



# BYD Fe Battery for HEV/EV

***Feb.8<sup>th</sup>, 2009***

***Build Your Dreams***



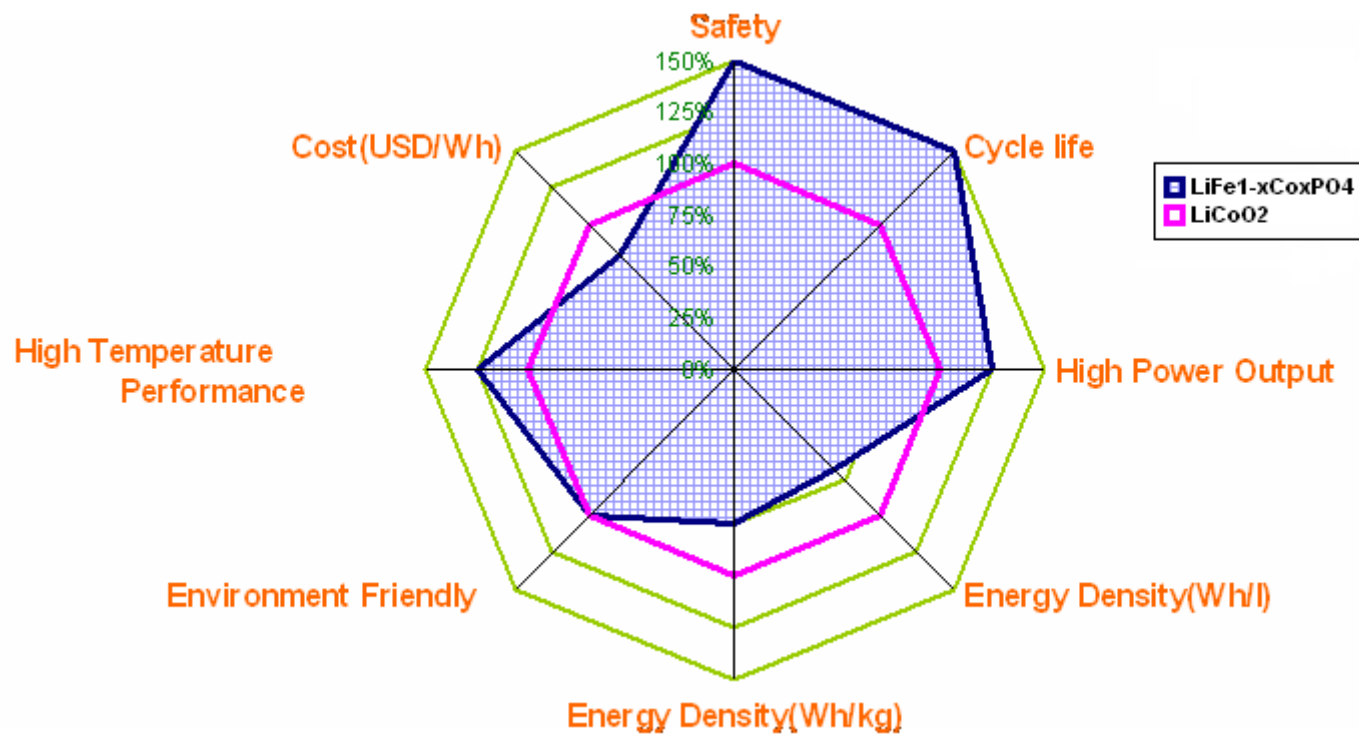
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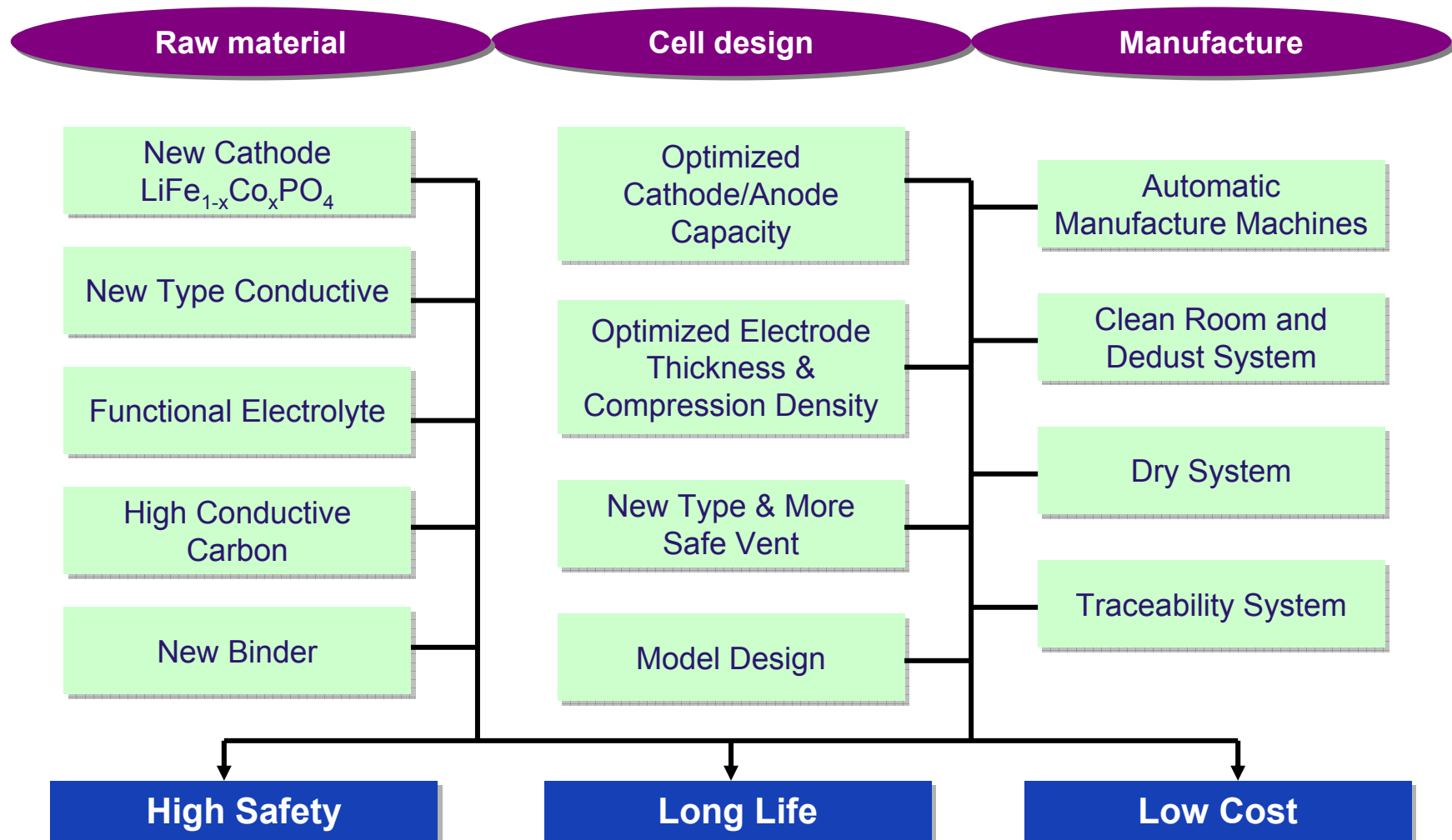
# Technology of Fe Battery

# Advantages of Fe Battery

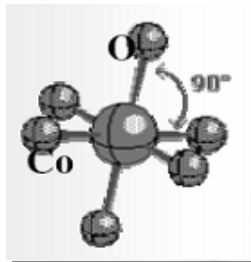
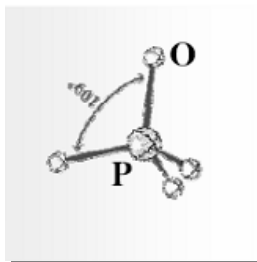
- According to the compare between the Fe and LCO battery, Fe battery has the advantages in safety, cycle life, high power output and high temperature performance. Also lower cost is it's advantage.
- Lower energy density is Fe battery's disadvantage, it is about 75% of LCO battery.



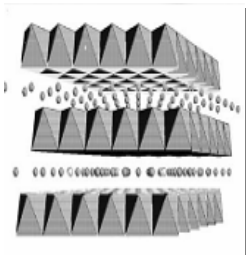
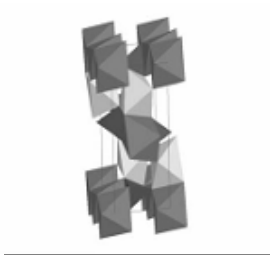
# Key Technology of BYD Fe Battery Development



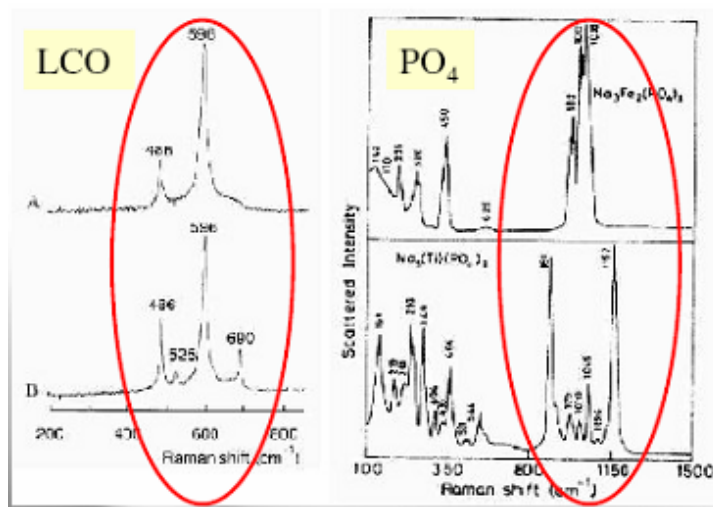
# High Safety – High Strong Bone Energy



In  $\text{LiCoO}_2$ : Co-O 1.91Å  
 In  $\text{LiFe}_{1-x}\text{Co}_x\text{PO}_4$ : P-O 1.63Å



Coordination and location determine bond distance and strength.

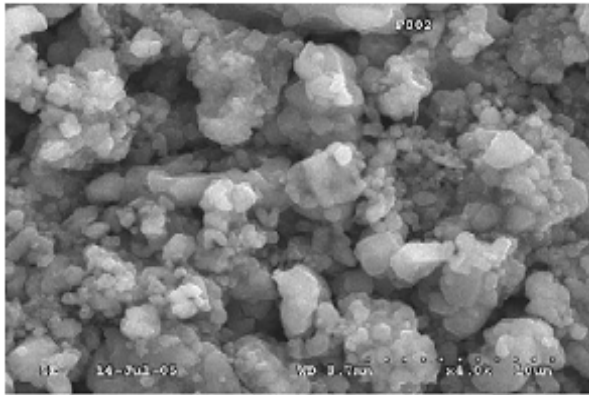


Raman Spectroscopy stretching bands:  
 P-O: 1100  $\text{cm}^{-1}$   
 Co-O: 540  $\text{cm}^{-1}$

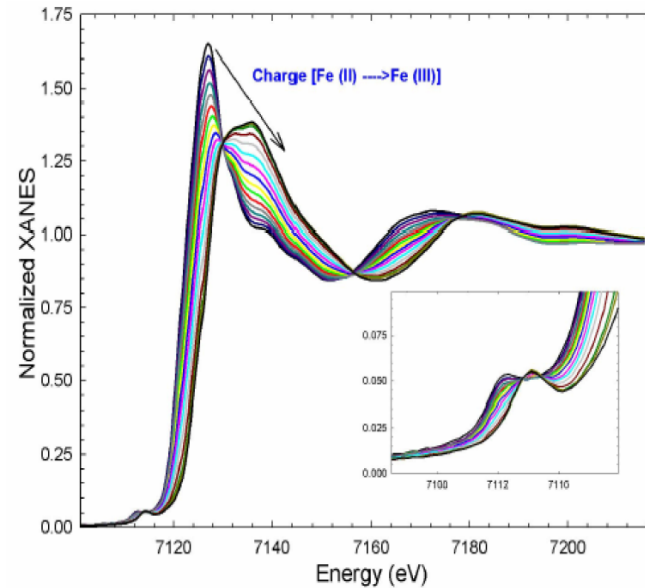
The P-O bond is stronger than Co-O bond.

