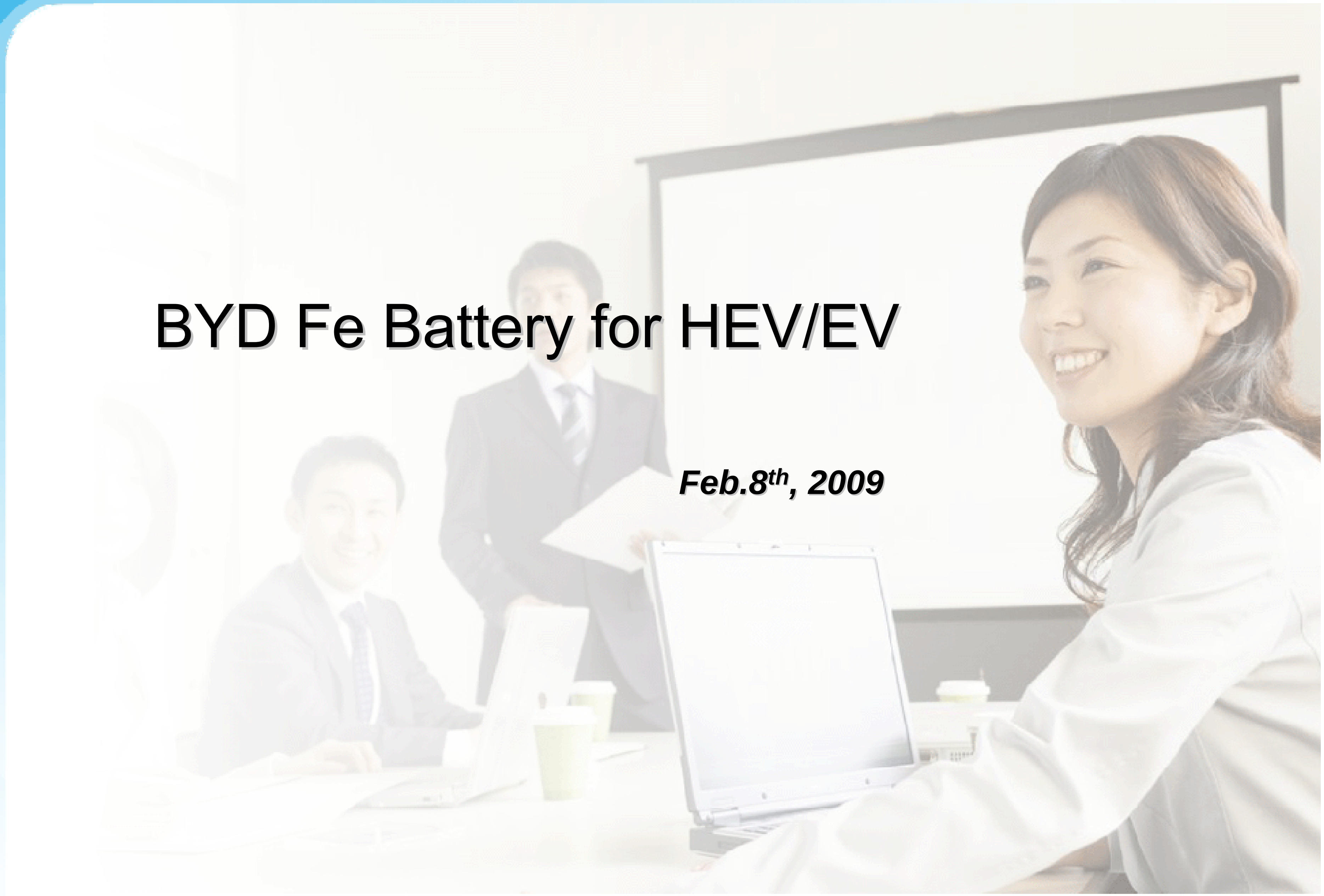
BYD Fe Battery for HEV/EV

Feb.8th, 2009



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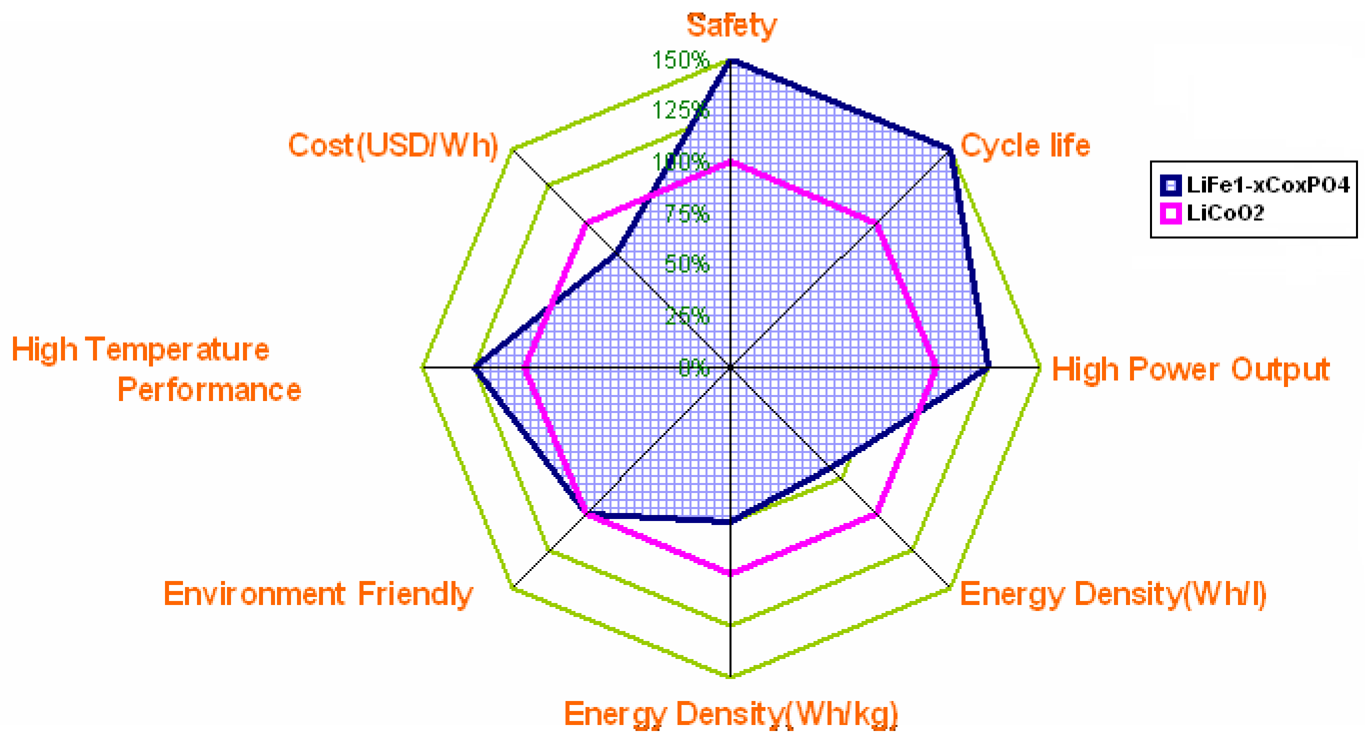
Contents

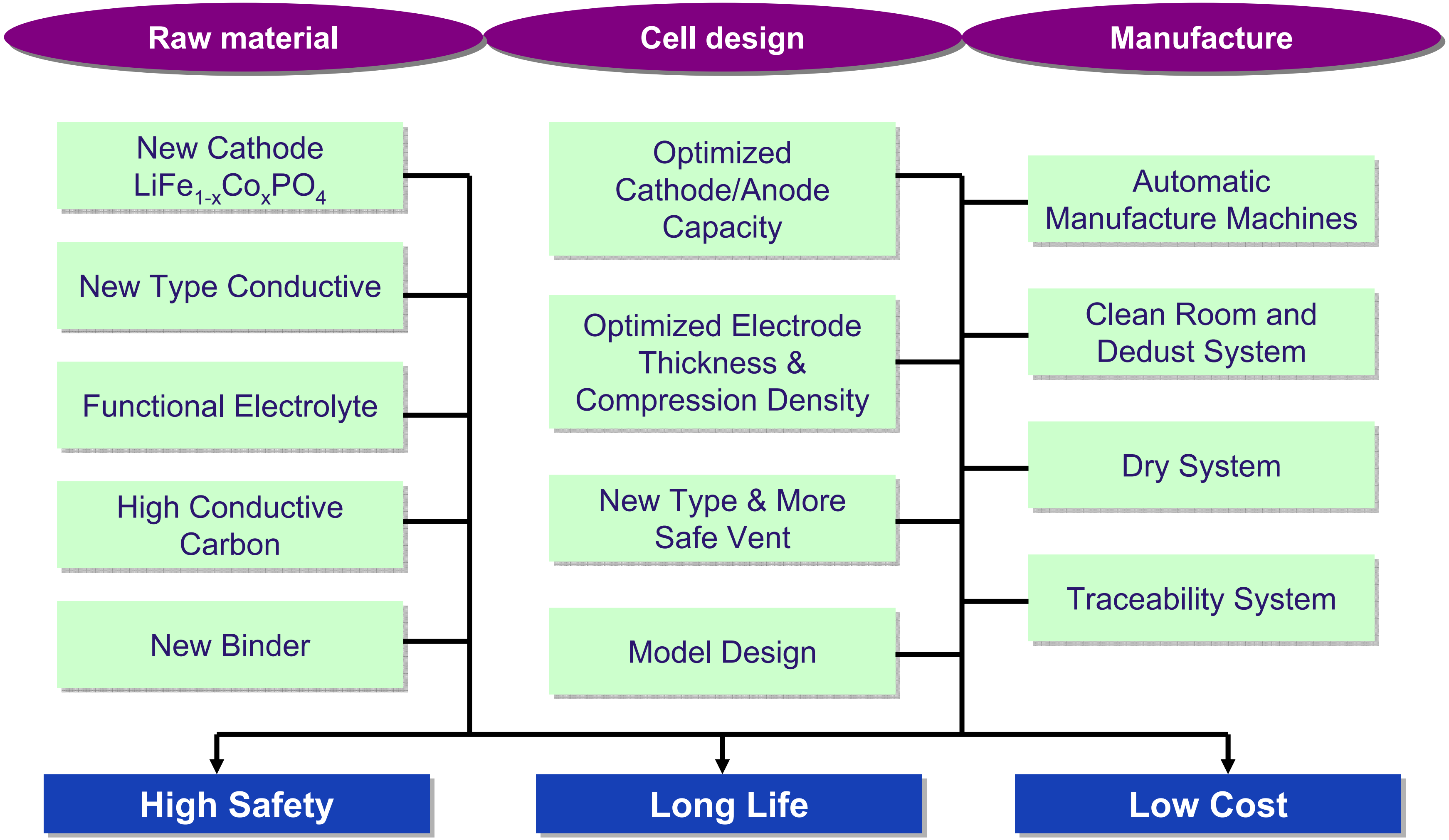
Technology of Fe Battery

Advantages of Fe Battery

- According to the compare between the Fe and LCO battery, Fe battery has the advantages in safety, cycle life, high power output and high temperature performance. Also lower cost is it's advantage.
- Lower energy density is Fe battery's disadvantage, it is about 75% of LCO battery.



Key Technology of BYD Fe Battery Development



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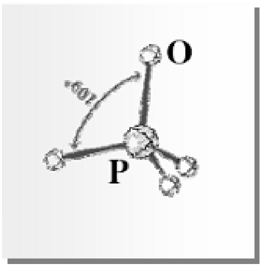
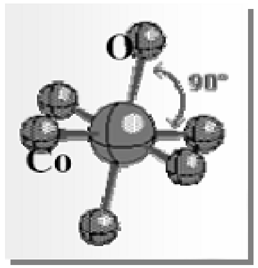
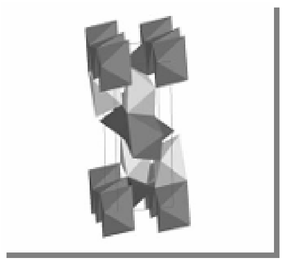
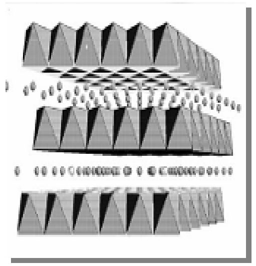
High Safety – High Strong Bone Energy



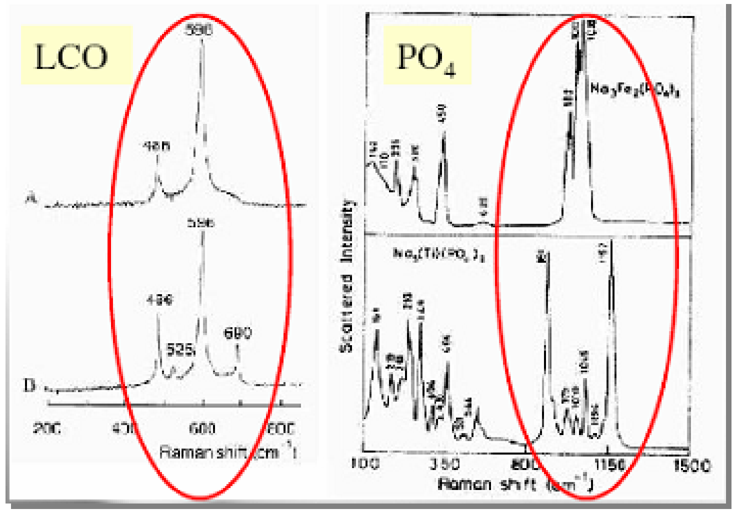


In $LiCoO_2$: Co-O 1.91Å
In $LiFe_{1-x}Co_xPO_4$: P-O 1.63Å





Coordination and location determine bond distance and strength.

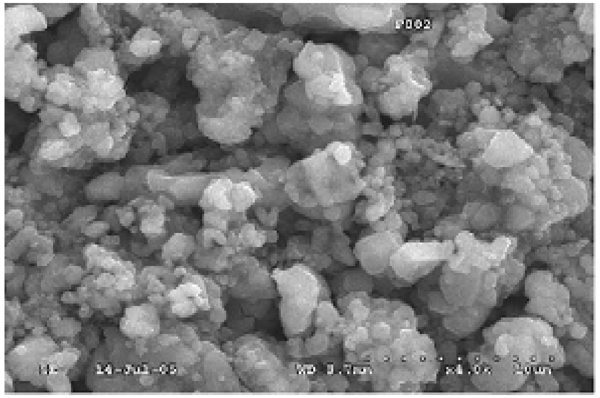


Raman Spectroscopy stretching bands:
P-O: 1100 cm^{-1}
Co-O: 540 cm^{-1}

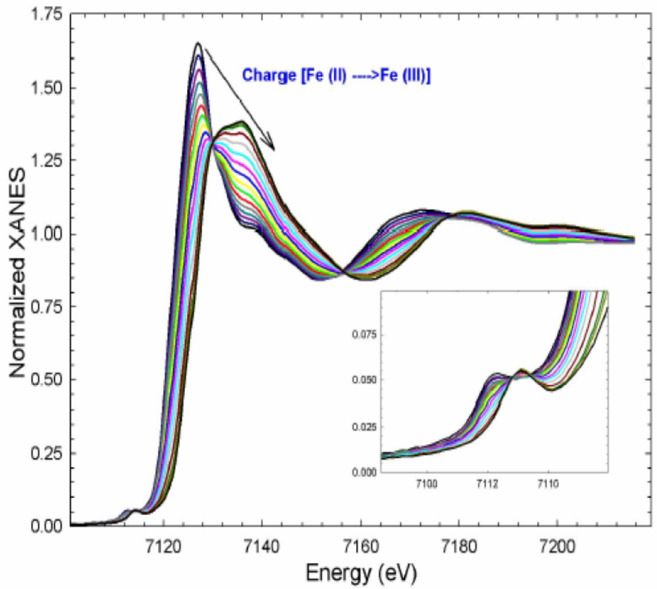
The P-O bond is stronger than Co-O bond.

