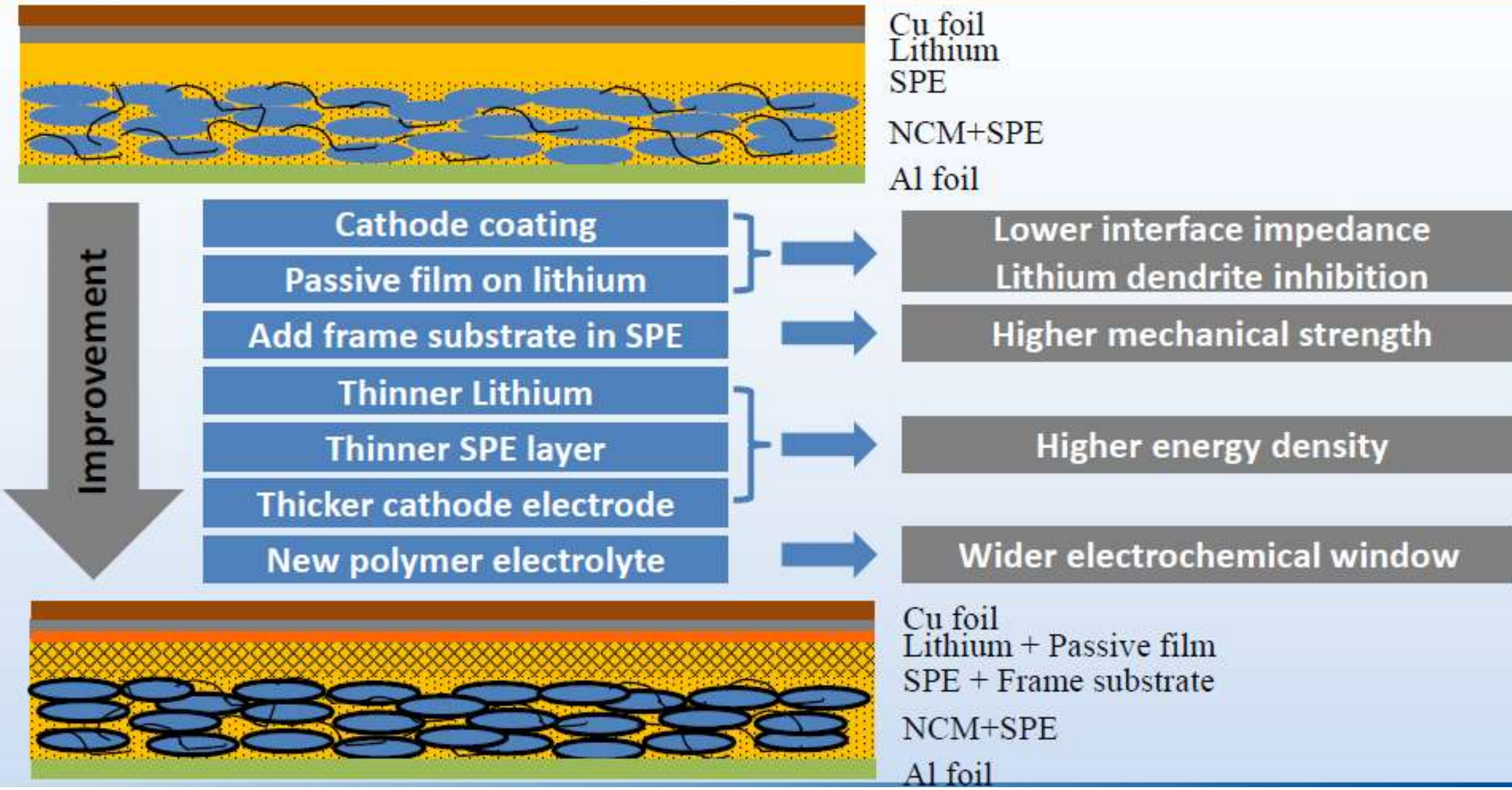
- Design capacity: 480 mAh
- Predicted life: 80%@500cycles
- Nail test: No fire, no explosion