**Tightly bound Oxygen = Safety !!**

# Long Life – Stable Structure between charging and discharging



**LiFe<sub>1-x</sub>Co<sub>x</sub>PO<sub>4</sub>**

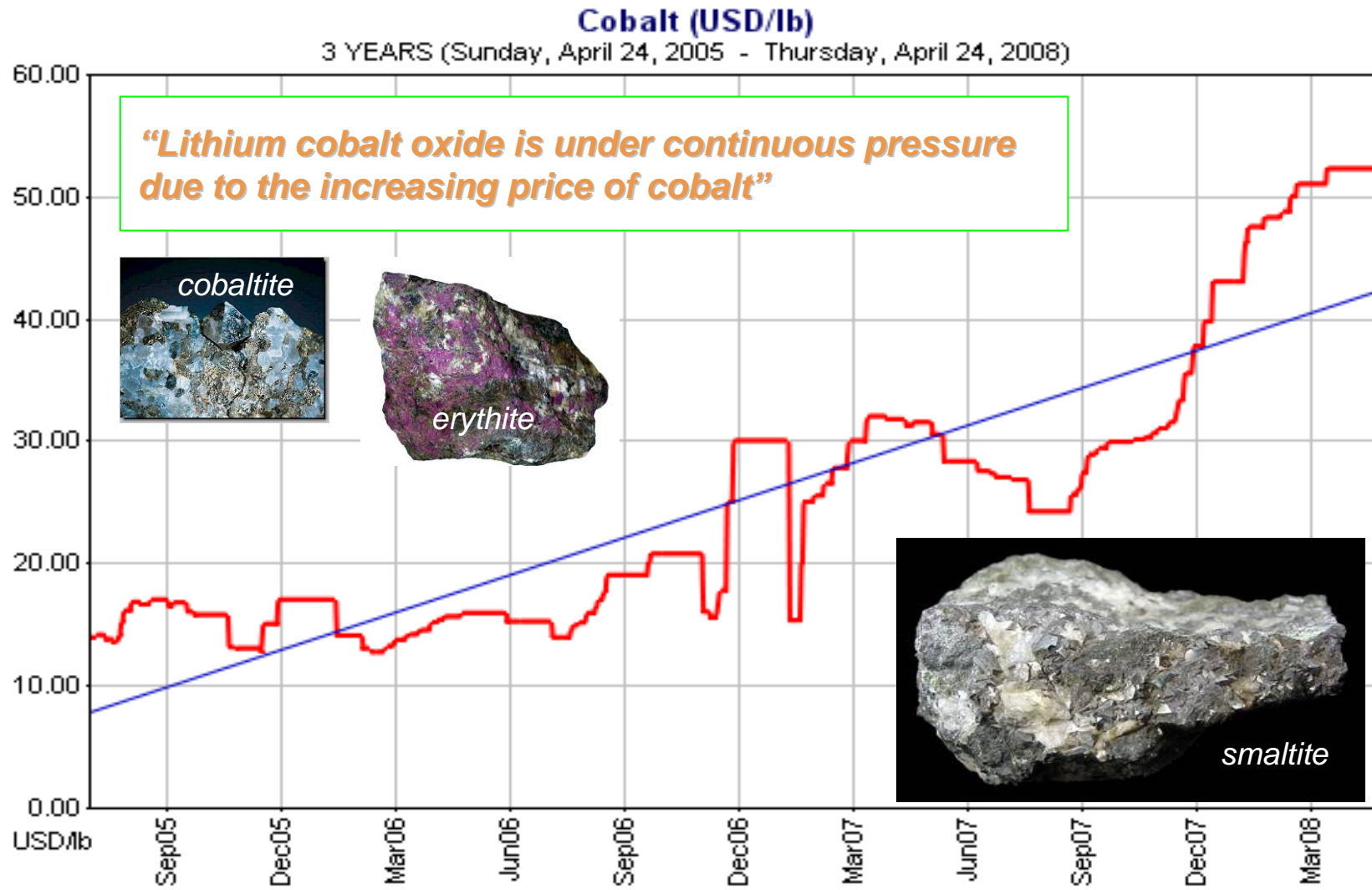


	LiFe <sub>1-x</sub> Co <sub>x</sub> PO <sub>4</sub>	Fe <sub>1-x</sub> Co <sub>x</sub> PO <sub>4</sub>
Space Group	Pbnm	Pbnm
a axis (nm)	0.6008	0.5792
b axis (nm)	1.0334	0.9821
c axis (nm)	0.4693	0.4788
<b>Volume (nm<sup>3</sup>)</b>	<b>0.2914</b>	<b>0.2724</b>

**For reverse volume change trend between LiFe<sub>1-x</sub>Co<sub>x</sub>PO<sub>4</sub> and graphite, total cell volume changes very small.**

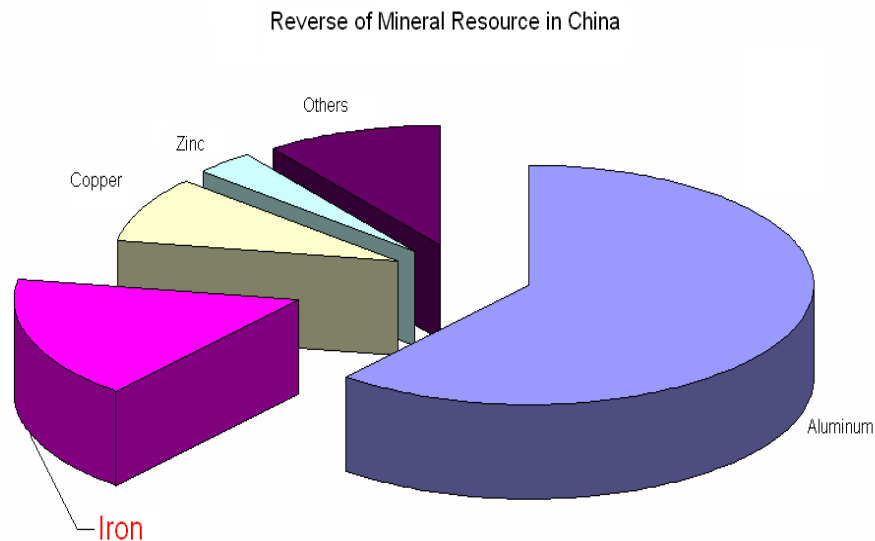


# Low Cost - Main components in traditional Li battery





## Low Cost - Inexpensive components in Fe battery



✓ Iron resource in abundance

✓ High mining technology

✓ Raw materials of  $\text{LiFe}_{1-x}\text{Co}_x\text{PO}_4$  synthesized are cheap

Fe and  $\text{PO}_4$  are common components.

# Battery Design

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# 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°C to 60°C.

## ➤ 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**

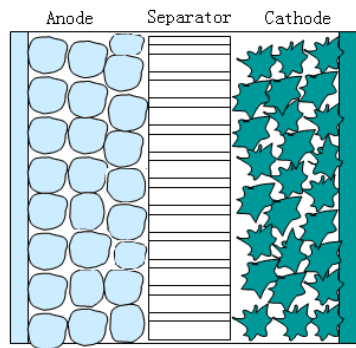
Characteristic	Value	
Normal Voltage	325V/315V (at 0.2C discharge/at 1.0C discharge current)	
Capacity	45Ah	
	(From 380V to 200V in 0.2C discharge current)	
Dimension	1780*806*120mm	
Weight	200Kg	
Cycle life	10 year	
Short-Time Discharge Power(10s)	135kw	
Long-Time Discharge Power	67.5kw	
Usable Energy	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	

## Table 2: e6 Battery System Major Parameters

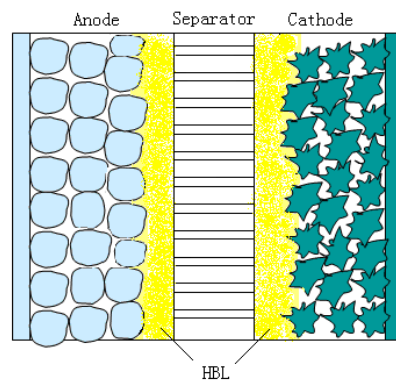
Characteristic	Value	
Normal Voltage	325V/315V (at 0.2C discharge/at 1.0C discharge current)	
Capacity	180Ah	
	(From 380V to 200V in 0.2C discharge current)	
Dimension	1730*915*330mm	
Weight	650Kg	
Cycle life	10 year	
Short-Time Discharge Power(10s)	270kw(5C)	
Long-Time Discharge Power	162kw	
Usable 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

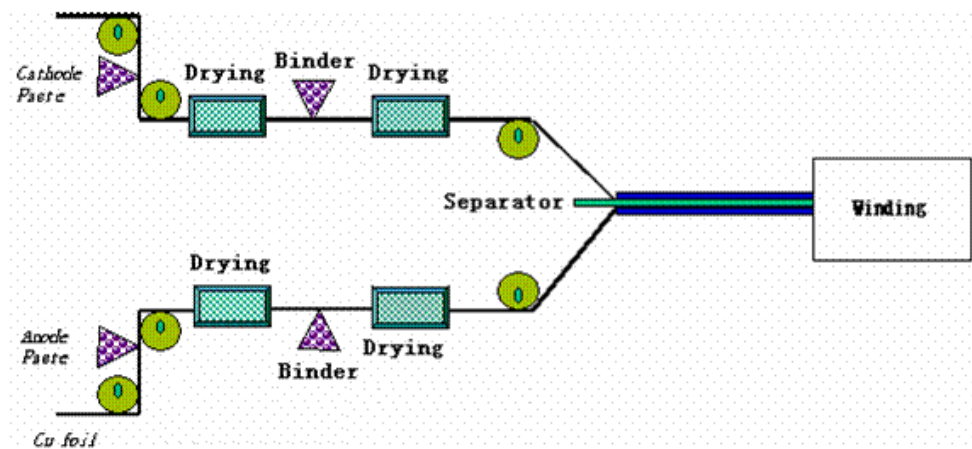
HBL (High-temperature Binder Layer) is a new technology developed by our company. The exfoliation of active materials, burr of electrode can be reduced by coating a heat-resistant micro porous binder layer, and the self-discharge, consistency, cycle-life and safety can be improved substantially.



Normal Battery Structure



HBL Battery Structure

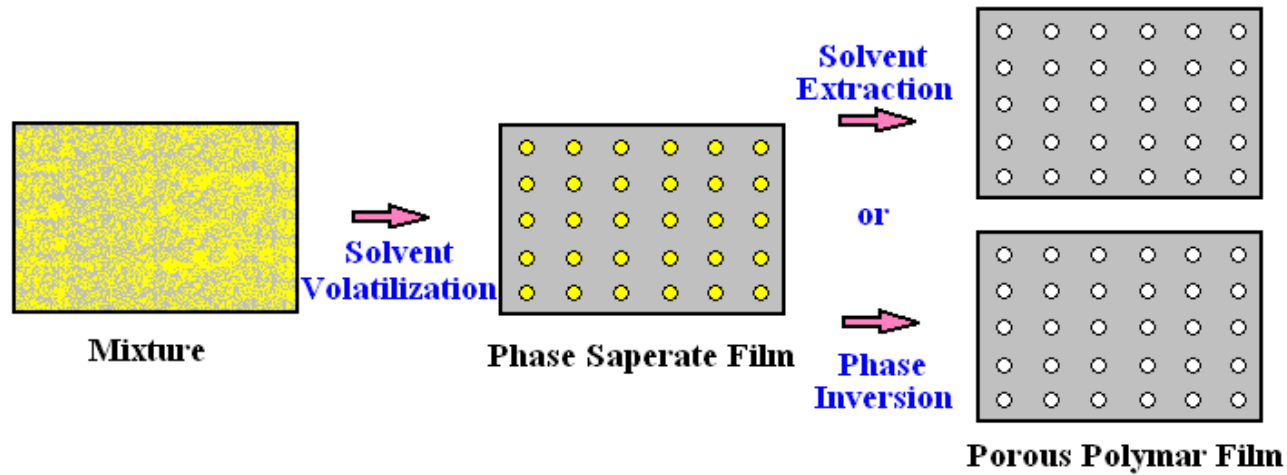


Flow chart of HBL

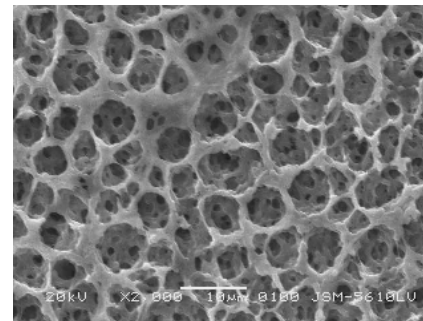
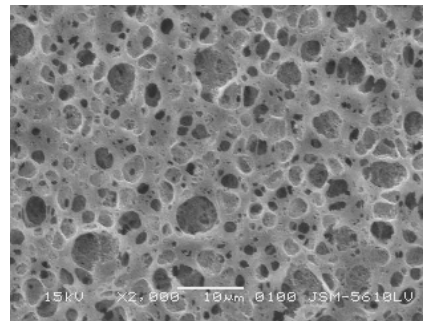
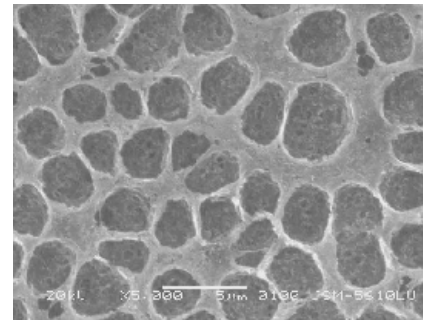
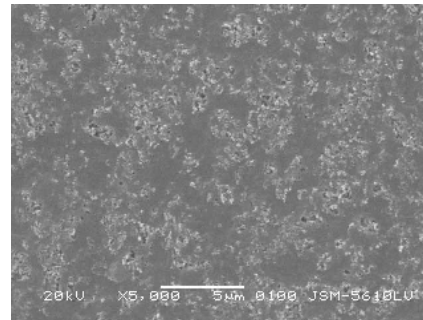