Tightly bound Oxygen = Safety !!

Long Life – Stable Structure between charging and discharging



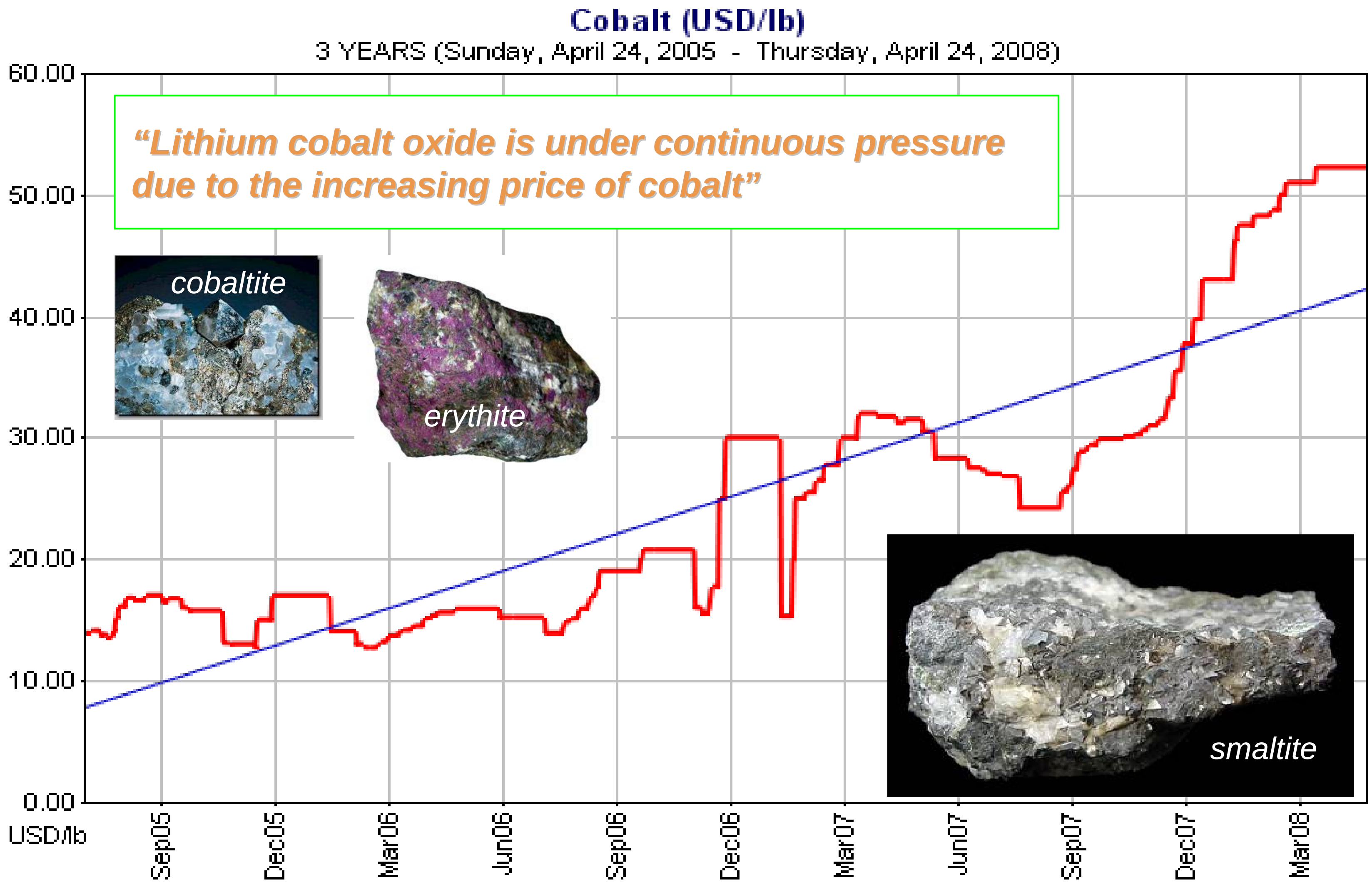
$LiFe_{1-x}Co_xPO_4$



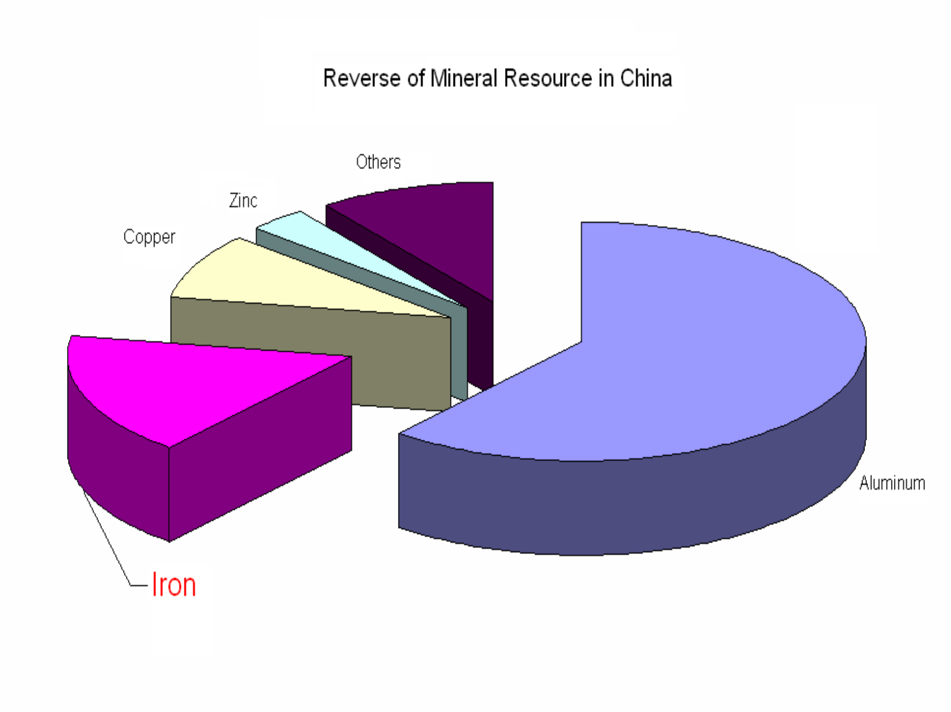
	$LiFe_{1-x}Co_xPO_4$	$Fe_{1-x}Co_xPO_4$
Space Group	Pbnm	Pbnm
a axis (nm)	0. 6008	0. 5792
b axis (nm)	1. 0334	0. 9821
c axis (nm)	0. 4693	0. 4788
Volume (nm^3)	**0. 2914**	**0. 2724**

For reverse volume change trend between $LiFe_{1-x}Co_xPO_4$ and graphite, total cell volume changes very small.

Low Cost - Main components in traditional Li battery



Low Cost - Inexpensive components in Fe battery



- ✓ **Iron resource in abundance**
- ✓ **High mining technology**
- ✓ **Raw materials of $LiFe_{1-x}Co_xPO_4$ synthesized are cheap**

Fe and PO_4 are common components.

Battery Design

BYD Battery's Advantages

- **Long Life**

  Adoption with new cathode and anode materials. After 3500 100% DOD cycles, the capacity remained 80%.

- **High Power Density**

  Optimizing the output power of cell. Power density of cell is more than 1720 W/L.

- **Faster Charging**

  Using high conductive anode material for fast charging. 80% capacity can be charged in 10min.

- **Low Resistance**

  Maxing the galvanizing area. The resistance of cell is about 0.5mΩ.

- **High Reliability**

  Identifying and preventing all potential risks in cell design, such as short circuit, cockled.

- **Low selfdischarge**

  With HBL technology, selfdischarge of cell is less than 1% capacity per month in storage.

- **Perfect adaptability with different temperature**

  All materials are stable for high or low temperature. The cell's operation temperature is -30℃ to 60℃.

- **Producible in Automatic**

  All processes are designed for automatic. Output of every product line is more than 2000pcs/day.

- **Low Cost**

  Key materials are made by ourselves. The cost is in minimum.

Difference Types of EV/HEV Battery

DM（PHEV） series and EV series:

（1）DM series

There is HEV and EV two modes in DM series. In short distance (in 100km) the EV mode will be used and startup the HEV mode in long distance. All is supported by Energy Feedback.

DM battery can be charged by general charging (220V) and faster charging. General charging for 100% capacity is about 5-6 hours and 80% capacity can be charged in 10min by faster charging.

The data of table 1 is DM battery’s parameters。

（2）EV series

It can be droved for more than 350km in EV mode with a full capacity. It is supported by Energy Feedback.

EV battery also can be charged by general charging (220V) and faster charging. General charging for 100% capacity is about 5-6 hours.

80% capacity can be charged in 16min by faster charging.

The data of table 2 is EV battery’s parameters。

Table1：F3DM Battery System Major Parameters

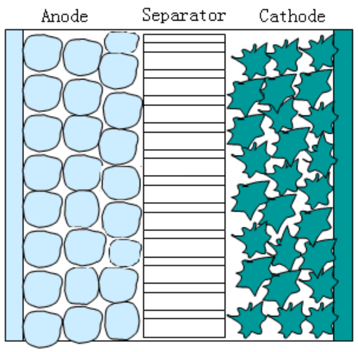
Characteristic	Value	
Normal Voltage	325V/315V（at 0.2C discharge/at 1.0C discharge current）	
Capacity	45Ah	
	(From 380V to 200V in 0.2C discharge current)	
Dimension	1780*806*120mm	
Weight	200Kg	
Cycle life	10 year	
Short-Time Discharge Power(10s)	135kw	
Long-Time Discharge Power	67.5kw	
Usable Energy	13.5kwh	
Working Temperature (° C)	Min	Max
	-40	60
Storage Temperature (° C)	Min	Max
	-46	66
Temperature Adjust System	Air (cooling and heating) Inside cycle Channel	
Voltage Sensor	Each Cell	
Temperature Sensor	Each Cell	

Taber2：e6 Battery System Major Parameters

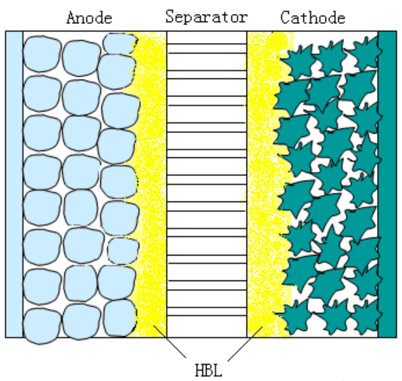
Characteristic	Value	
Normal Voltage	325V/315V（at 0.2C discharge/at 1.0C discharge current）	
Capacity	180Ah	
	(From 380V to 200V in 0.2C discharge current)	
Dimension	1730*915*330mm	
Weight	650Kg	
Cycle life	10 year	
Short-Time Discharge Power(10s)	270kw(5C)	
Long-Time Discharge Power	162kw	
Usable Energy	57kwh	
Working Temperature (° C)	Min	Max
	-40	60
Storage Temperature (° C)	Min	Max
	-46	66
Temperature Adjust System	Air (cooling and heating) Inside cycle Channel	
Voltage Sensor	Each Cell	
Temperature Sensor	Each Cell	

Technology of HBL

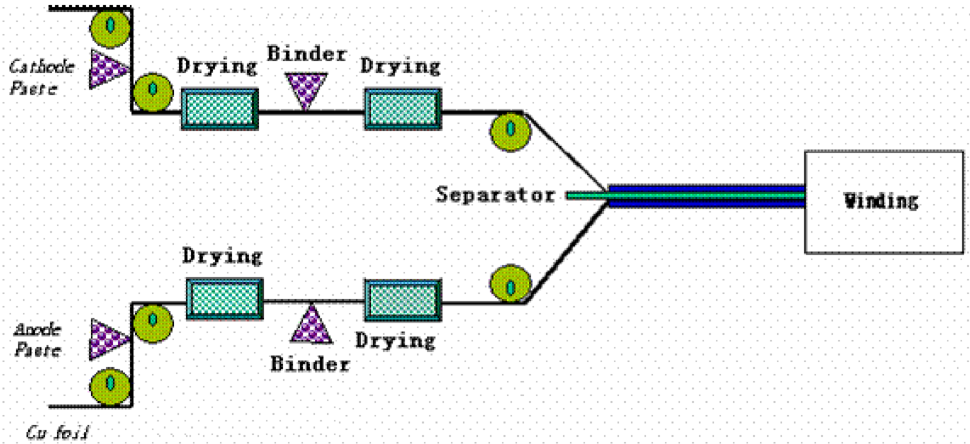
HBL (High-temperature Binder Layer) is a new technology developed by our company. The exfoliation of active materials, burr of electrode can be reduced by coating a heat-resistant micro porous binder layer, and the self-discharge, consistency, cycle-life and safety can be improved substantially.



Normal Battery Structure



HBL Battery Structure



Flow chart of HBL

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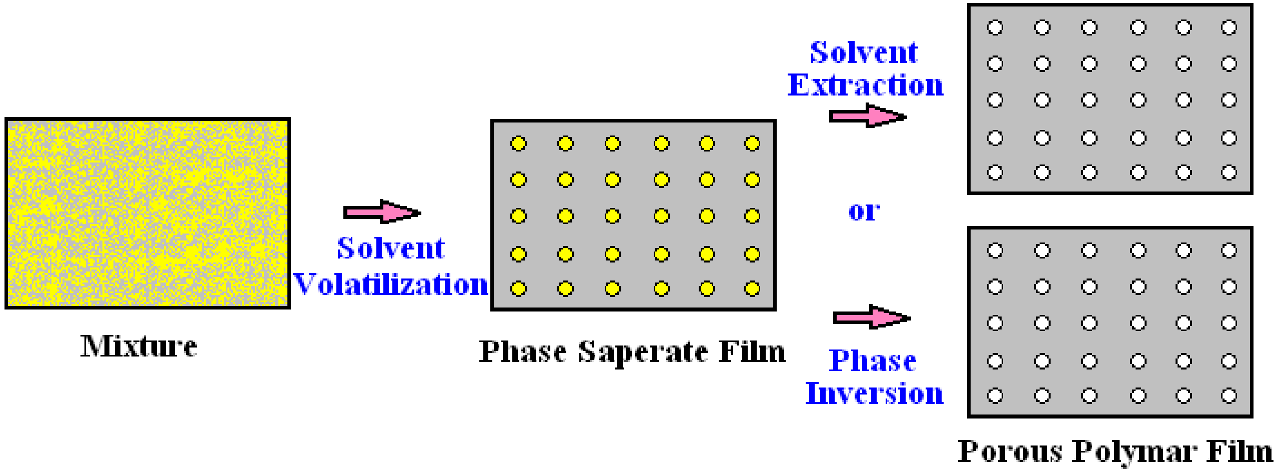
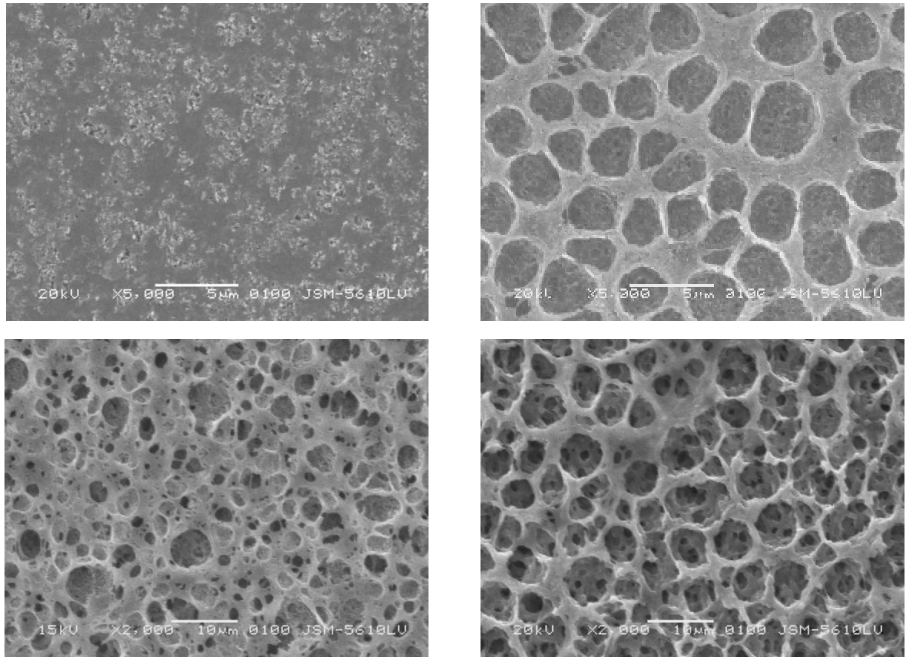
Technology of HBL