Nail test

Solid battery   Liquid LIB

Strategies to improve the performance



Panasonic

Panasonic
ideas for life

LITHIUM-ION

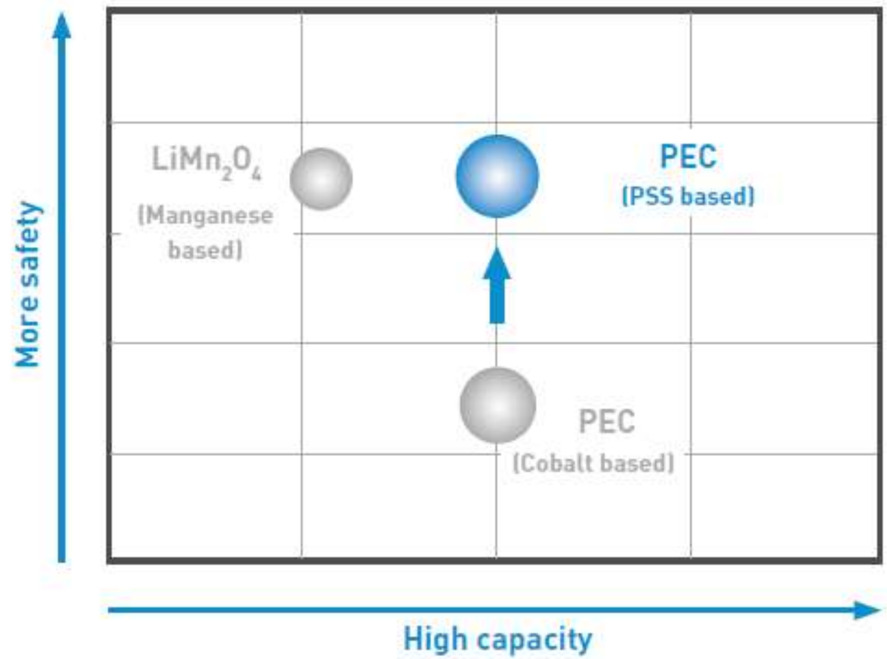
Panasonic Solid Solution (PSS)

The **Panasonic Solid Solution** technology combines two major battery properties: capacity and safety. This technology provides the customer with a high capacity such as the standard Panasonic Lithium-Ion (Cobalt based) cells and also owns a high safety standard like the $LiMn_2O_4$ (Manganese based) Lithium-Ion batteries.*[1]

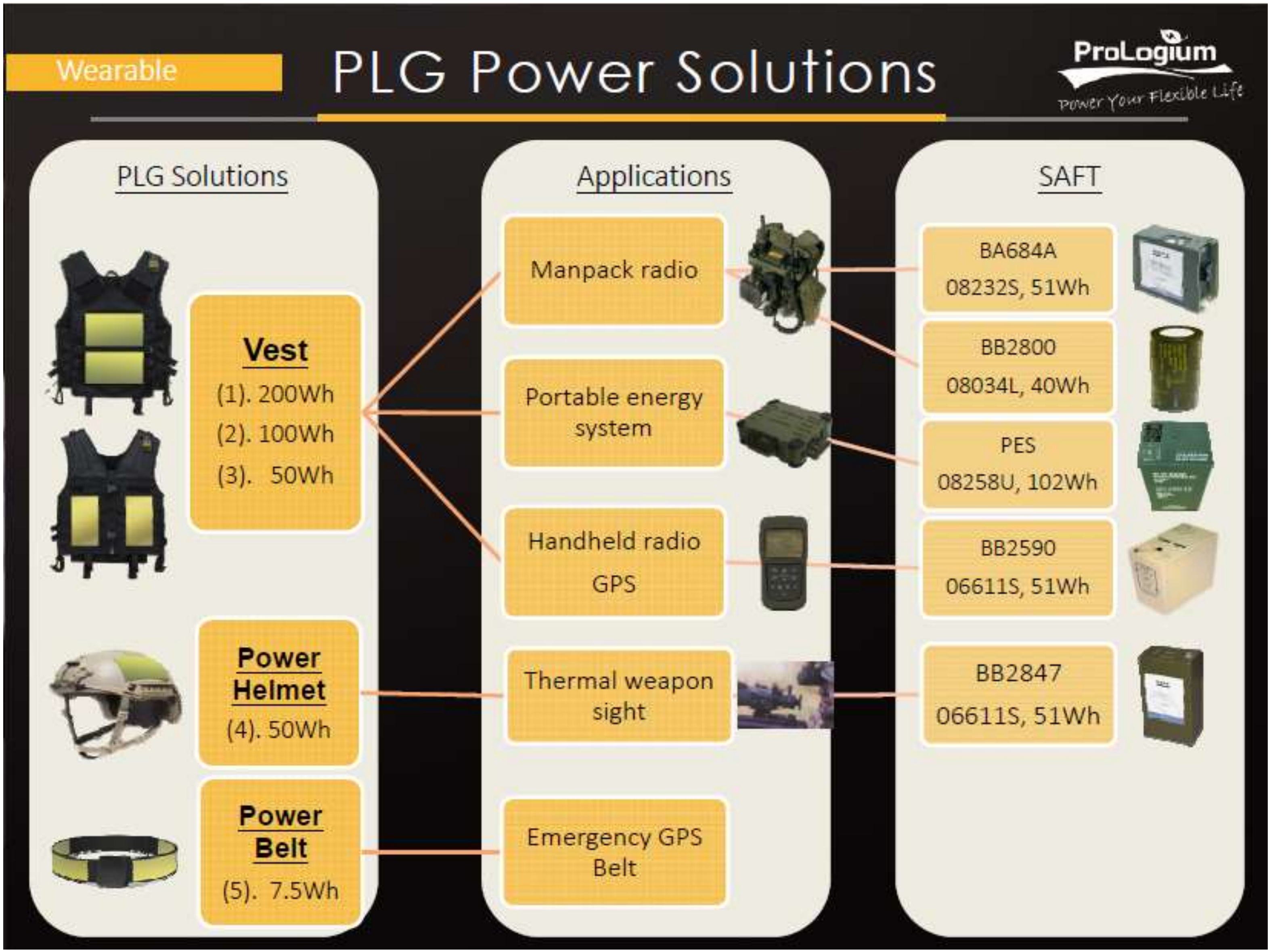
Characteristics of the Panasonic PSS featured Lithium-Ion battery:

- Thermal stability of cathode materials leads to high safety
- Same energy density as cobalt based Lithium-Ion batteries
- Excellent cycle life
- Less voltage drop at initial discharge than other Lithium-Ion batteries

COMPARISON BETWEEN CAPACITY AND SAFETY OF CATHODE MATERIALS



Prologiun


Wearable
PLG Power Solutions
ProLogium
Power Your Flexible Life
PLG Solutions
Vest
(1). 200Wh
(2). 100Wh
(3). 50Wh
Power Helmet
(4). 50Wh
Power Belt
(5). 7.5Wh
Applications
Manpack radio
Portable energy system
Handheld radio
GPS
Thermal weapon sight
Emergency GPS Belt
SAFT
BA684A
08232S, 51Wh
BB2800
08034L, 40Wh
PES
08258U, 102Wh
BB2590
06611S, 51Wh
BB2847
06611S, 51Wh

Toyota

Looking to gather momentum in the electric vehicle field, Toyota's focus is also on batteries. The Japanese giant has recently unveiled a solid-state $LiCoO_2$ (lithium cobalt oxide) battery that features higher energy density and bears temperatures of up to 100 degrees Celsius. The new cell is made from 4 x 3.6V units, totaling a 14.4 V.

Solid state batteries have the advantage of being able to be used far above the temperatures an organic electrolyte battery would be. When an all-solid-state battery is in an ideal state, the lithium spreads faster than electrolyte, and thus obtains higher power output.

Some Solid State Battery Developers/Manufacturers

Company Name	Battery Type	Cathode	Anode	Electrolyte	Link to Home Page	Country
Bathium	Undisclosed	LFP	Lithium Metal	Polymer	http://www.bathium.com/	Canada
Cymbet	Thin Film Solid State	LCO	Undisclosed	Ceramic (LiPON)	http://www.cymbet.com	USA
Excellatron	Solid State	Undisclosed	Lithium Metal	Ceramic (Not LiPON)	http://www.excellatron.com/	USA
Front Edge	Thin Film Solid State	LCO	Lithium Metal	Ceramic (LIPON)	http://www.frontedgetechnology.com/	USA
Infinite Power Solution	Undisclosed	Undisclosed	Undisclosed	Undisclosed	http://www.infinitepowersolutions.com/	USA
Samsung SDI	Solid State	Undisclosed	Undisclosed	Undisclosed	http://www.samsungsdi.com/	Korea
Solicore	Undisclosed	Undisclosed	Undisclosed	Undisclosed	http://www.solicore.com/	USA
SolidEnergy	Solid State	LCO, NCA	Lithium	Polymer and ionic liquid	http://solidenergysystems.com	USA
Toyota	Solid State	LCO	Indium metal	Ceramic ($Li_{10}GeP_2S_{12}$)		Japan

In total we know 21 Developer/Manufacturers and ~ 20 Universities/Institutes working on Solid Electrolyte Technologies!!!

Market Forecast & Trends

- Solid Electrolyte Batteries may provide the break through we are waiting for – farther development needed.

- Technology Status - Still under development – few companies to reach prototype manufacturing level.

- Power capacities are essential for that technology success

- Mass worldwide research efforts will lead to some progress on the coming years that will allow technology commercialization within 10 years time frame.

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1. **Public web sources.**
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