# Technology of HBL

Phase  
Inversion  
Method

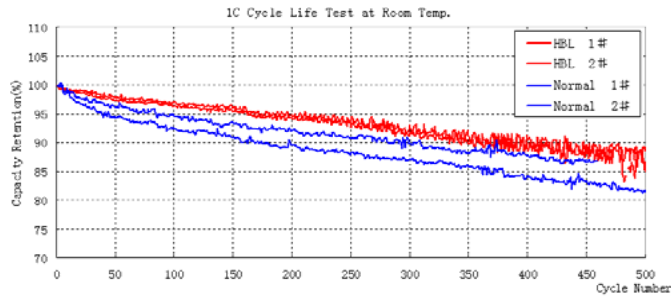


SEM of  
HBL

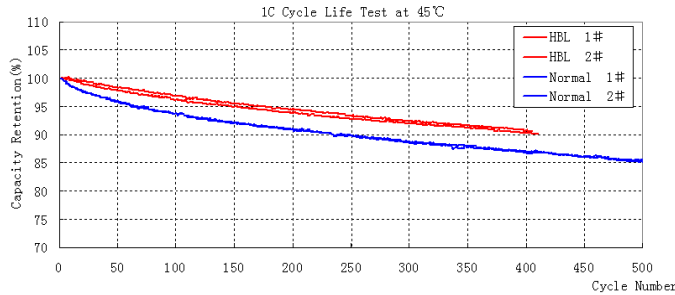


# The Advantage of HBL

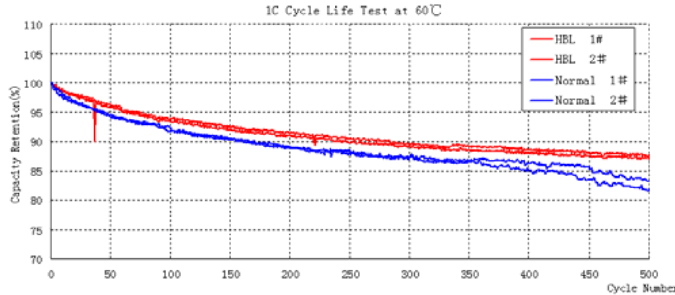
**Long Cycle Life  
Low Self-discharge**



**1C Cycle at Room Temp.**



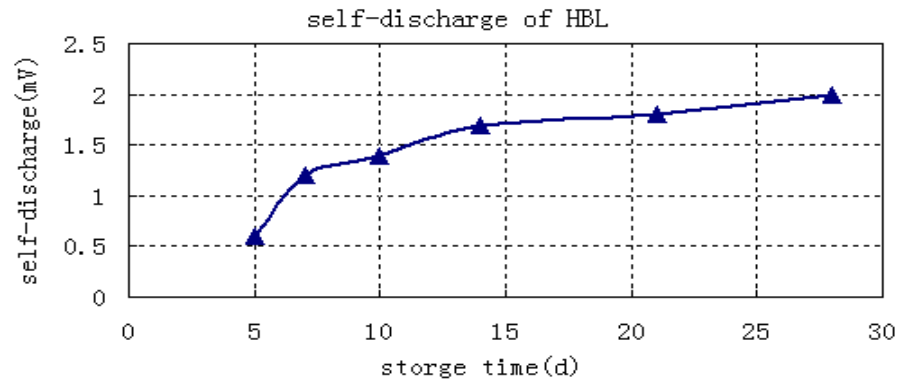
**1C Cycle at 45 °C**



**1C Cycle at 60 °C**

**Why Does HBL Low Self-discharge?**

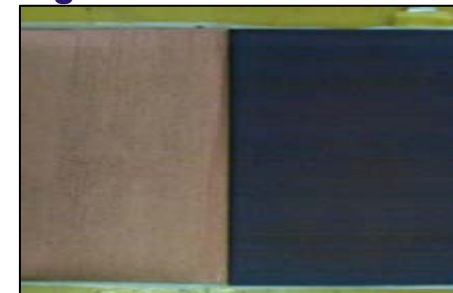
- 1. No Exfoliation;**
- 2. No Burr;**
- 3. Little Side Reaction.**



**Self-discharge of HBL**



**Normal Negative Electrode:  
Active Material Exfoliation**



**HBL Negative Electrode:  
No Active Material  
Exfoliation**

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# The Advantage of HBL

## High Safety

Why Does HBL High Safety?

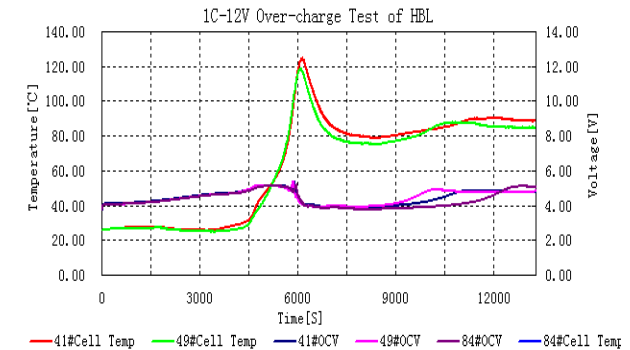
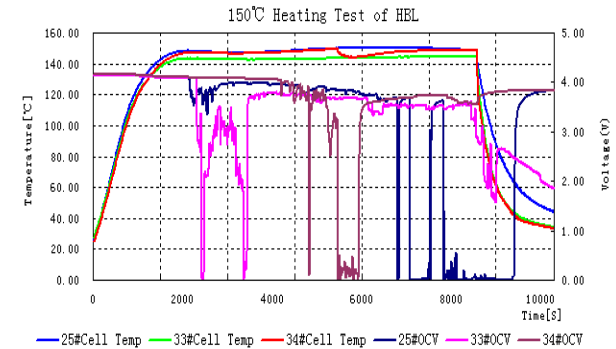
1. Three Protective Layers;
2. High Temp. Additive in the Layer, No Short-circuit;
3. No gap between Electrode and Separator, No Lithium Dendrite.