Phase Inversion Method

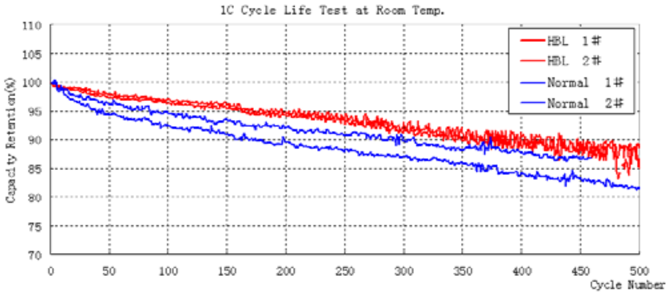


SEM of HBL

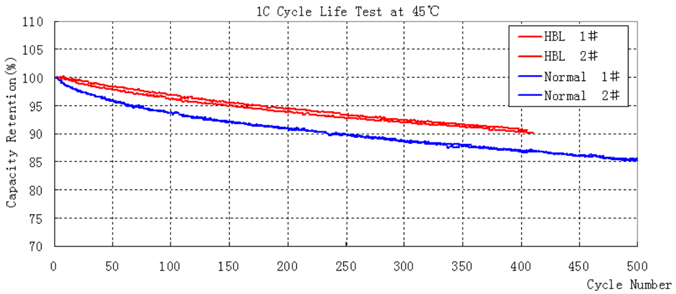


The Advantage of HBL

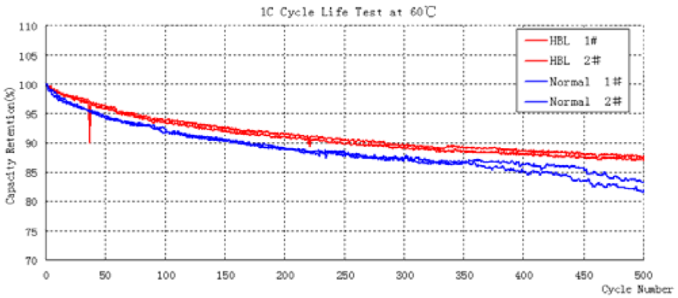
Long Cycle Life
Low Self-discharge



1C Cycle at Room Temp.



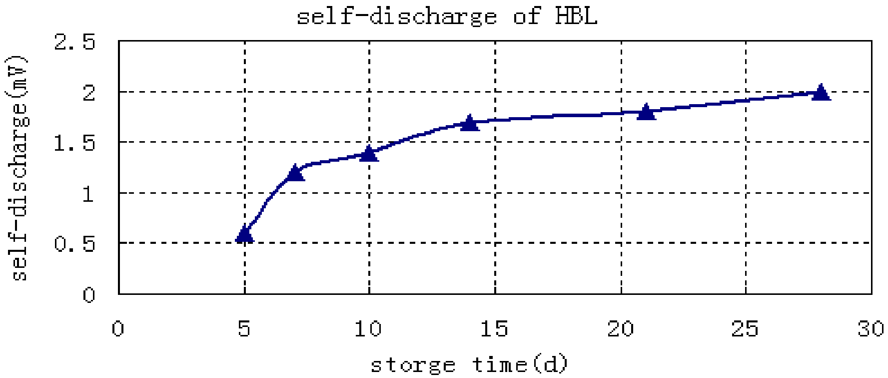
1C Cycle at 45 ℃



1C Cycle at 60 ℃

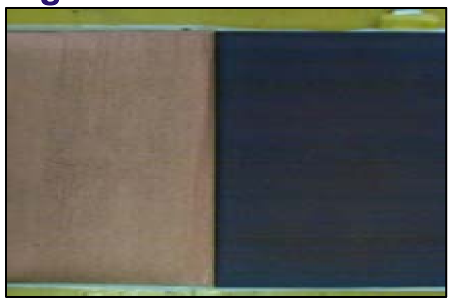
Why Does HBL Low Self-discharge?

1. No Exfoliation;
2. No Burr;
3. Little Side Reaction.



Self-discharge of HBL

Normal Negative Electrode:
Active Material Exfoliation



HBL Negative Electrode:
No Active Material Exfoliation

The Advantage of HBL

High Safety

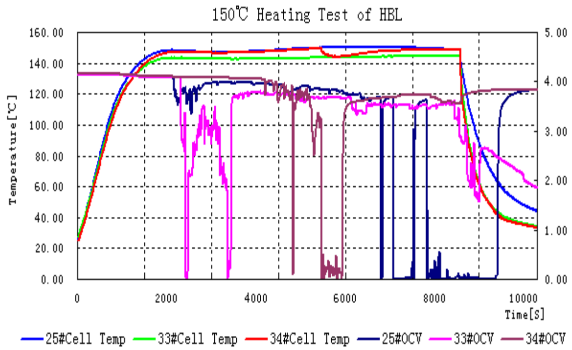
Why Does HBL High Safety?

1. Three Protective Layers;

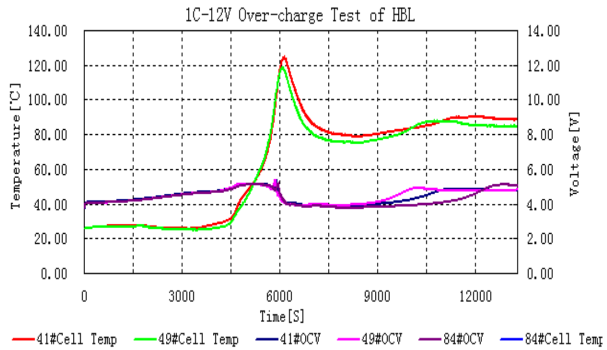
2. High Temp. Additive in the Layer, No Short-circuit;

3. No gap between Electrode and Separator, No Lithium Dendrite.

150 ℃ heating test of HBL



1C/12V over-charge test of HBL



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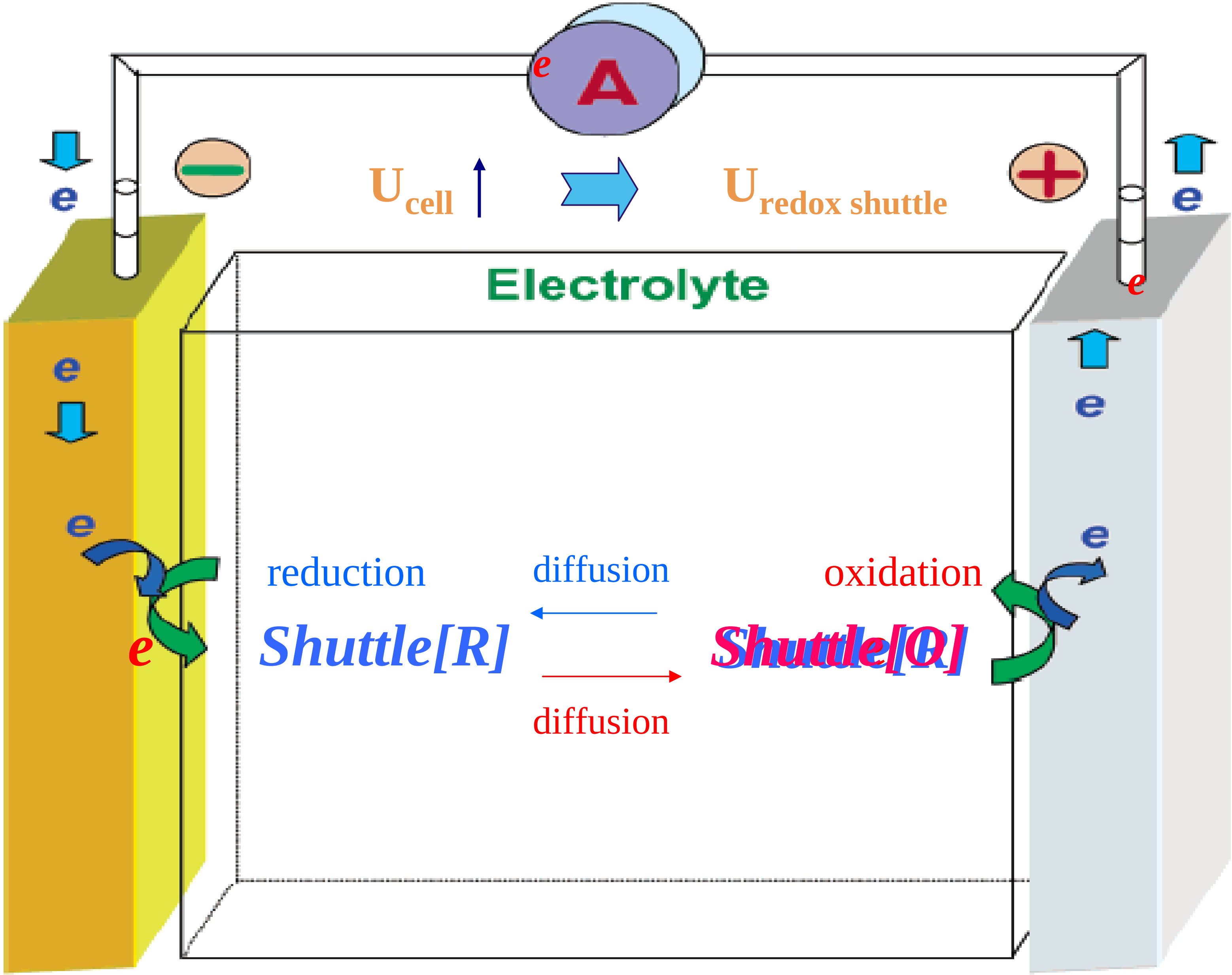
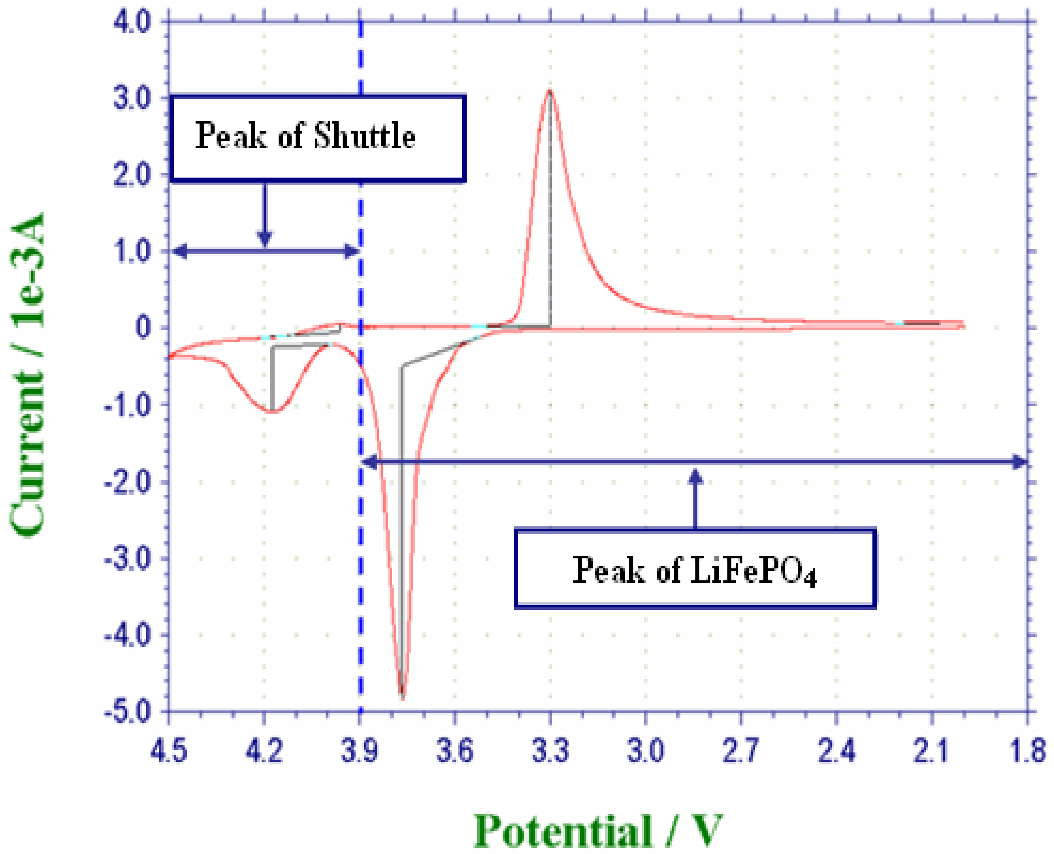
A schematic showing the working of a redox shuttle

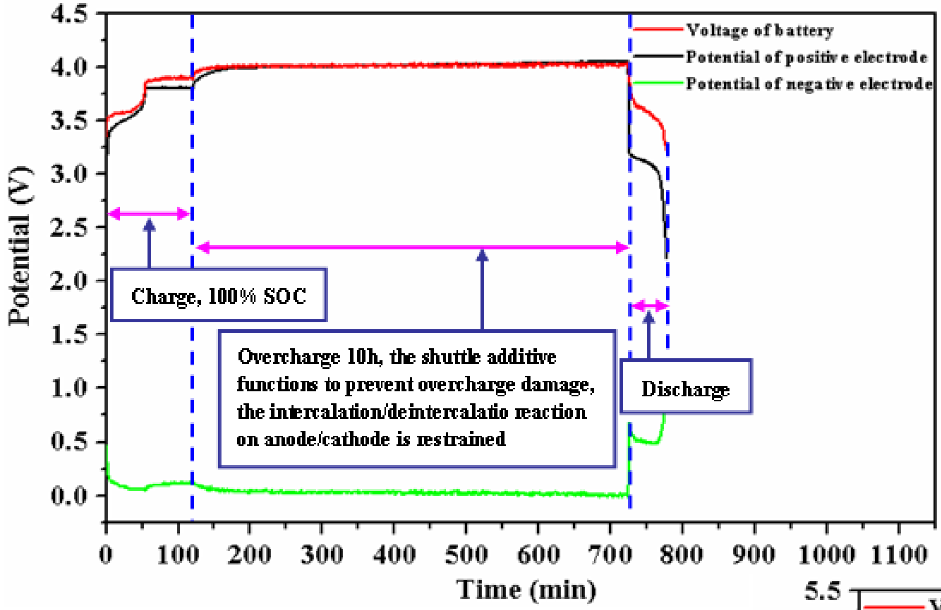


The working voltage of Shuttle



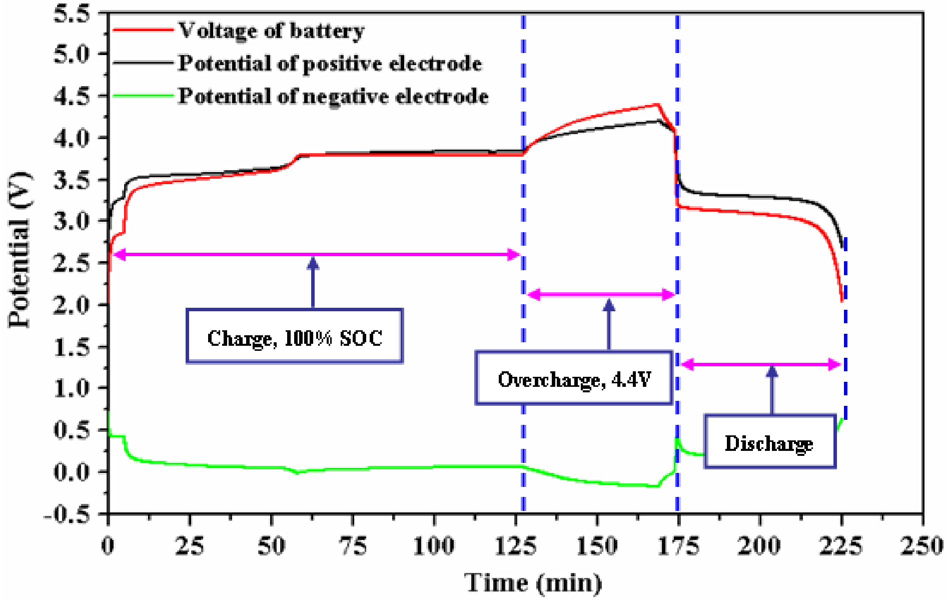
The operation voltage of Shuttle is about 4.0-4.2V when the oxidation reaction happens on cathode. It's suitable for Fe Battery.