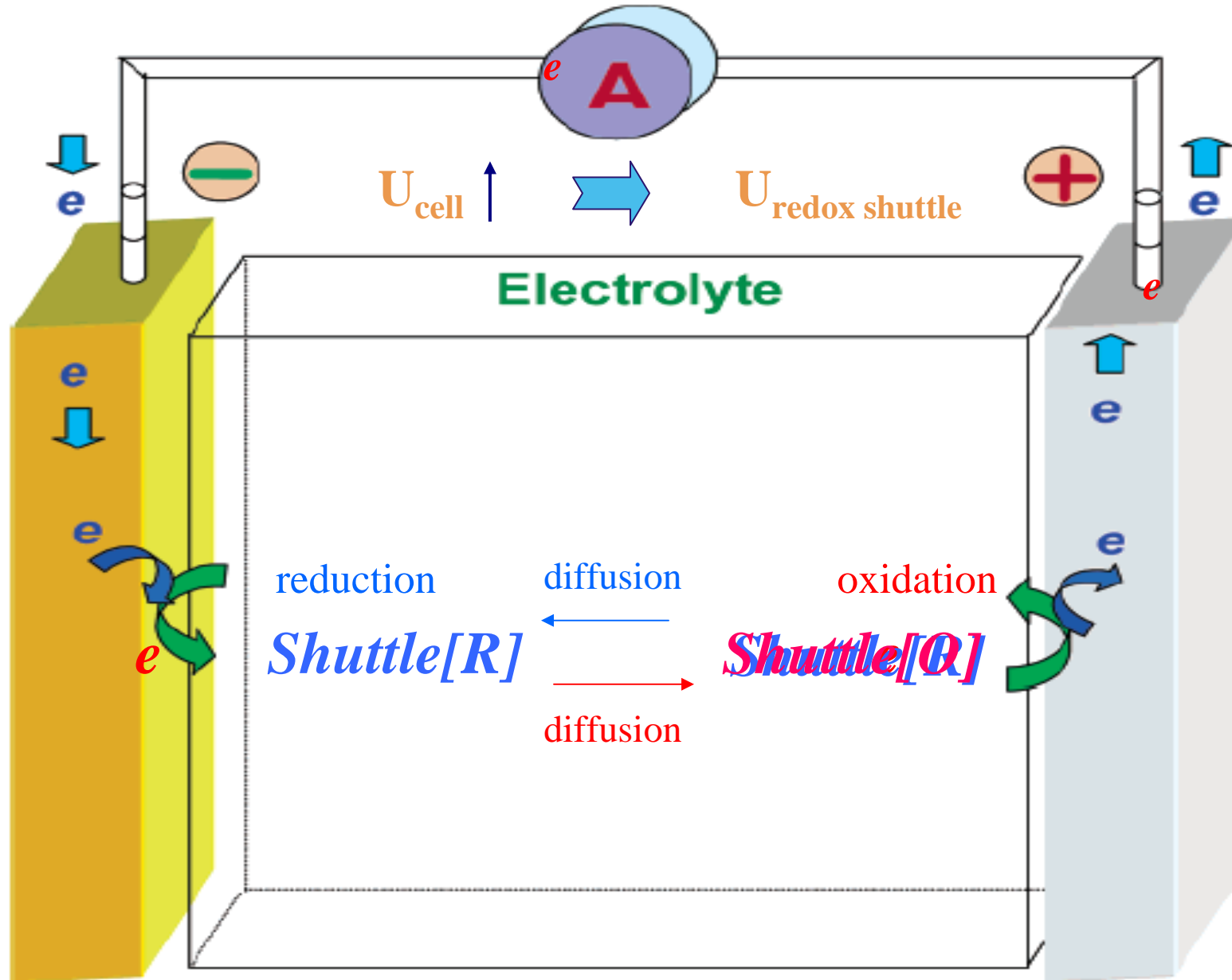
150 °C heating test of HBL



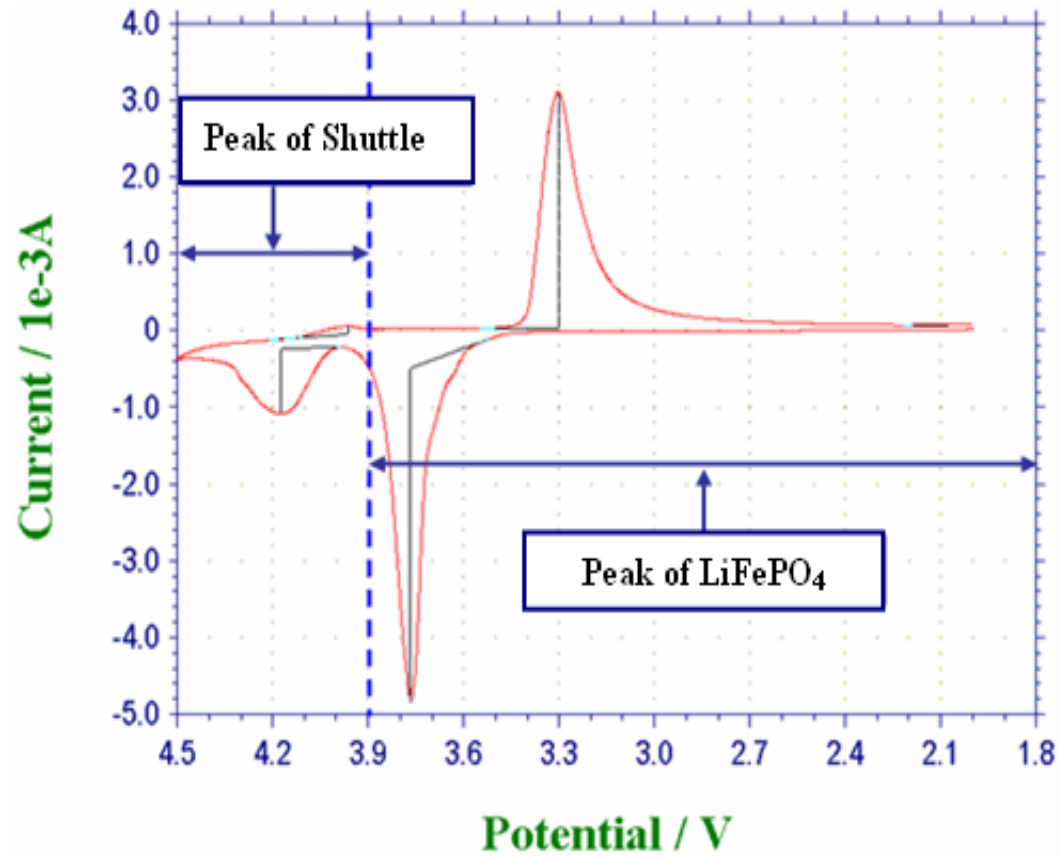
1C/12V over-charge test of HBL



# A schematic showing the working of a redox shuttle



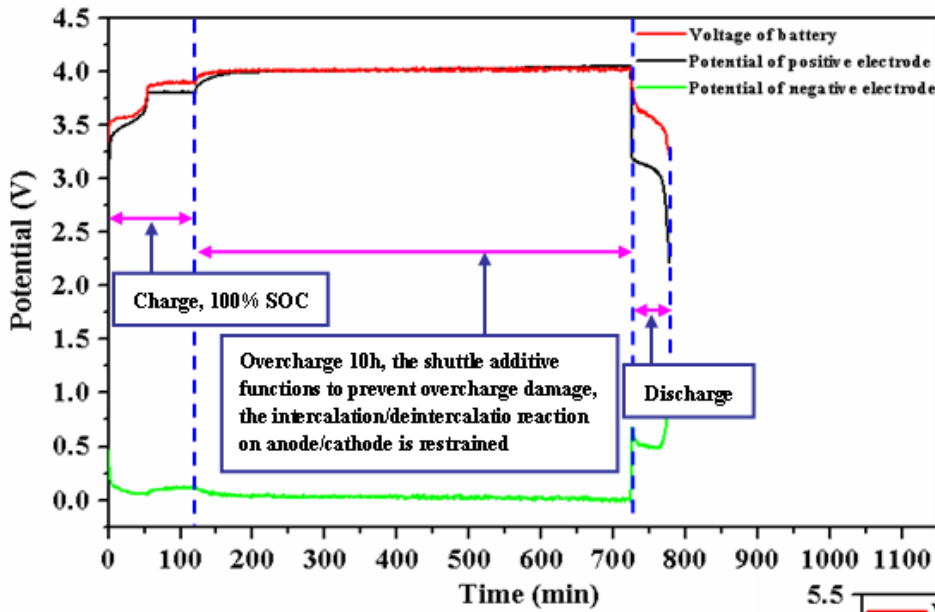
## The working voltage of Shuttle



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

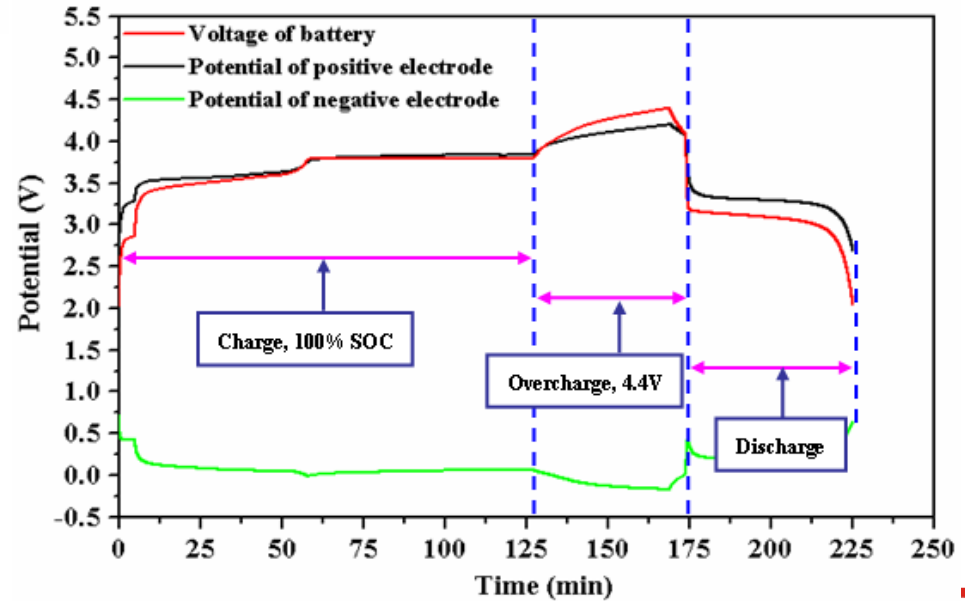
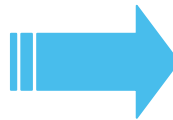


## The charge comparison in LIB



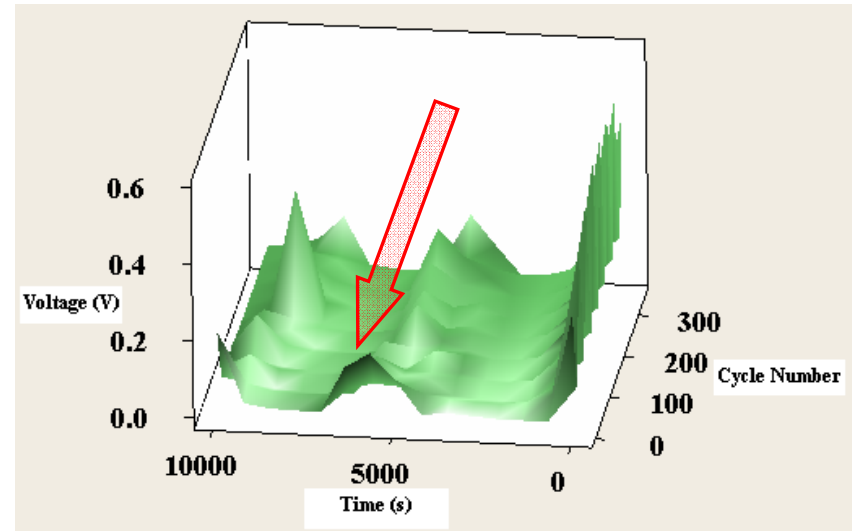
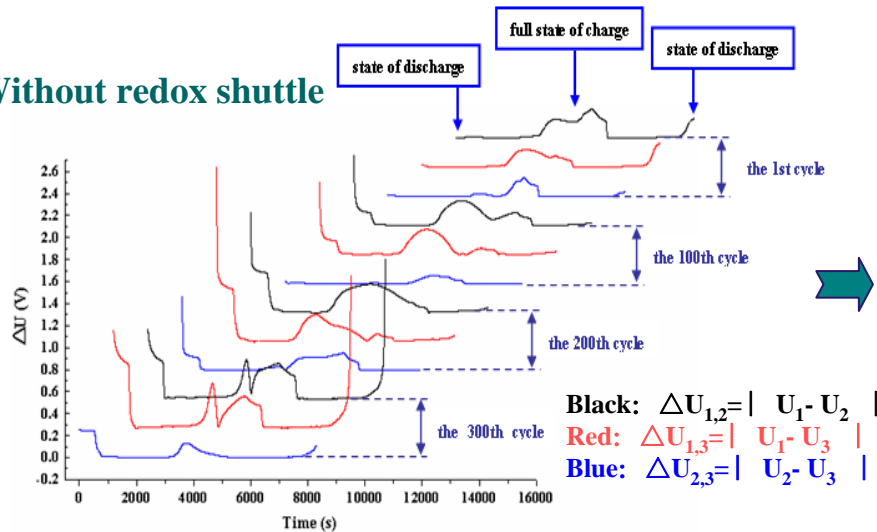
With redox shuttle

Without redox shuttle

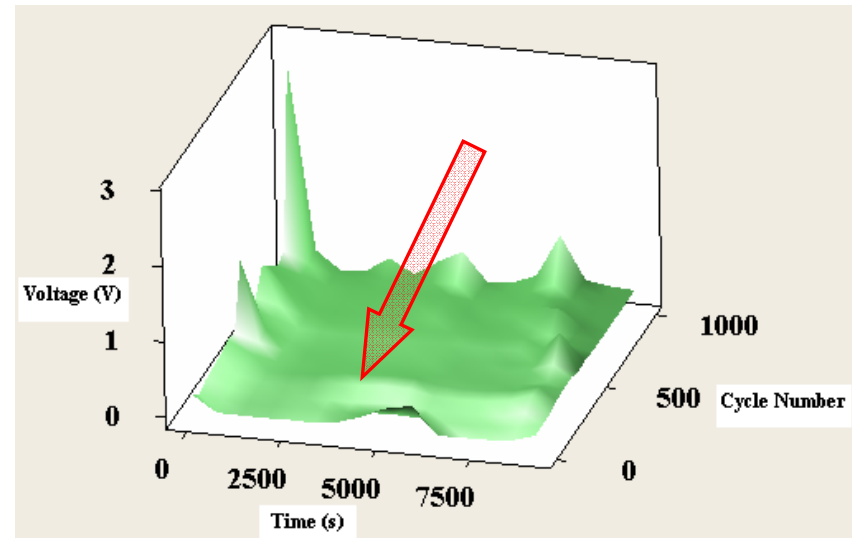
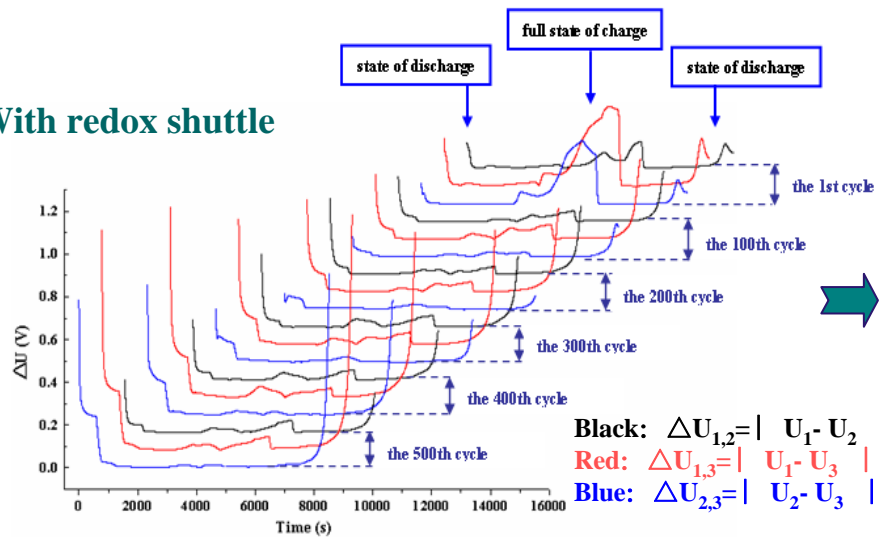


## The voltage difference comparison during cycle in LIB

### Without redox shuttle



### With redox shuttle

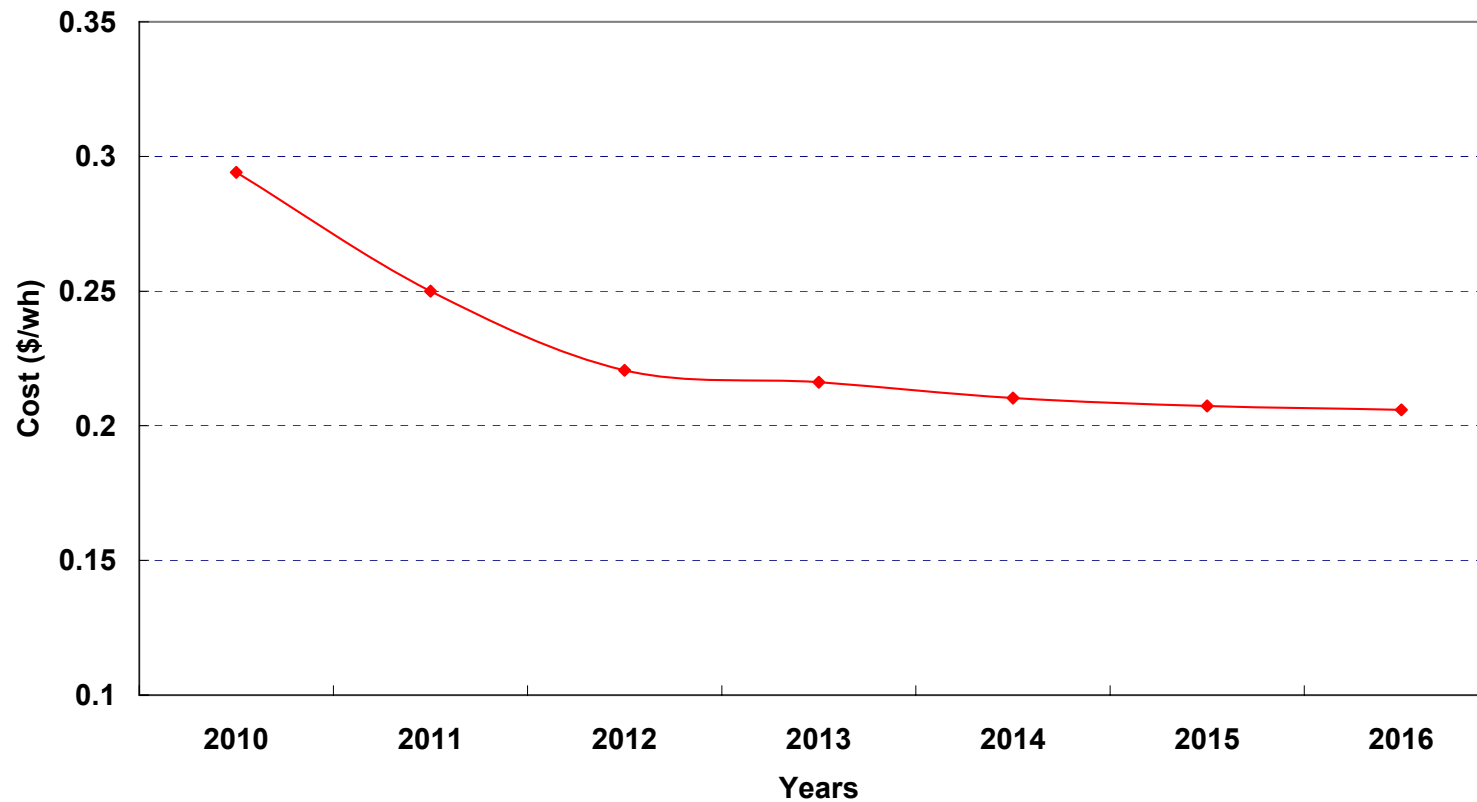


During the course of charge-discharge cycling, the variation of voltage difference in each cell connected in series as a function of cycles.



# Cost Down Roadmap

## Cost Down



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

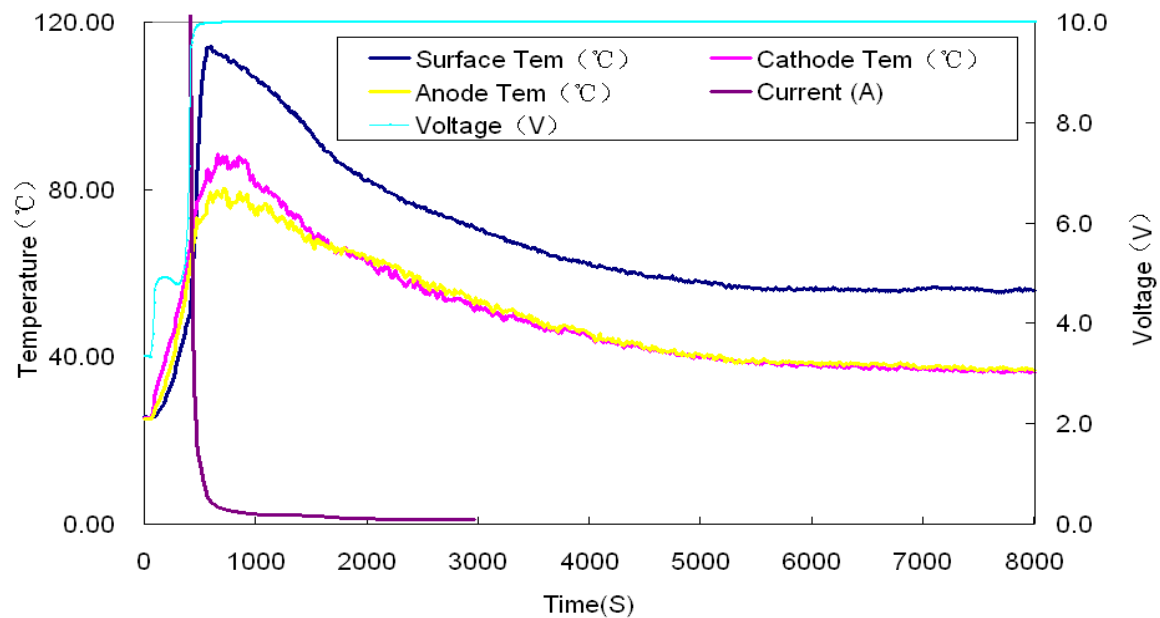
# Battery Performance

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1

## Overcharge

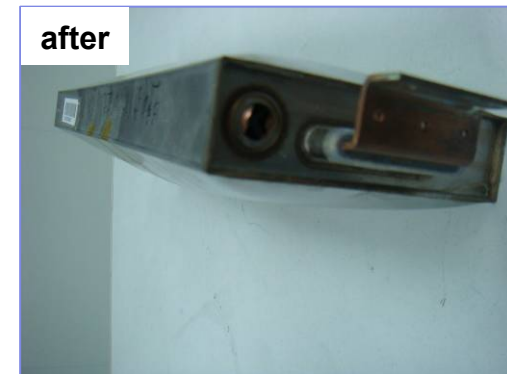
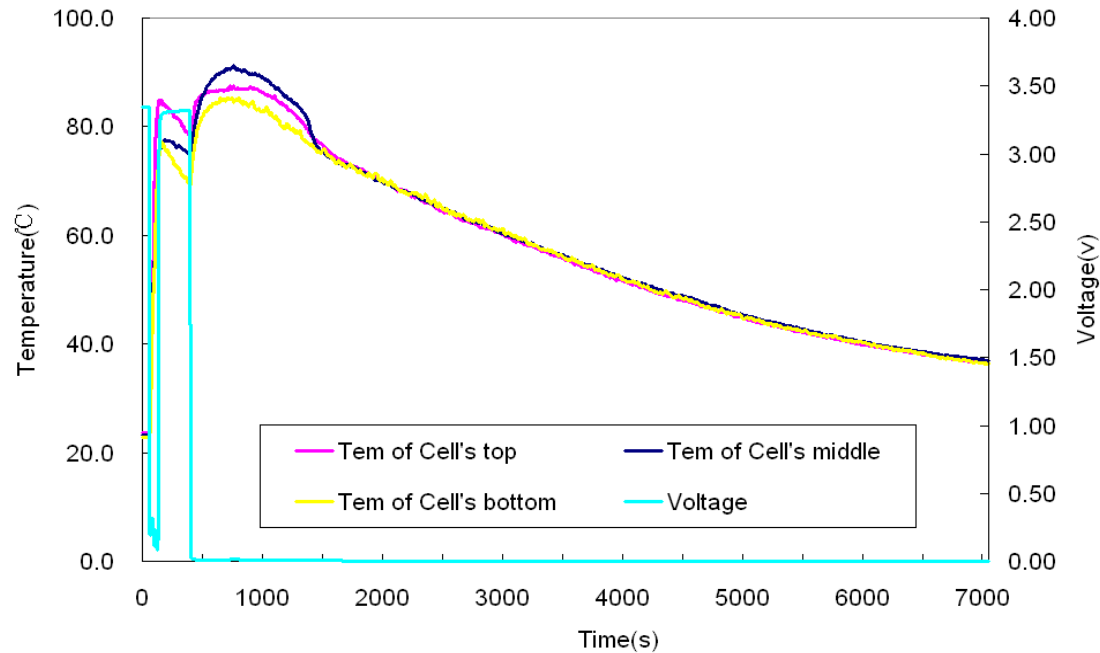


**Test procedure**  
**Charge current : 3C**  
**End-of-charge voltage : 10V**

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

1

## Short Circuit

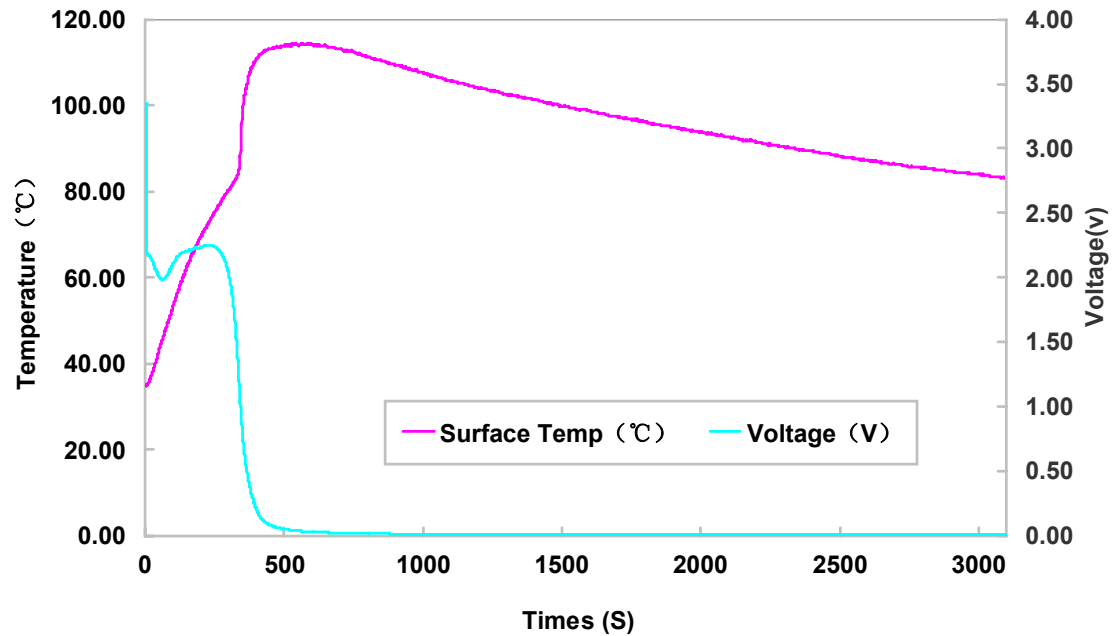


**Test procedure**  
**Charge current : 0.2C**  
**End-of-charge voltage : 3.8V**  
**Method : external short circuit,**  
**<5mOhm**

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

1

## Short Circuit at 60°C



### Test procedure

Temperature : 60 °C

Charge current : 0.2C

End-of-charge voltage : 3.8V

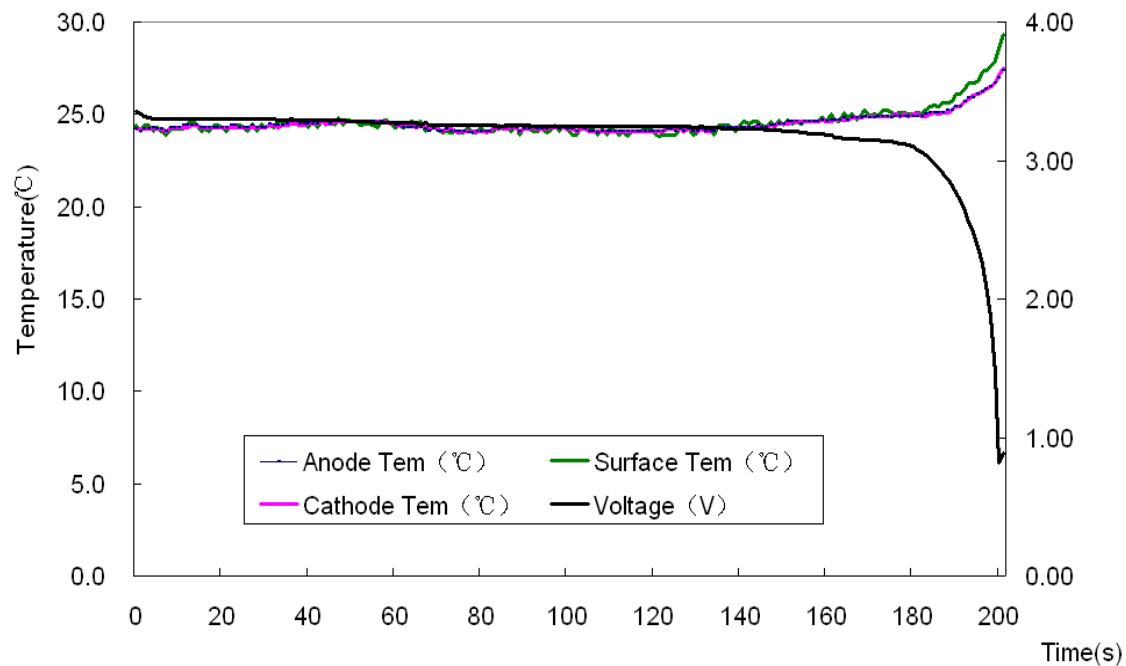
Method : external short circuit,  
<5mOhm