The charge comparison in LIB



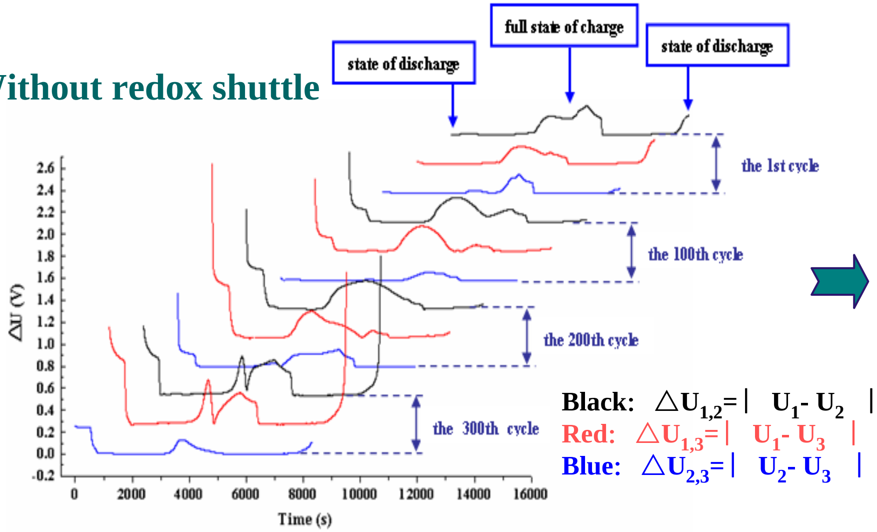
With redox shuttle

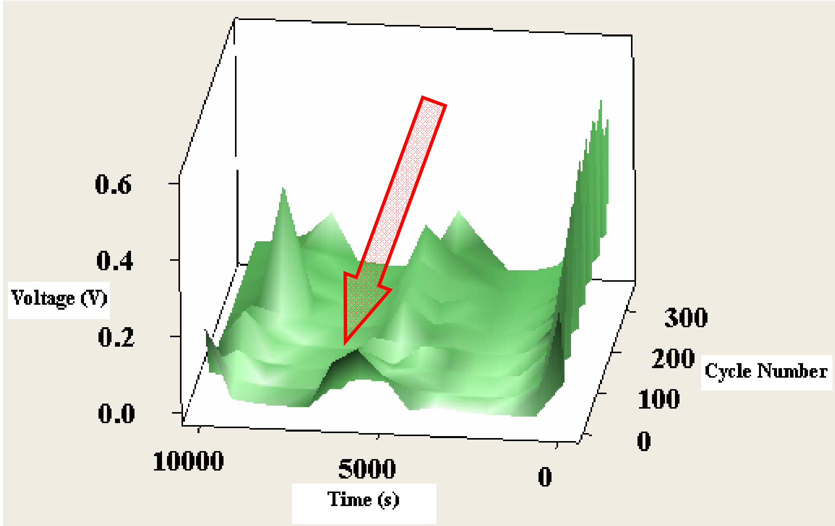
Without redox shuttle



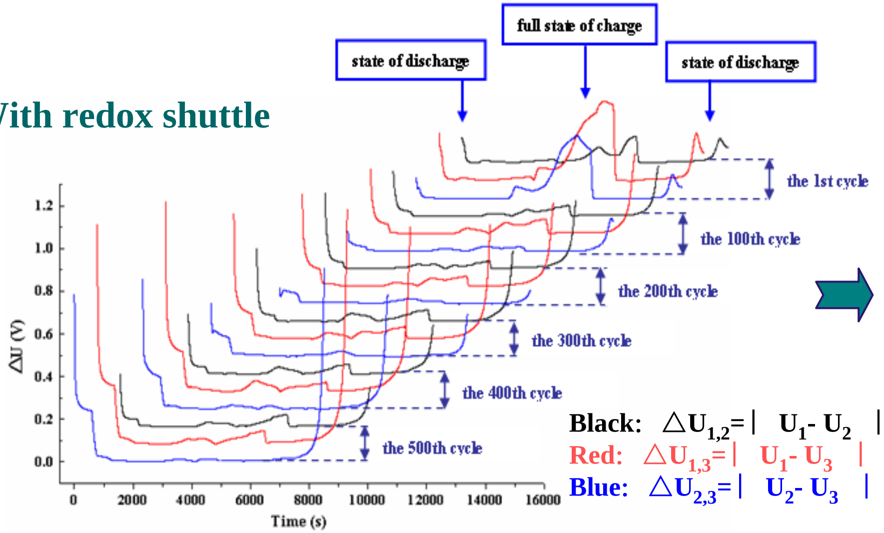
The voltage difference comparison during cycle in LIB

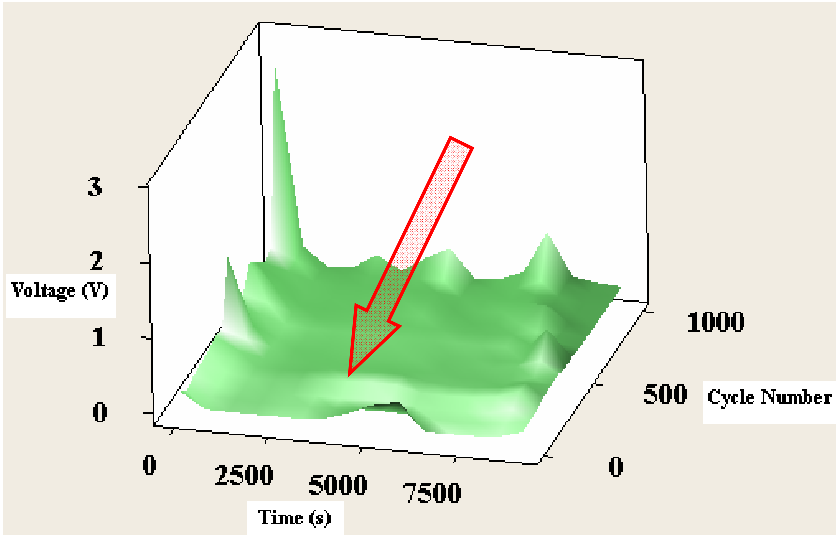
Without redox shuttle





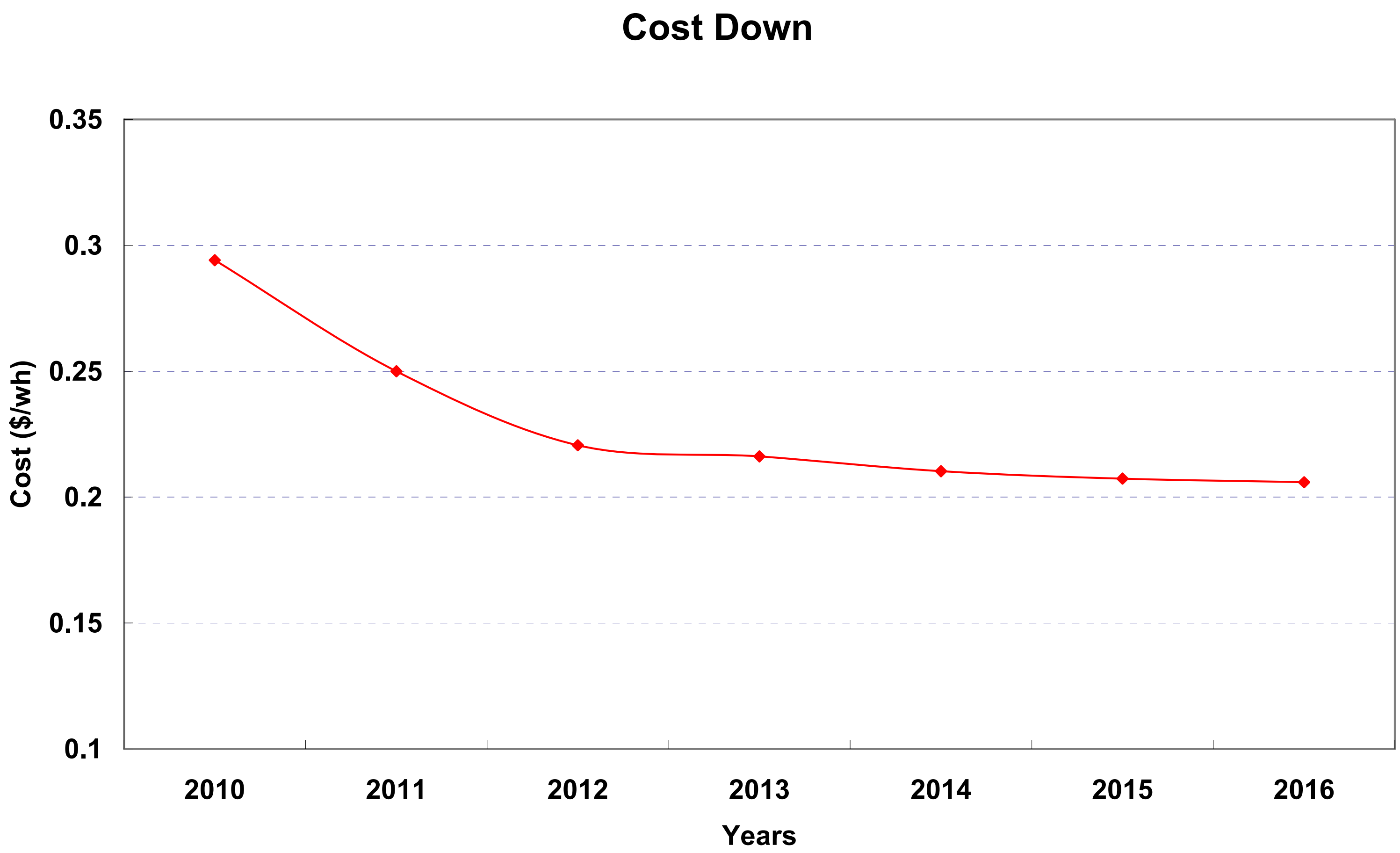
With redox shuttle





During the course of charge-discharge cycling, the variation of voltage difference in each cell connected in series as a function of cycles.

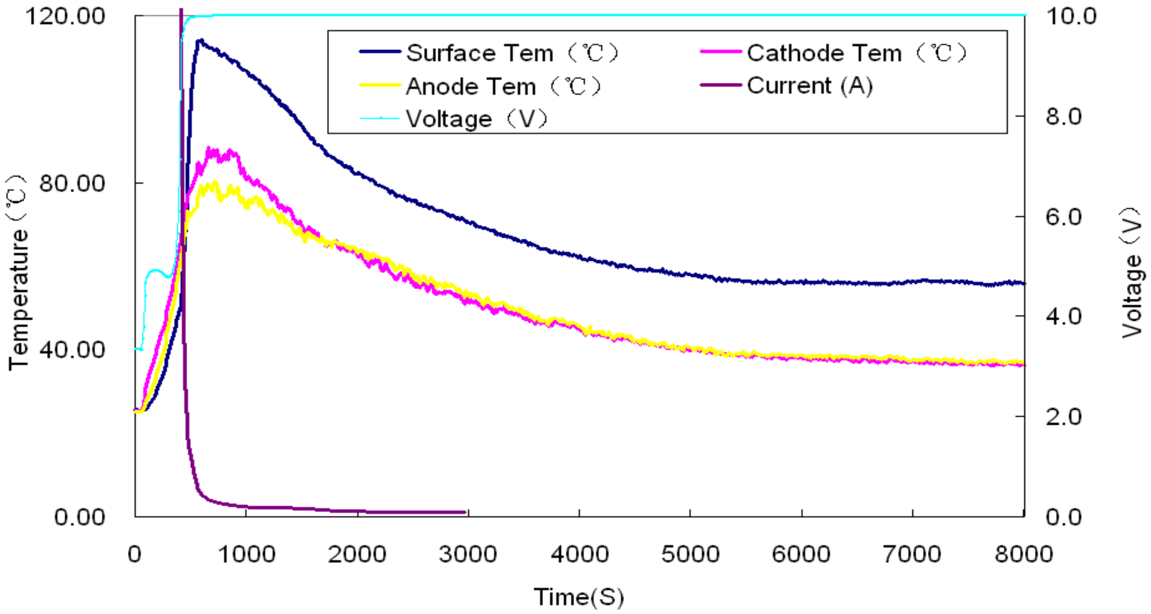
Cost Down Roadmap

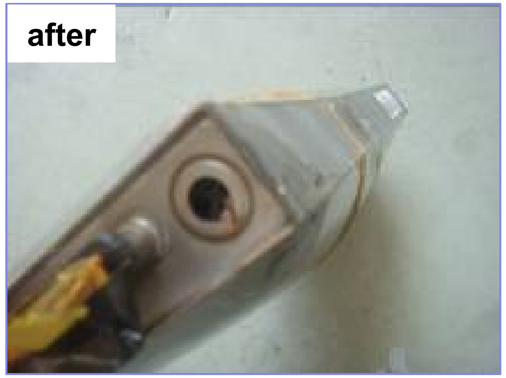


In 2016, the cost of per wh will be about 0.2$!!