Dimension : 28\*100\*330mm

Result : Pass, cell inflation, no leakage

1

## Over-discharge



**Test procedure**

**Discharge current : C/3**

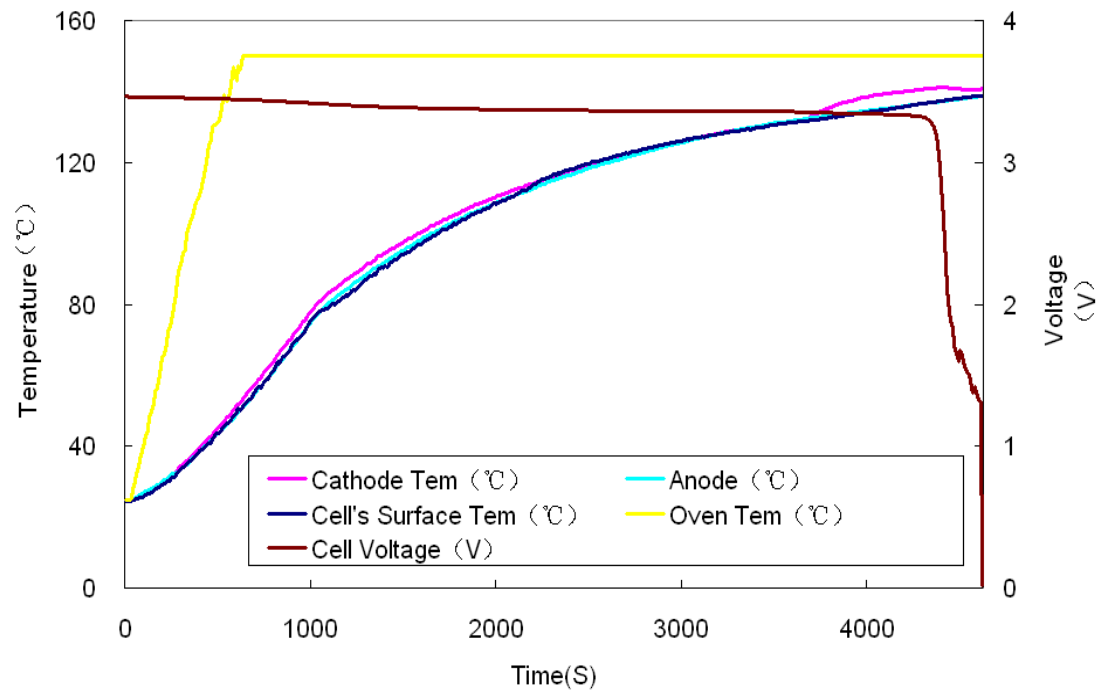
**End-of-discharge voltage : 0 V**

**Dimension : 28\*100\*330mm**

**Result : Pass with cell inflation**

1

## Hot Oven



### Test procedure

Temperature :  $150 \pm 2$  °C

Rest time : 120mins

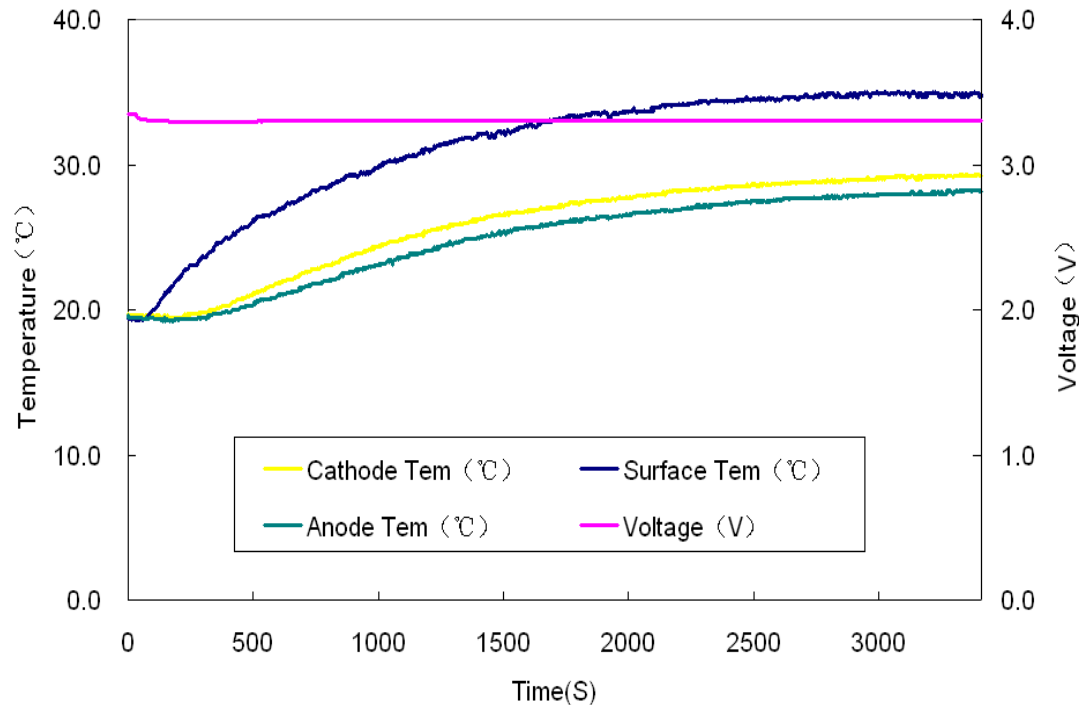
Dimension : 28\*100\*330mm

Result : Pass, cell inflation and vent open



1

## Nail Penetration



### Test procedure

Temperature :  $20 \pm 5$  °C

Diameter of steel pin : 3~8mm

Speed of penetration : 10~40mm/s

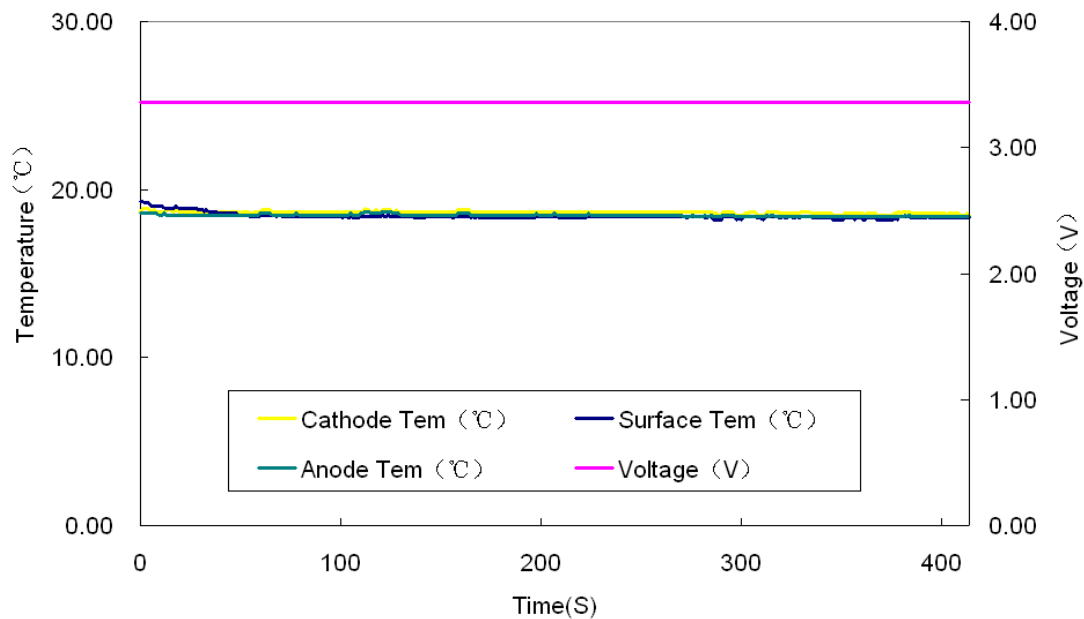
Penetration orientation :  
perpendicular to the wide side

Dimension : 28\*100\*330mm

Result : Pass, cell inflation

1

## Crush



### Test procedure

Temperature :  $20 \pm 5$  °C

Crush path : perpendicular to the wide side

Crush Platen area:  $\geq 20\text{cm}^2$

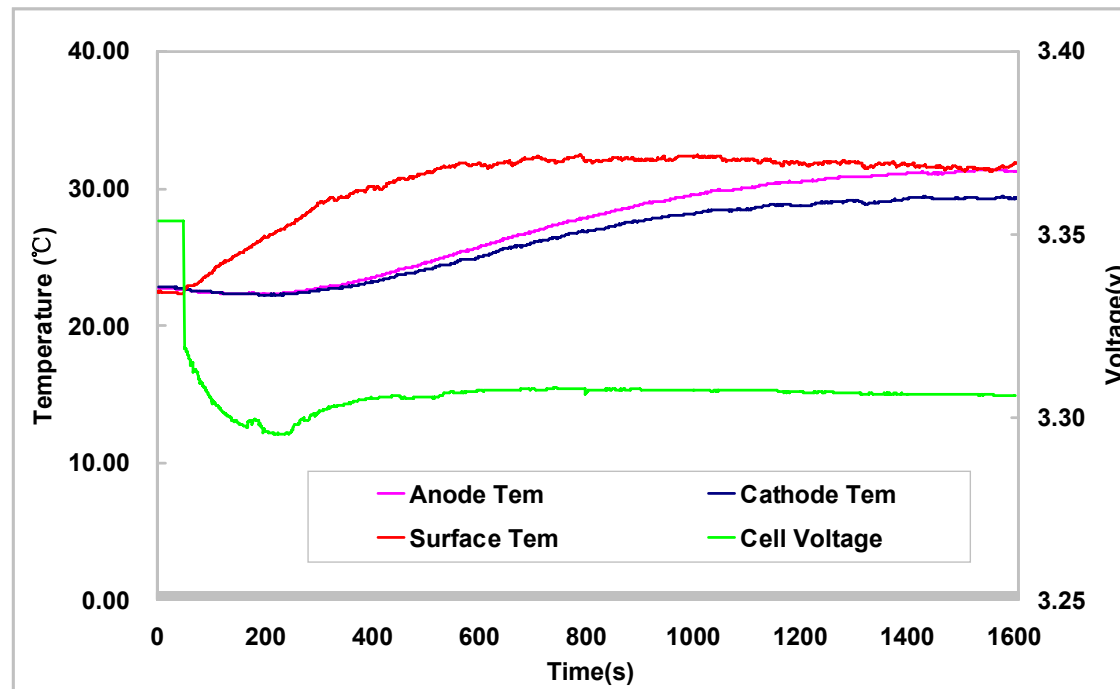
End of test: Cell case rupture or inner short

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, with30° wedge

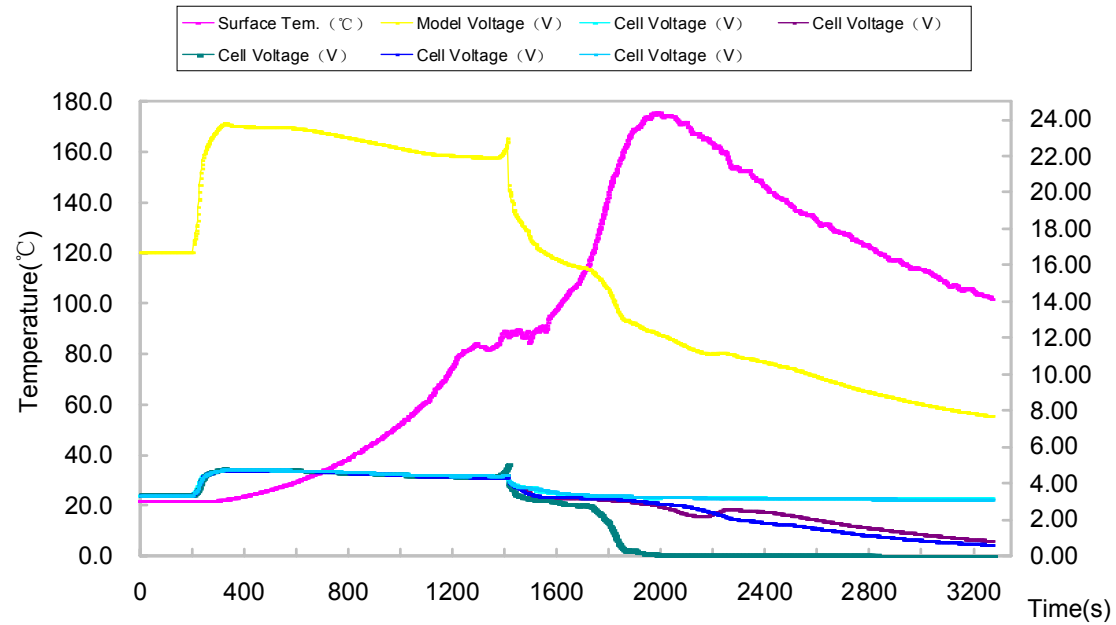
Impact orientation3 : right side, with30° wedge

Dimension : pack (cell 28\*100\*330mm)

Result : Pass with smoke

1

# Battery Module Overcharge



**Test procedure**

**Charge current : 1C**

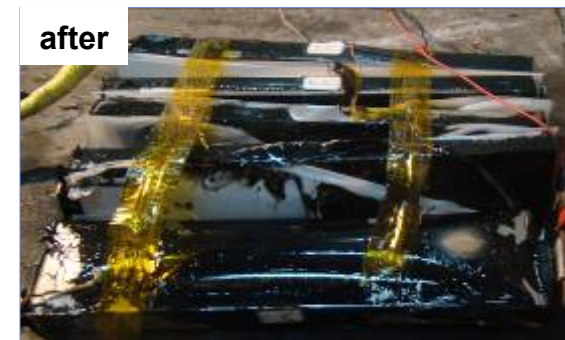
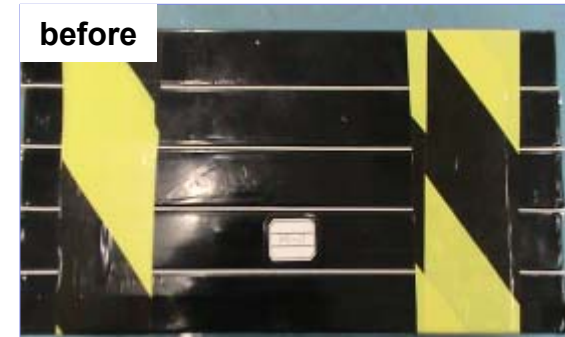
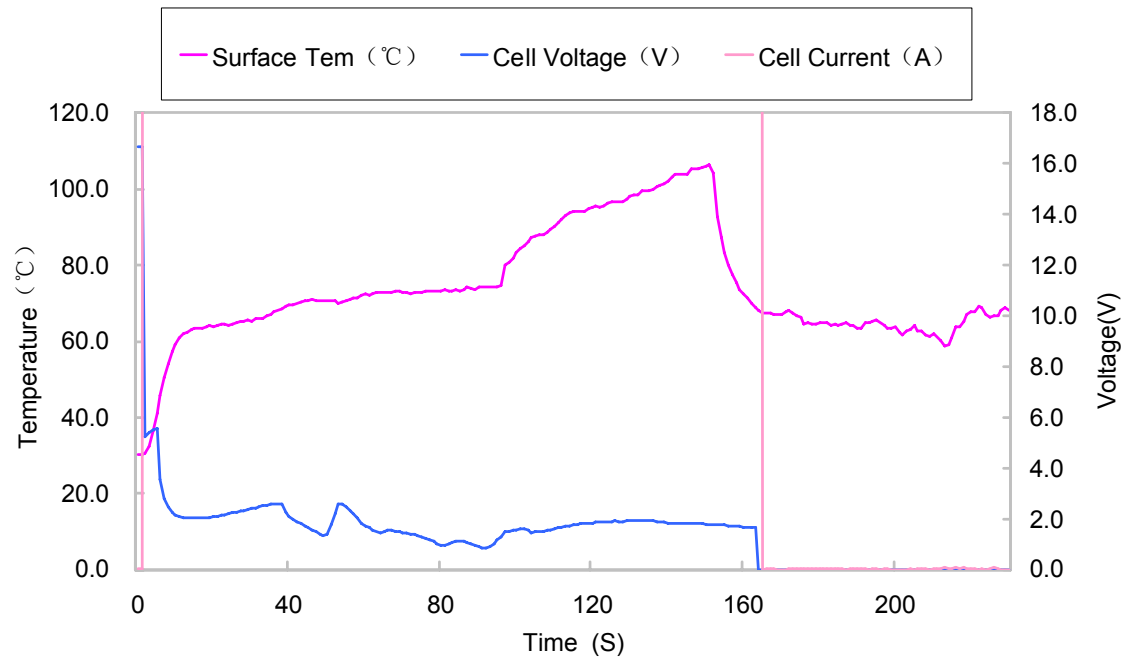
**End-of-charge voltage : 25V**