Battery Performance

1 Overcharge





Test procedure
Charge current : 3C
End-of-charge voltage : 10V

Dimension : 28*100*330mm
Result : Pass, cell inflation and vent open

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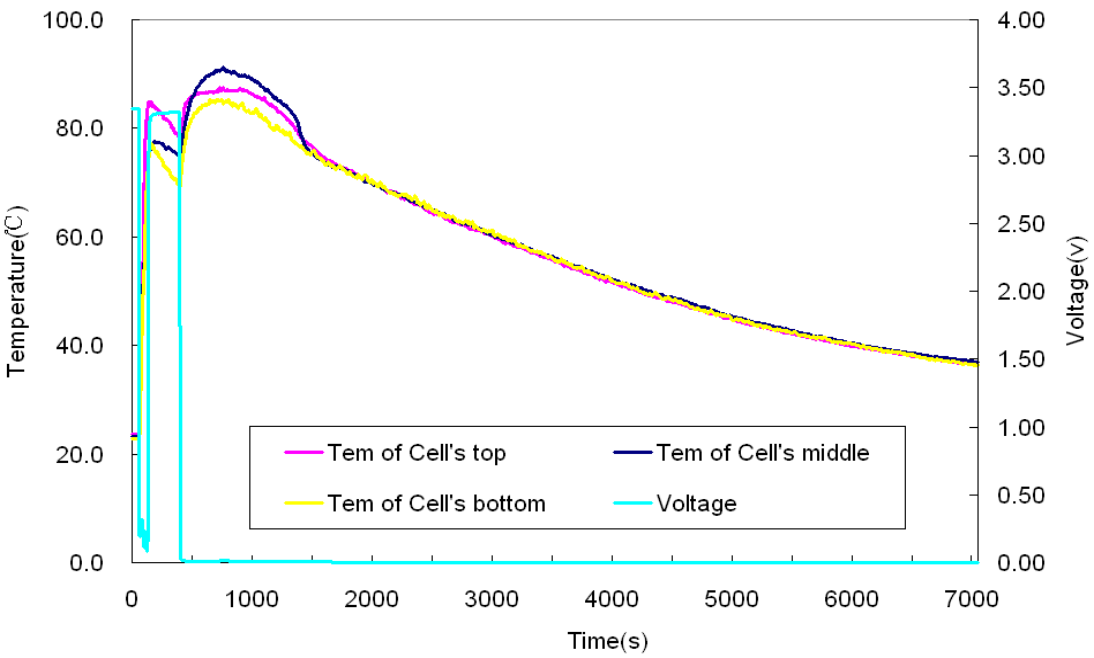
1 Short Circuit

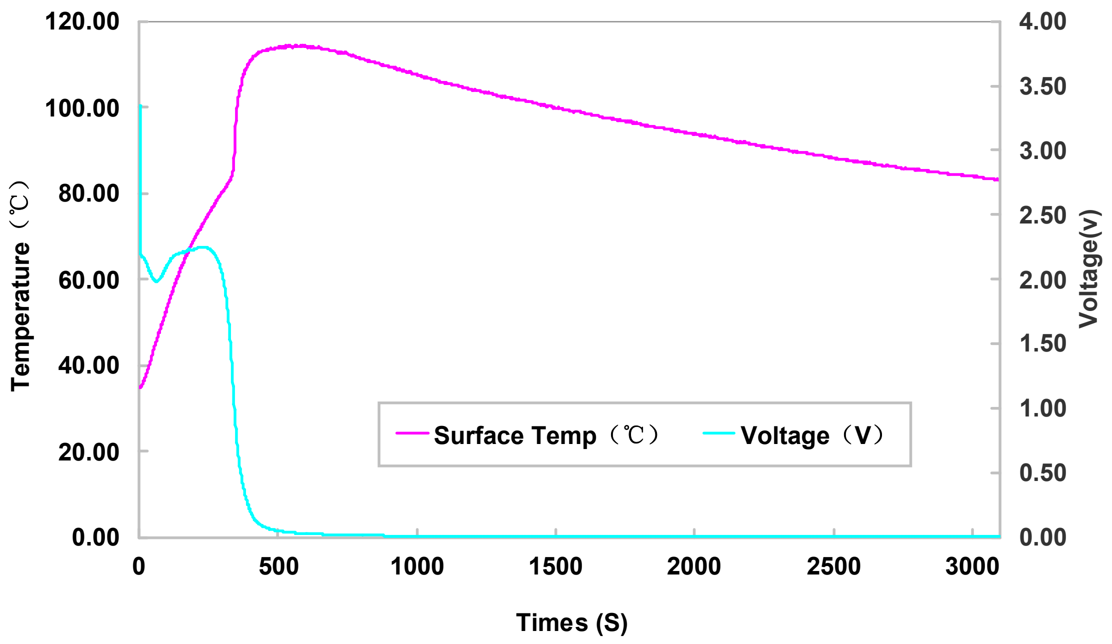


Test procedure
Charge current : 0.2C
End-of-charge voltage : 3.8V
Method : external short circuit, <5mOhm

Dimension : 28*100*330mm
Result : Pass, cell inflation and vent open

Build Your Dreams

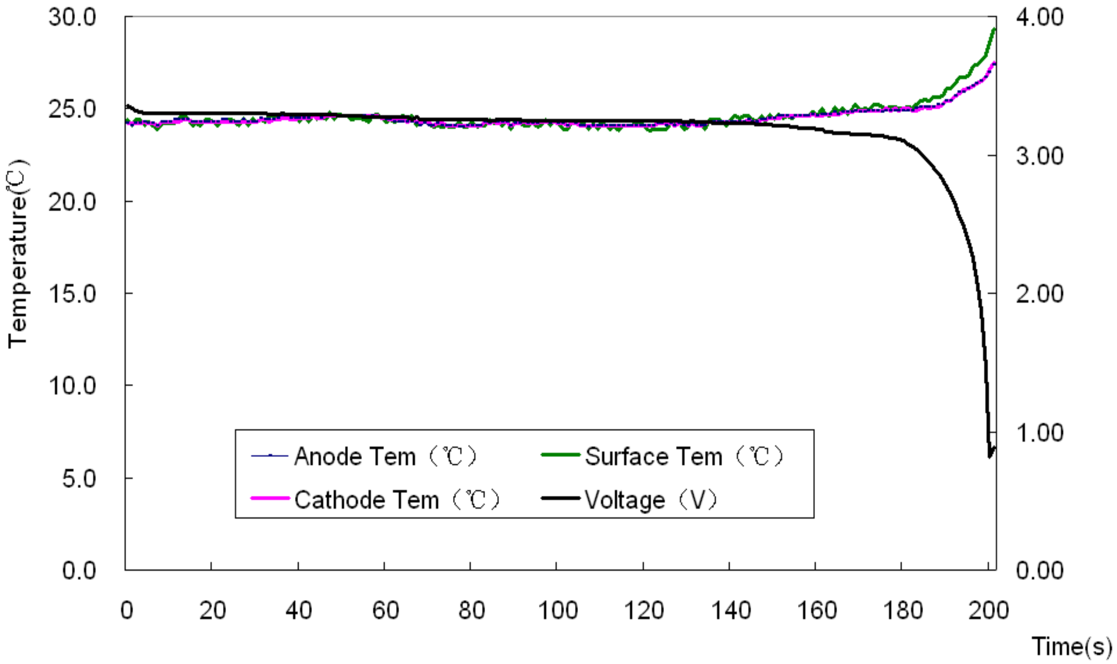
1 Short Circuit at 60°C

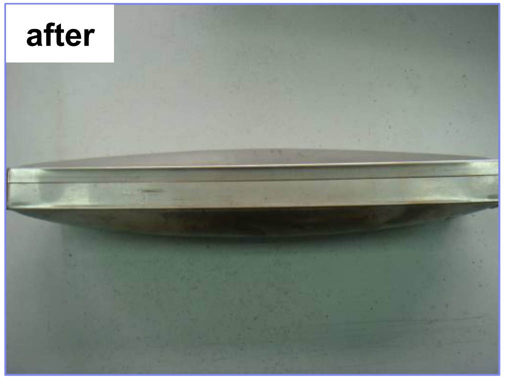


Test procedure
Temperature : 60 ℃
Charge current : 0.2C
End-of-charge voltage : 3.8V
Method : external short circuit, <5mOhm

Dimension : 28*100*330mm
Result : Pass, cell inflation, no leakage

1 Over-discharge

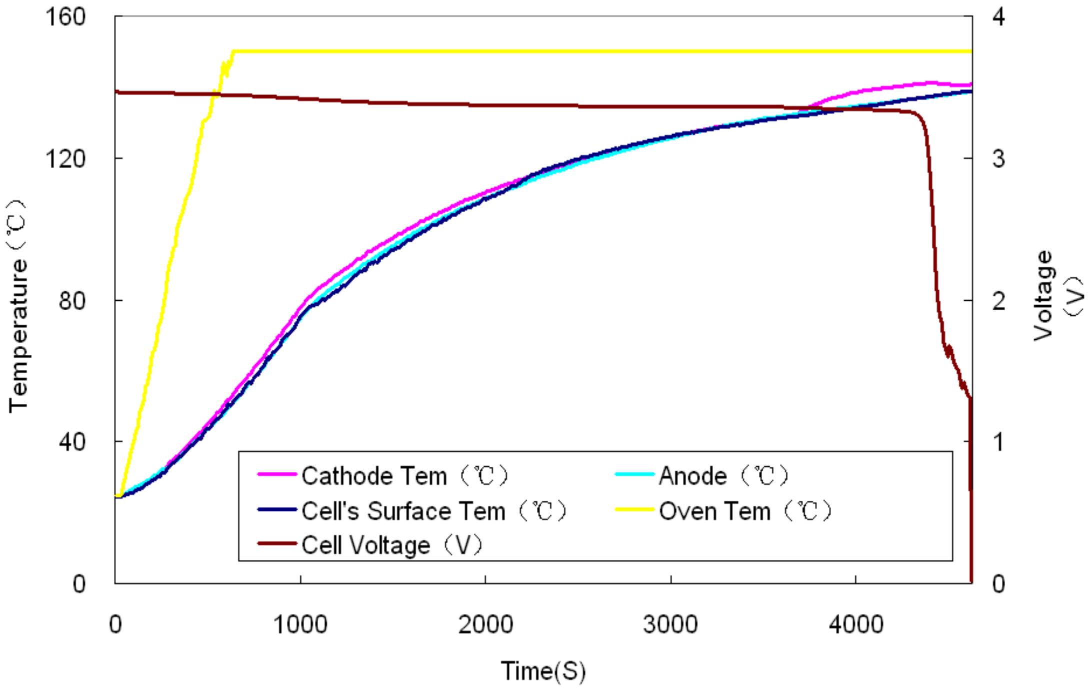




Test procedure
Discharge current : C/3
End-of-discharge voltage : 0 V

Dimension : 28*100*330mm
Result : Pass with cell inflation

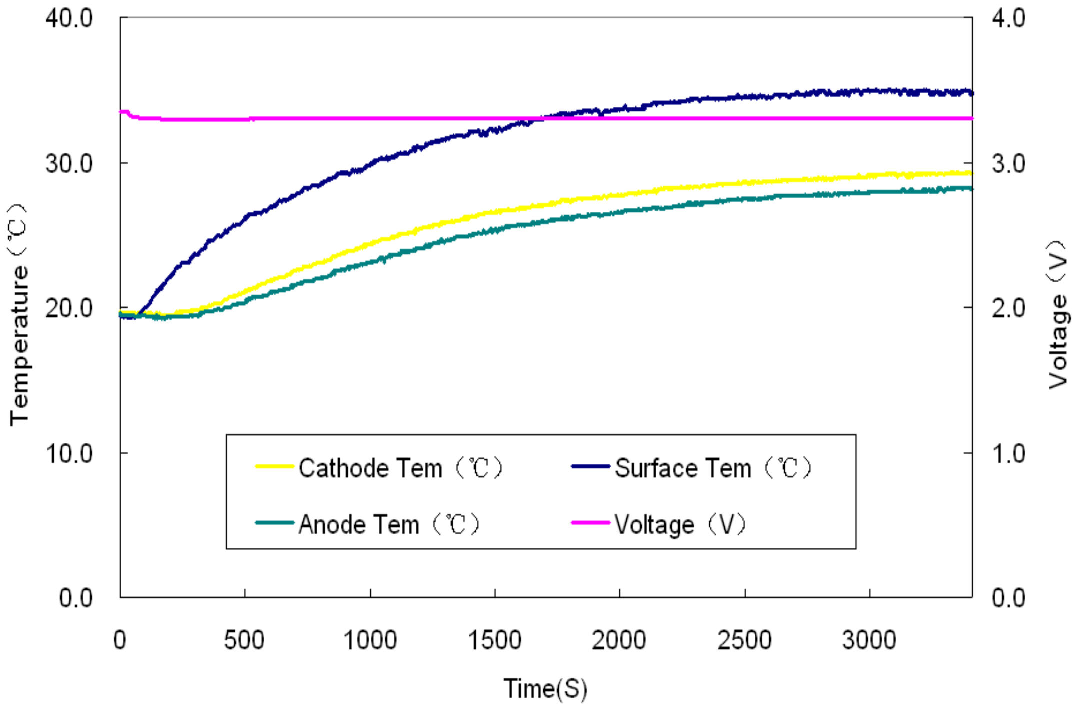
1 Hot Oven



Test procedure
Temperature : 150±2 ℃
Rest time : 120mins

Dimension : 28*100*330mm
Result : Pass, cell inflation and vent open

1 Nail Penetration



Test procedure
Temperature : 20±5 ℃
Diameter of steel pin : 3~8mm
Speed of penetration : 10~40mm/s
Penetration orientation :
perpendicular to the wide side

Dimension : 28*100*330mm
Result : Pass, cell inflation

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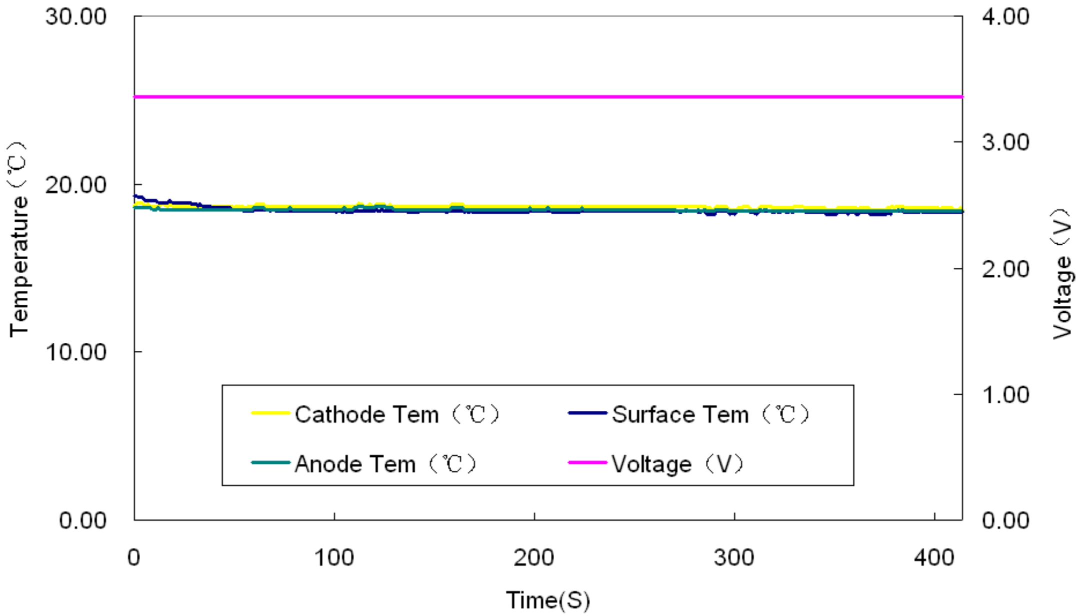
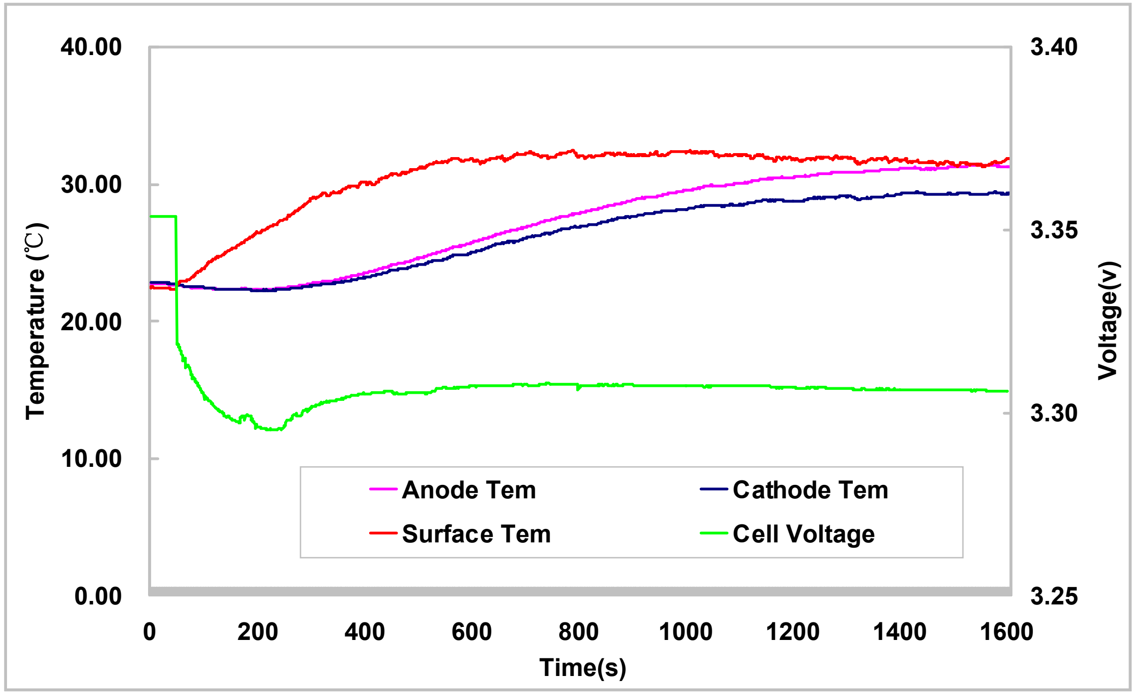
1 Crush



Test procedure
Temperature : 20±5 ℃
Crush path : perpendicular to the wide side
Crush Platen area：≥ 20cm²
End of test：Cell case rupture or inner short

Dimension : 28*100*330mm
Result : Pass with cell deformation

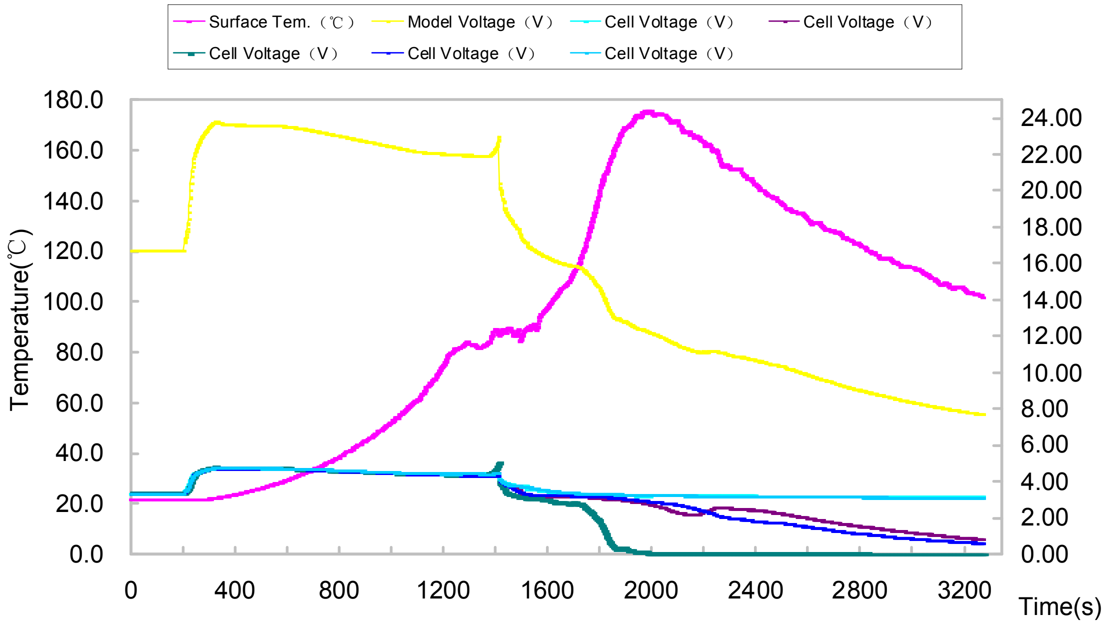
1 Impact



Test procedure
Charge current : 0.2C
Speed : 50Km/h
Impact orientation1 : Front side
Impact orientation2 : left side, with30º wedge
Impact orientation3 : right side, with30º wedge

Dimension : pack (cell 28*100*330mm)
Result : Pass with smoke

Battery Module Overcharge



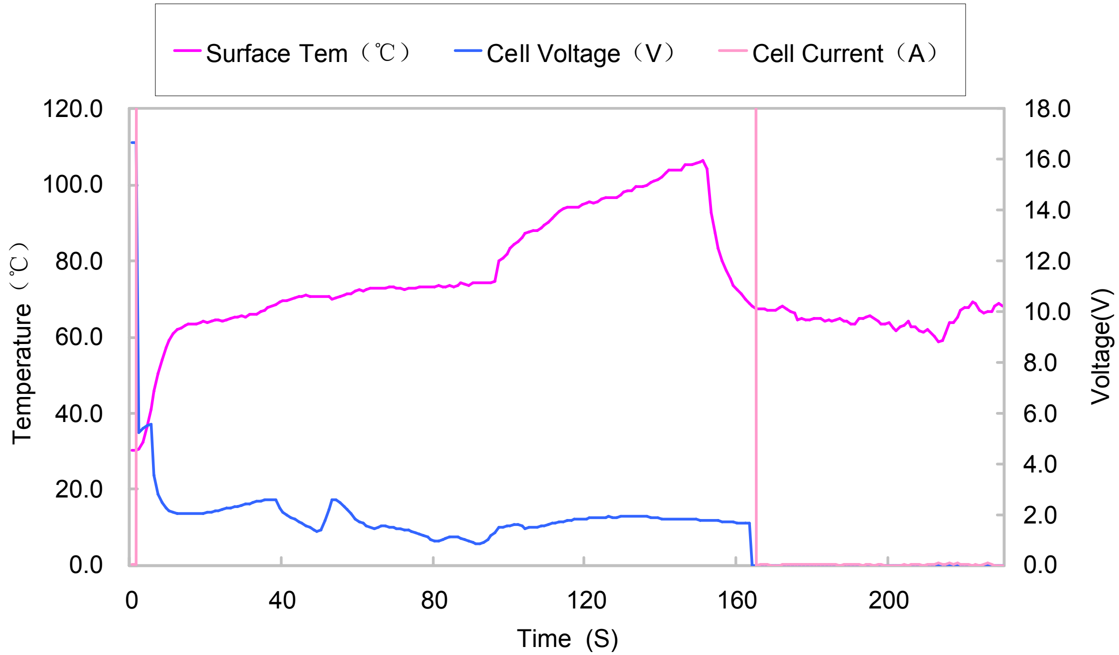
before

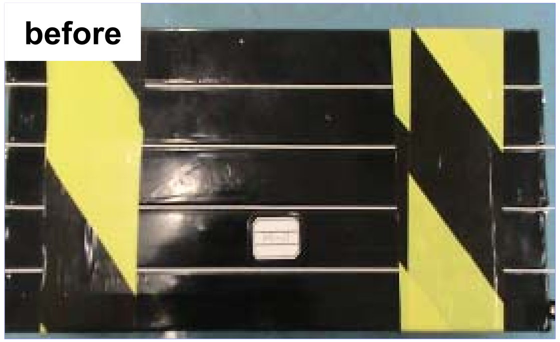
after

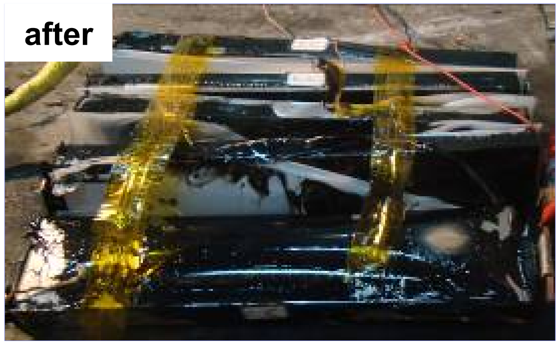
Test procedure
Charge current : 1C
End-of-charge voltage : 25V

Dimension : Module (cell28*100*300mm*5)
Result : Pass, cell vent open

Battery Module Short Circuit







Test procedure
Charge current : 0.2C
End-of-charge voltage : 3.8V
Method : external short circuit, <5mOhm

Dimension : Module (cell28*100*300mm*5)
Result : Pass, cell inflation , vent open

Build Your Dreams

1 Battery Module Fire Test

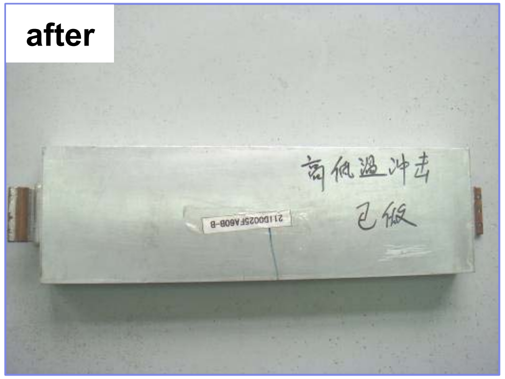
Pls see the video

- No explosion during fire test
- Battery module start fire after 27 minutes

2 Thermal Shock

before

after

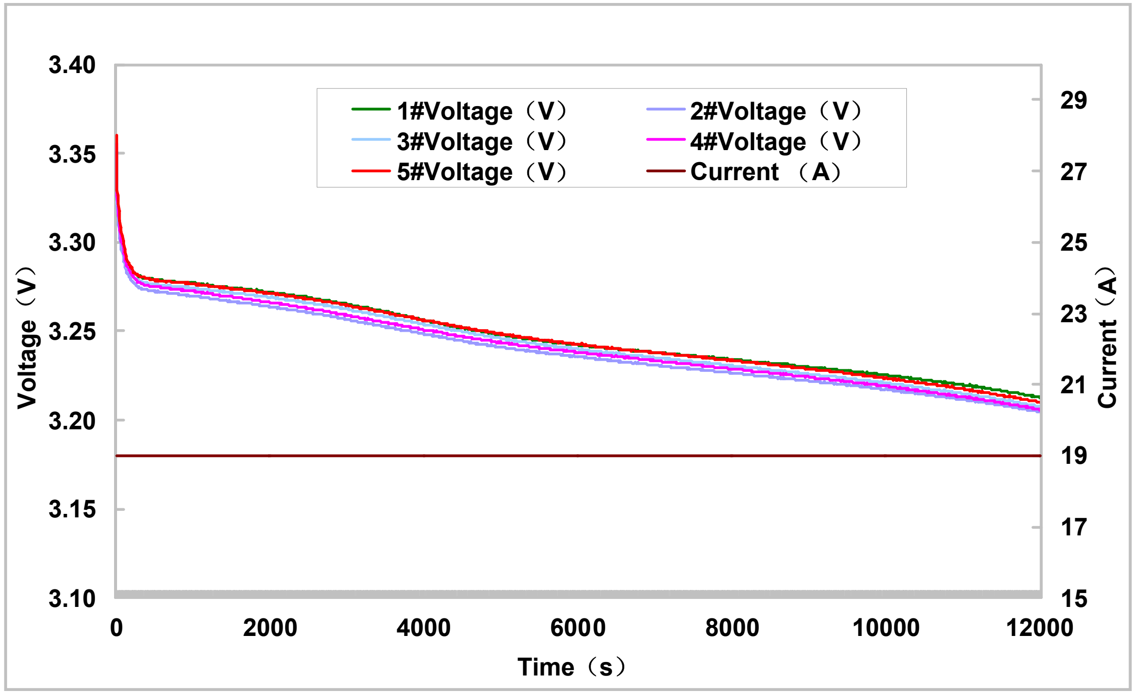


Cell No.	Capacity Retention （%）	Capacity recovery rate （%）
1#	89.8%	92.3%
2#	90.6%	93.0%
3#	90.1%	92.1%

Test procedure
Charge current : 0.2C
End-of-charge voltage : 3.8V
Temp. range： -40~85 ℃
hold time at each temp. ： 6h

Dimension : 28*100*330mm

2 Vibration



Test procedure

Discharge current : C/3

Vibration direction : up and down

Frequency : 10~55Hz

Max. acceleration rate : 30m/s^2

Screening cycle : 10

Test time : 2h

Dimension : 28*100*300mm

Result : Pass, cell current and voltage remain normal

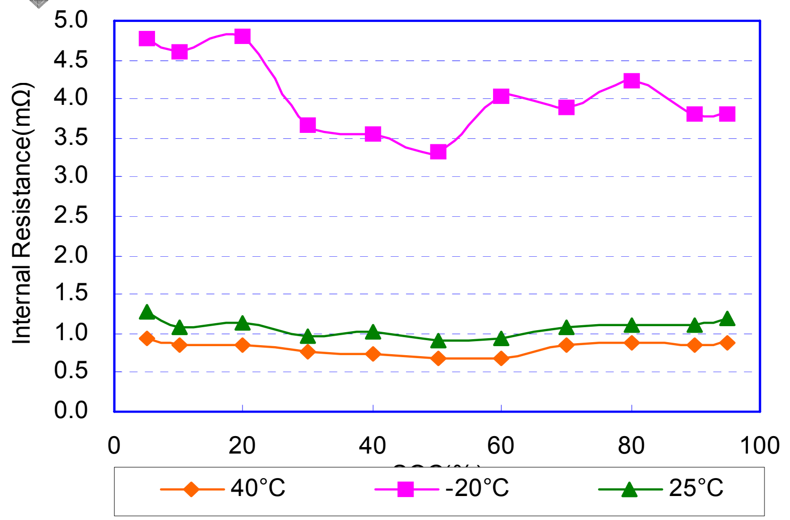
2

Drop

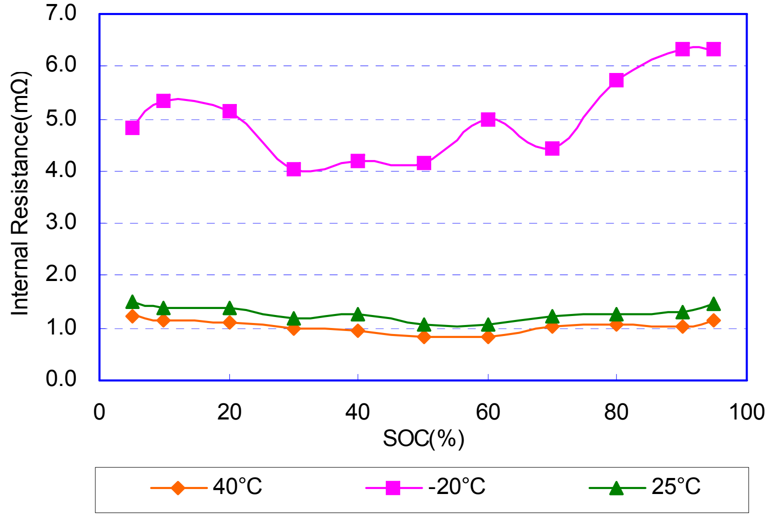
Test procedure
Height : 1.5m
Thickness of board : 20mm
Orientation : once at each side

Dimension :   28*100*330mm
Result : Pass with cell deformation and no leakage

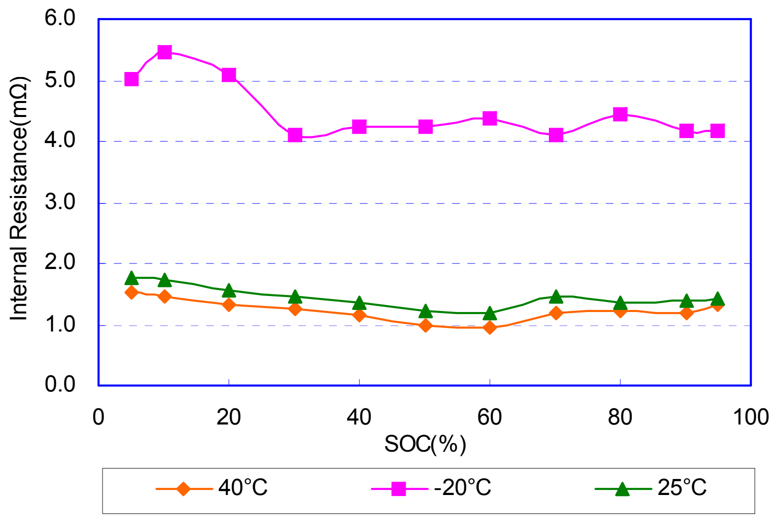
3 Charge Pulse



1s duration



10s duration



18s duration

Excellent charge pulses performance

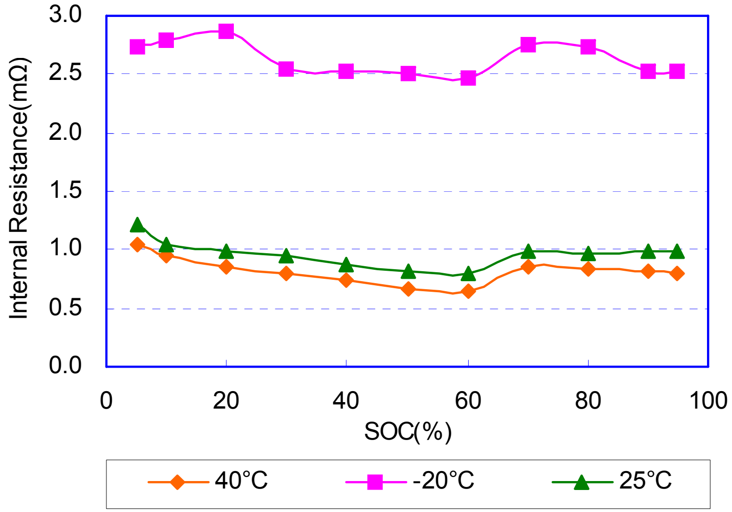
At -20℃, the internal resistance is about 6mΩ.

At room temperature or high temperature, all internal resistances are lower than 2mΩ .

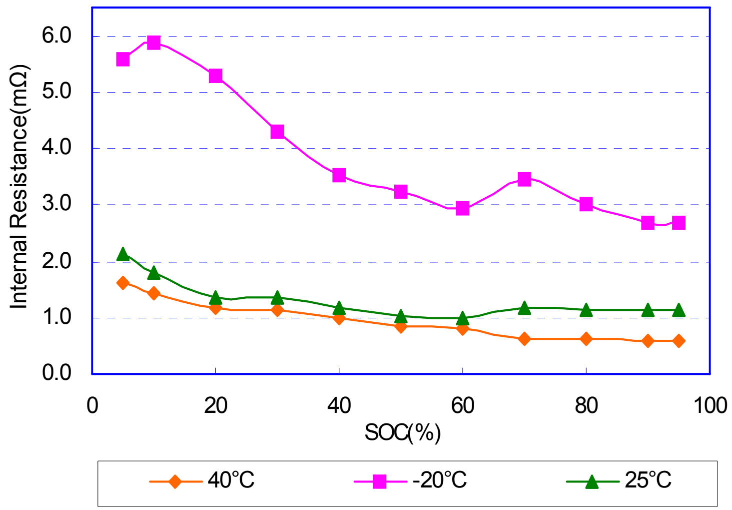
Build Your Dreams

BYD

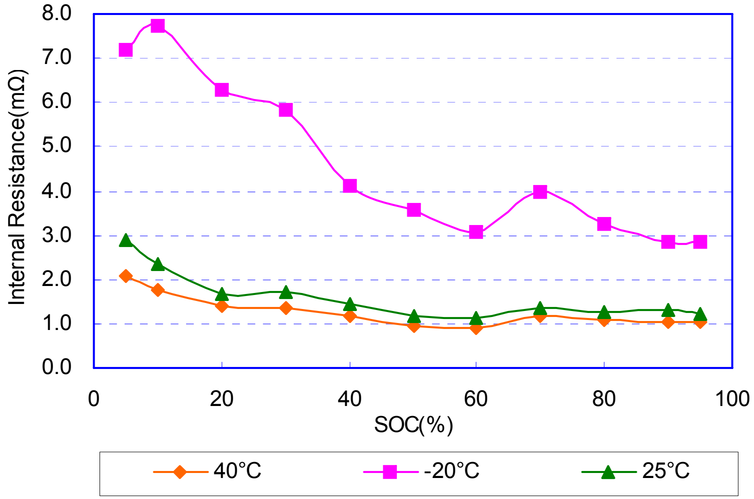
3 Discharge Pulse



1s duration



10s duration



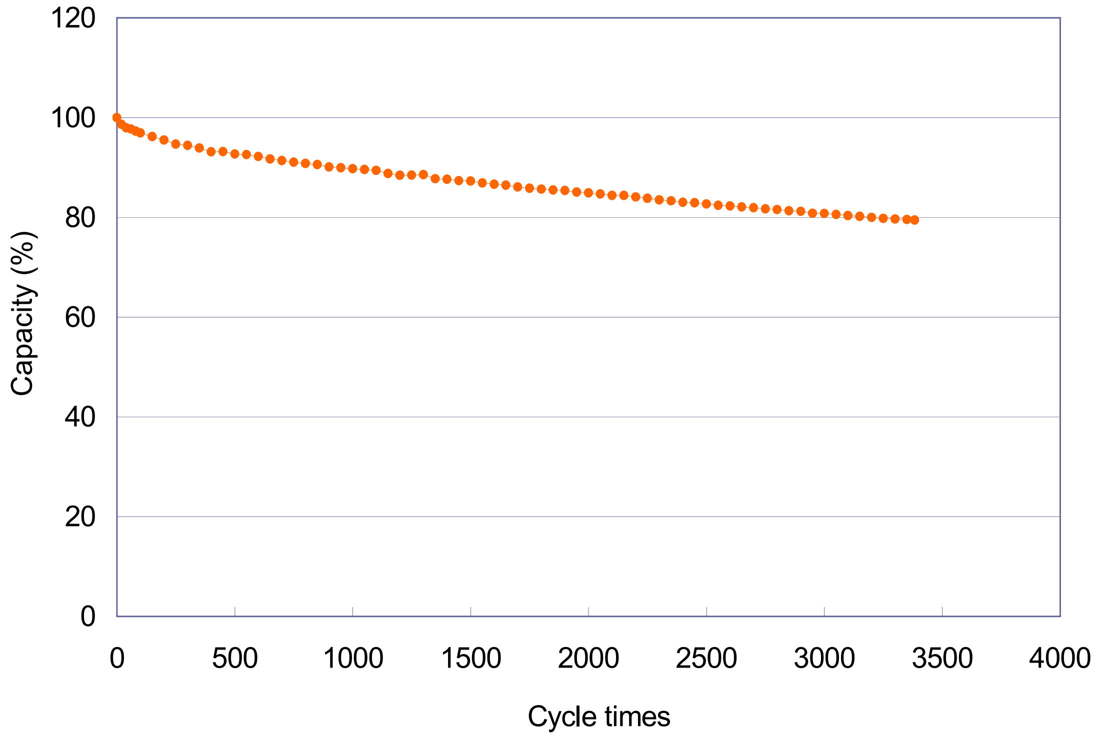
18s duration

Excellent discharge pulses performance

At -20℃, the internal resistance is about 5mΩ.

At room temperature or high temperature, all internal resistances are lower than 3mΩ .

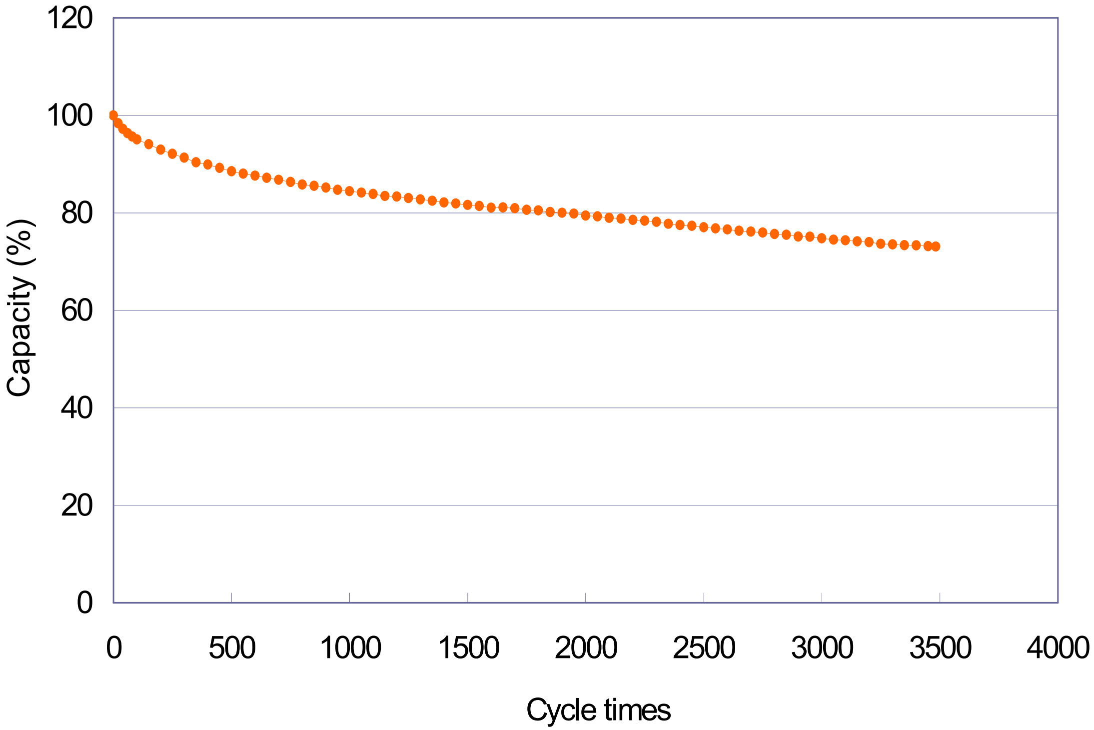
3 Cycle Test at Room Temperature



Test procedure
Temperature : 20±5 ℃
Charge current : 1C
End-of-charge current : 0.001C
End-of-charge voltage : 3.8V

Dimension : 28*100*330mm
Cycle times : 3500
Retention : 80%

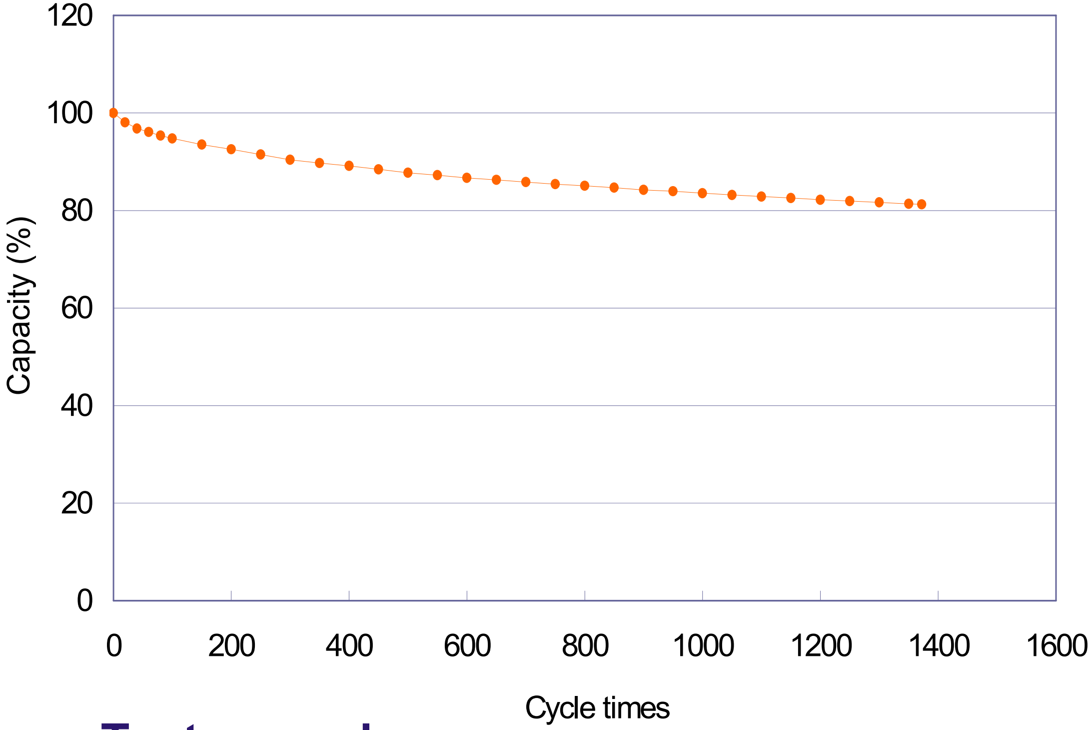
3 Cycle Test at 45ºC



Test procedure
Temperature : 45 ℃
Charge current : 1C
End-of-charge current : 0.001C
End-of-charge voltage : 3.8V

Dimension : 28*100*330mm
Cycle times : 3500
Retention : 70%

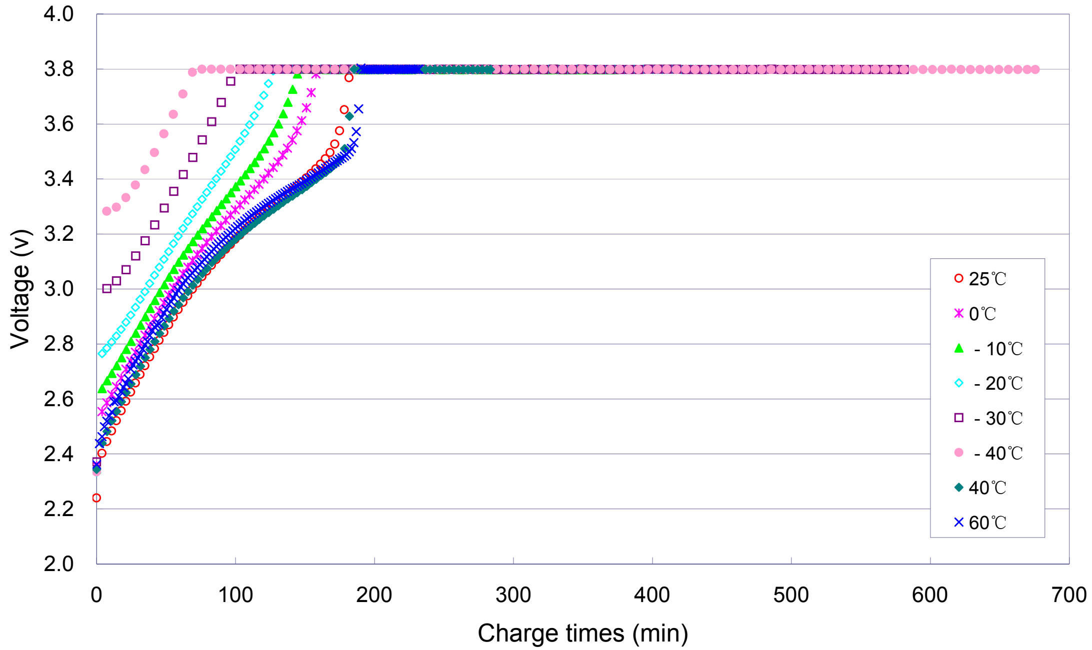
3 Cycle Test at 60ºC



Test procedure
Temperature : 60 ℃
Charge current : 1C
End-of-charge current : 0.001C
End-of-charge voltage : 3.8V

Dimension : 28*100*330mm
Cycle times : 1400
Retention : 80%

3 Charge at Different Temperature



Test procedure
Discharge current : 0.2C
End-of-discharge voltage : 2.0V
Rest time after discharge : 6h
Charge current : 1C
End-of-charge current : 0.02C
End-of-charge voltage : 3.8V

Dimension : 28*100*330mm
Charge temp. : -30~60 ℃

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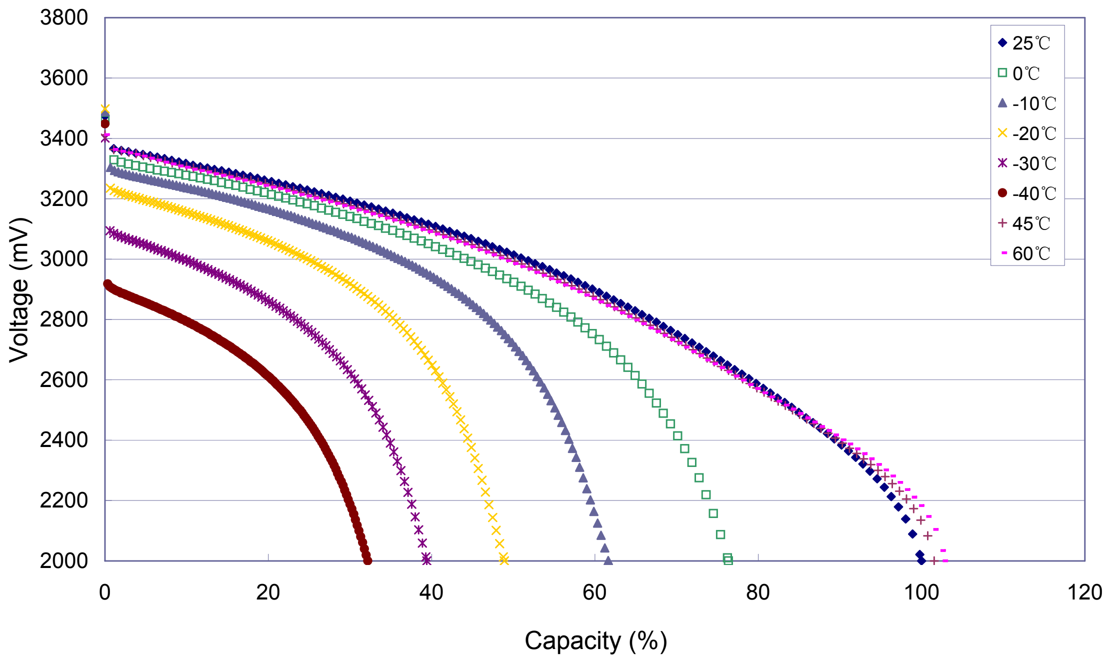
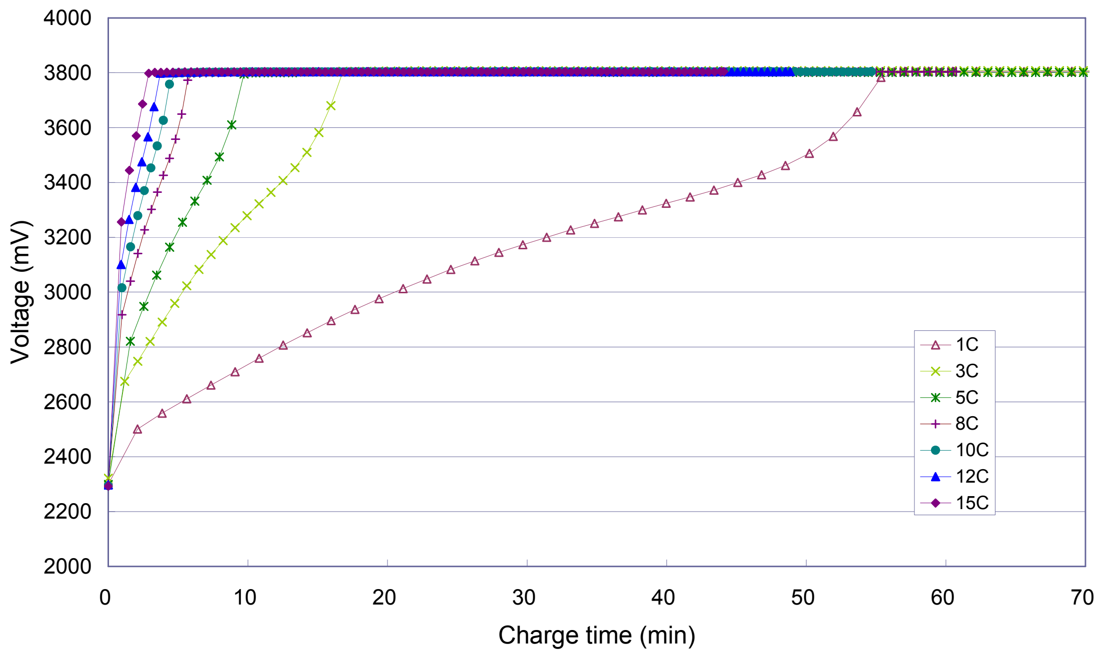
3 Discharge at Different Temperature



Test procedure
Charge current : 0.2C
End-of-charge voltage : 3.8V
Rest time after charge : 6h
Discharge current : 1C
End-of-discharge voltage : 2.0V

Dimension : 28*100*330mm
Discharge temp. : -40~60 ℃

3 Charge at Different Current

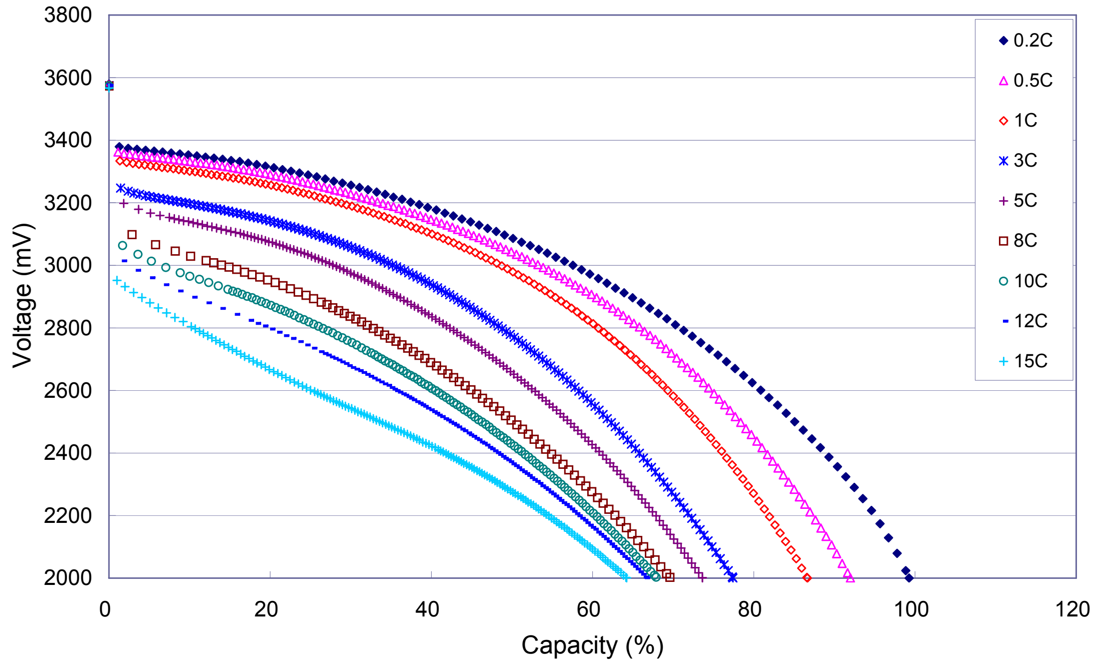


Test procedure
Temperature : 20±5 ℃
Discharge current : 0.2C
End-of-discharge voltage : 2.0V
Rest time after discharge : 6h
End-of-charge voltage : 3.8V
End-of-charge current : 0.02C

Dimension : 28*100*330mm

80% capacity can be charged in 10mins .

3 Discharging at Different Current

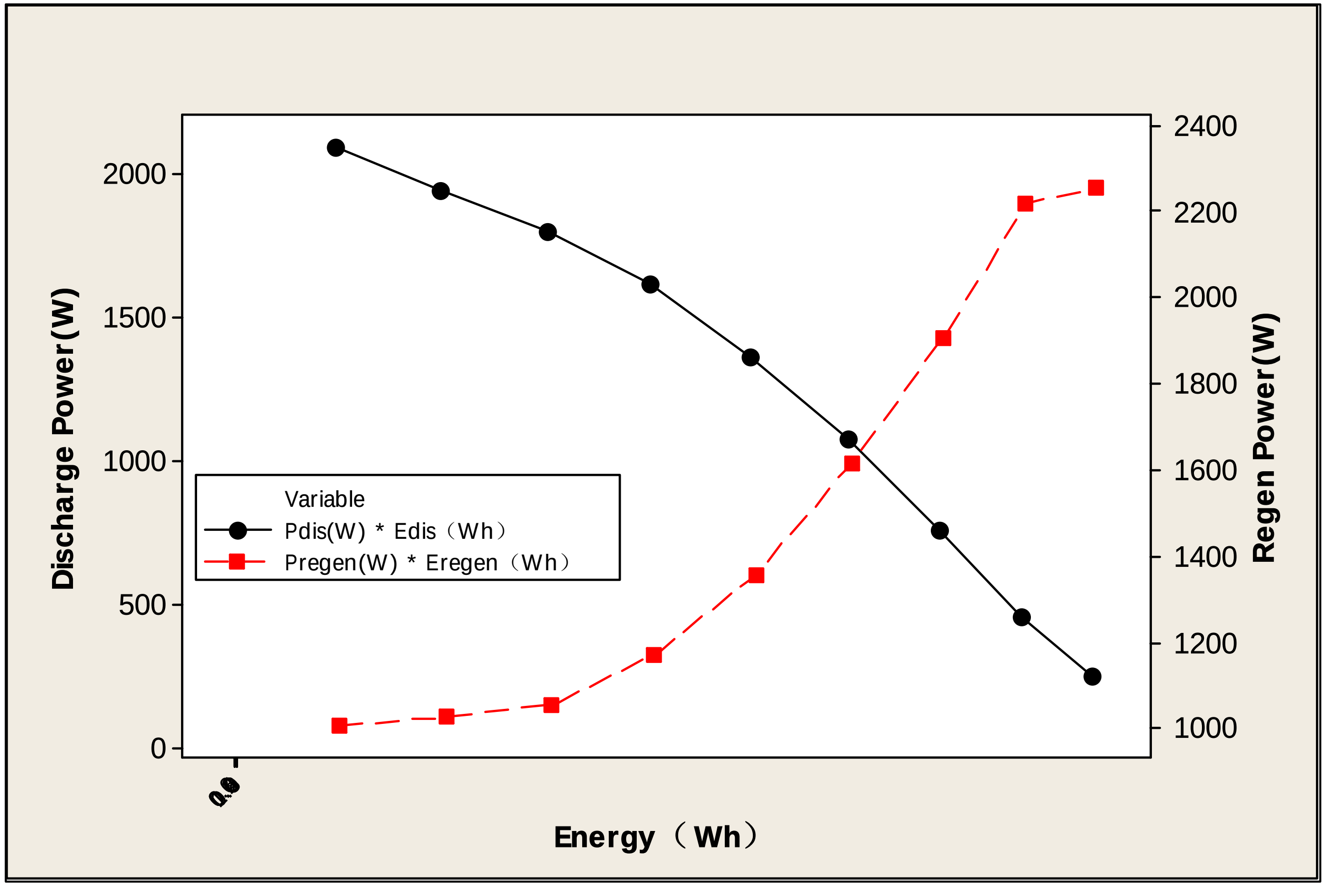


Test procedure
Temperature : 20±5 ℃
Charge current : 0.2C
End-of-charge voltage : 3.8V
Rest time after charge : 6h
End-of-discharge voltage : 2.0V

Dimension : 28*100*330mm

The battery can be discharged at 15C .

3 Peak Power Test



Excellent Power performance

The max discharge power and regen power are all above 2000w in room temperature.

Test method: Referenced as US DOE INL/EXT-07-12536

China National Standard Update

Difference between QCT-743/2006 and New National Standard Draft

	QCT/743-2006 Lithium-ion Batteries for Electric Vehicles(2006)	Secondary Batteries for Electric Vehicles (Draft, 2009)
Cell Performance		
Storage	20℃, 90days, Residual Capacity>95%	55℃, 56days, Residual Capability>60%
Cycle Life	Residual Capacity>80% after 500 cycles	Residual Capacity>90% after 500 cycles
Cell Safety		
Hot Oven	85℃, 120min	150℃, 20min
Batteries Safety		
Vibration	10~55Hz sweep vibration for 120min in Z direction while discharging	1) 33Hz, 70m/s2, 240min for Z direction and 120min for X and Y fixed vibration 2) 10~200Hz, 50m/s2, 240min sweep vibration
Hot Oven	85℃, 120min	150℃, 20min

Global patent analysis

US patent of Phostech is re-examed. Co is deleted

AMENDMENT TO THE CLAIMS

1. (Twice Amended) A cathode [material for] in a rechargeable electrochemical cell, said cell also comprising an anode and an electrolyte, the cathode [material] comprising a compound of the ordered or modified olivine structure having the formula:

$$Li_xM_{1-(d+t+q+r)}D_dT_tQ_qR_r(XO_4)$$

wherein:

[N] M is a cation of a metal selected from the group consisting of Fe, Mn, [Co,] Ti, Ni or mixtures thereof;

D is a metal having a +2 oxidation state selected from the group consisting of Mg^{2+}, Ni^{2+}, [Co^{2+},] Zn^{2+}, Cu^{2+}, and Ti^{2+};

European patent of Phostech is revoked

AUSTIN, Texas, Dec 09, 2008 (BUSINESS WIRE) --

the Opposition Board of the European Patent Office (EPO) revoke the European Patent granted to the University of Texas (UT) relating to lithium metal phosphates. The decision revoking the Goodenough et. al. UT European Patent eliminates any risk that UT could assert the European Patent against other company's proprietary lithium iron phosphate cathode material, which is a critical material for the next generation of electric vehicle batteries.

Thank you!