**Dimension : Module (cell28\*100\*300mm\*5)**

**Result : Pass, cell vent open**

1

## 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



1

## Battery Module Fire Test

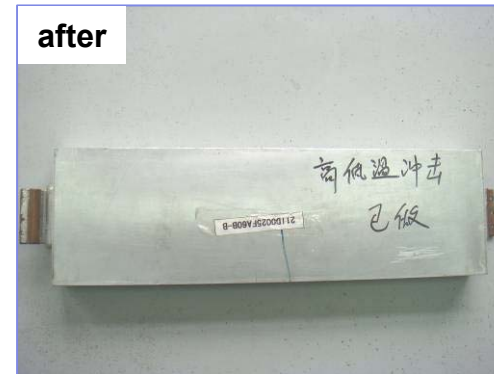
**Pls see the video**

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



## 2

## Thermal Shock



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 °C

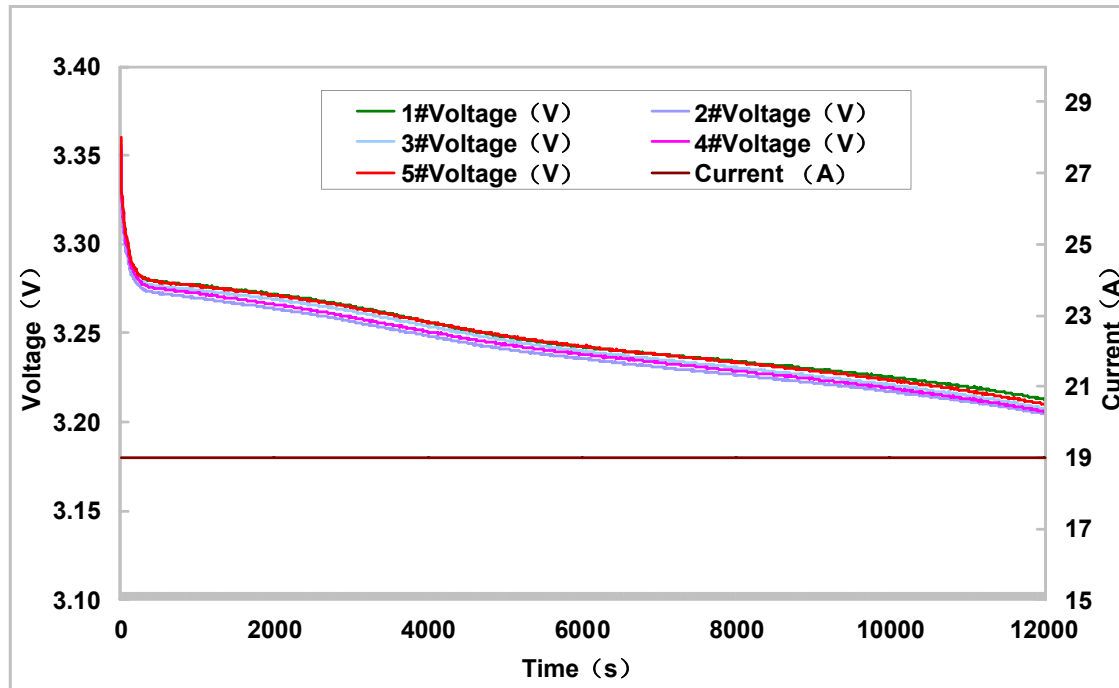
hold time at each temp. : 6h

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<sup>2</sup>

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

before

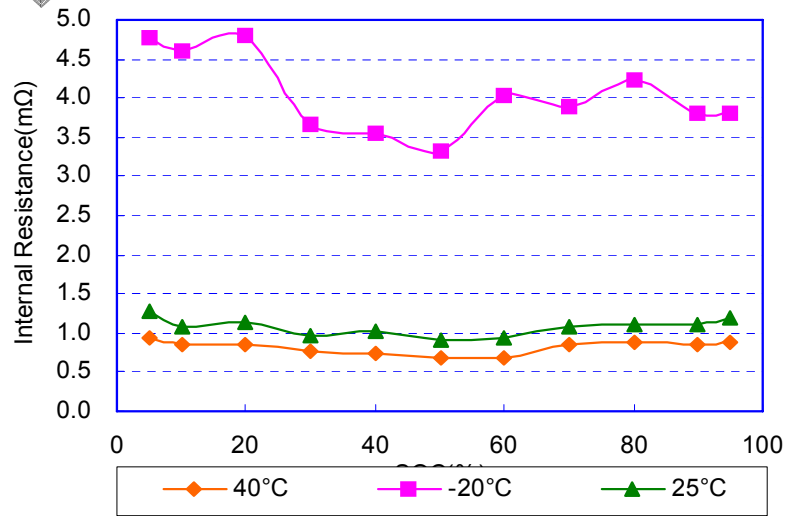


after

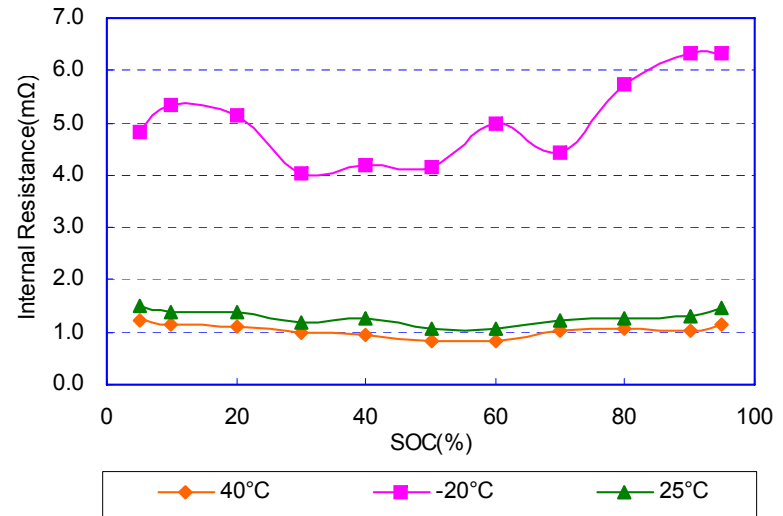


# 3

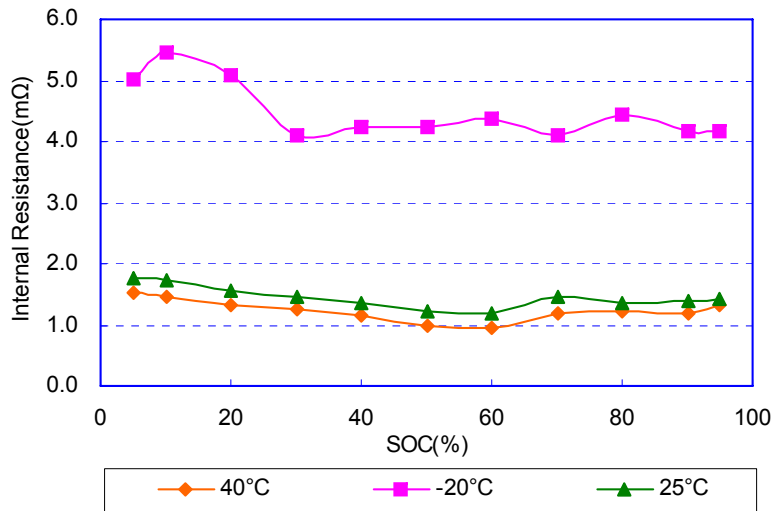
## Charge Pulse



1s duration



10s duration



18s duration

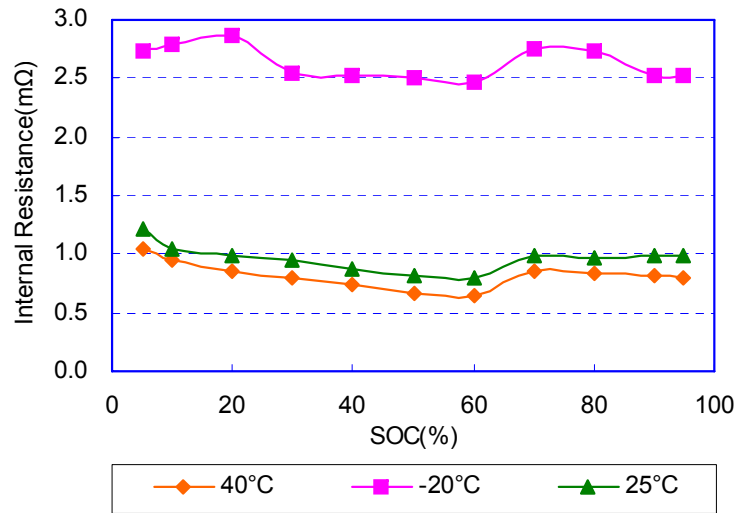
**Excellent charge pulses performance**

**At -20°C, the internal resistance is about 6m Ω .**

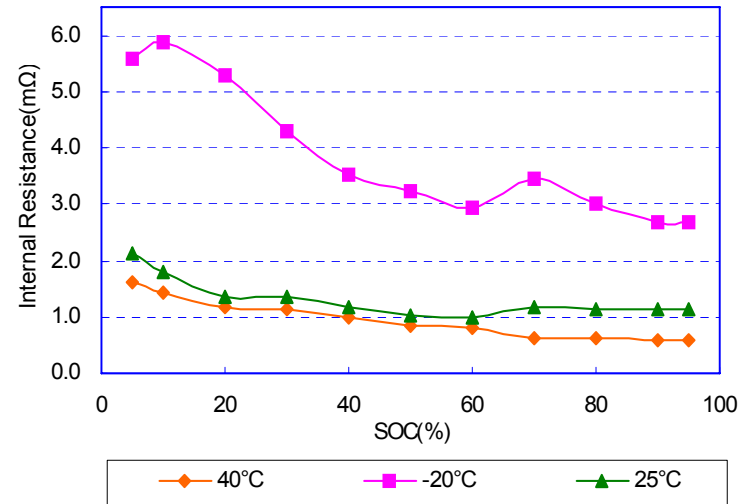
**At room temperature or high temperature, all internal resistances are lower than 2m Ω .**

# 3

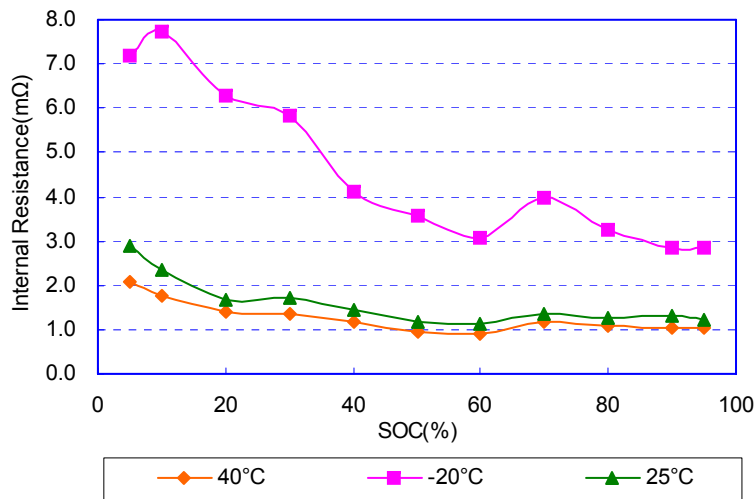
## Discharge Pulse



1s duration



10s duration



18s duration

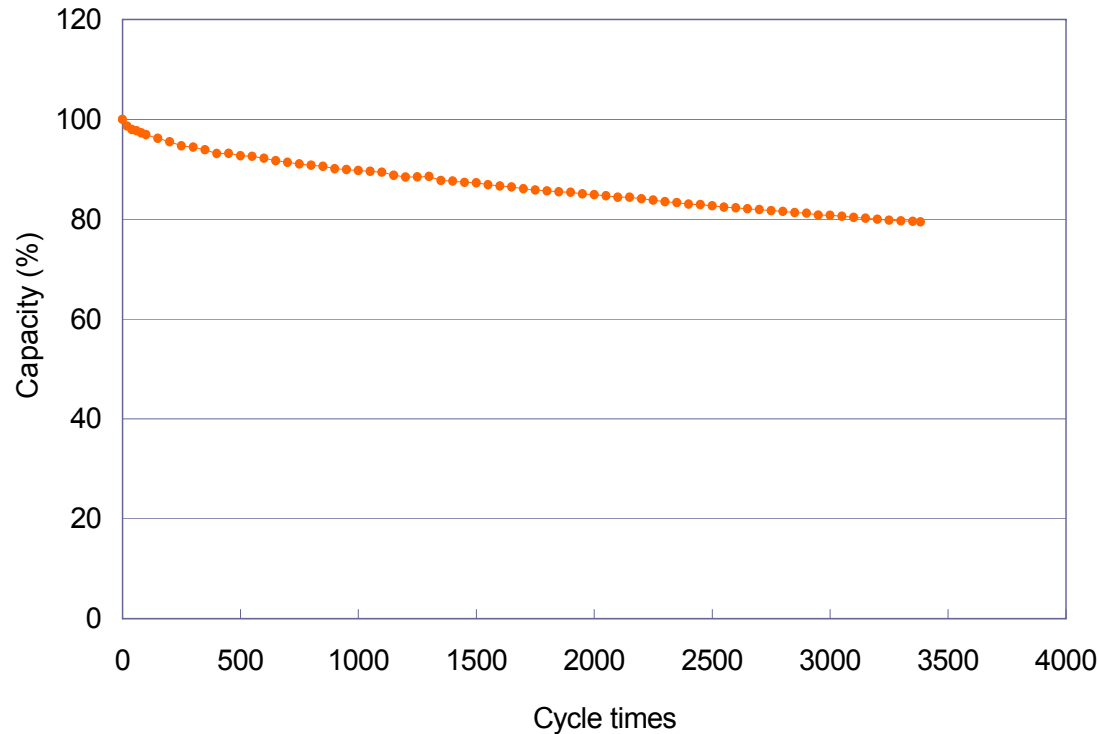
**Excellent discharge pulses performance**

**At -20°C, the internal resistance is about 5m Ω .**

**At room temperature or high temperature, all internal resistances are lower than 3m Ω .**

3

## Cycle Test at Room Temperature



### Test procedure

Temperature :  $20 \pm 5$  °C

Charge current : 1C

End-of-charge current : 0.001C

End-of-charge voltage : 3.8V

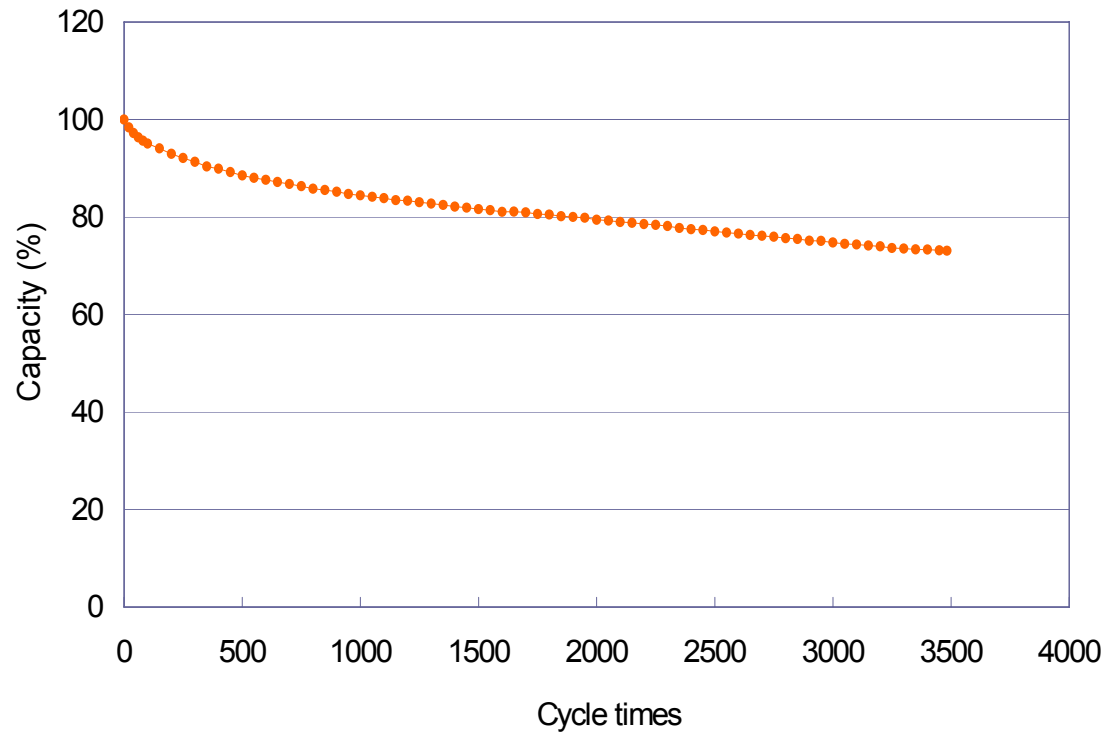
Dimension : 28\*100\*330mm

Cycle times : 3500

Retention : 80%

3

## Cycle Test at 45°C

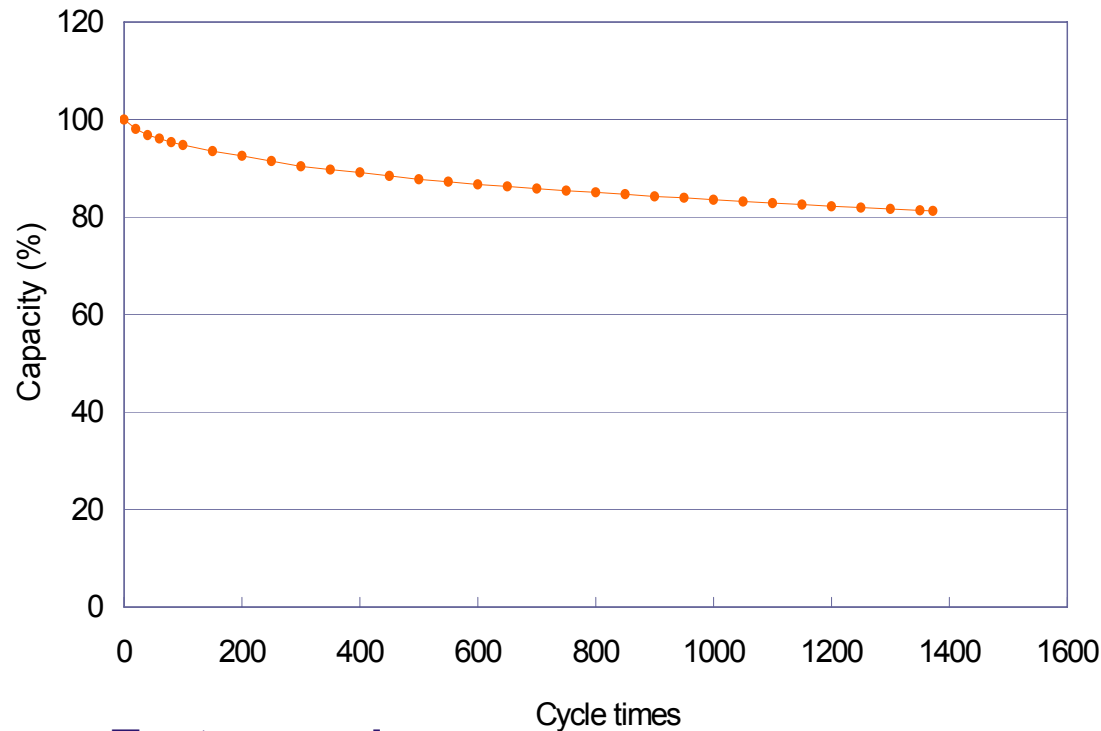


**Test procedure**  
**Temperature : 45 °C**  
**Charge current : 1C**  
**End-of-charge current : 0.001C**  
**End-of-charge voltage : 3.8V**

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

3

## Cycle Test at 60°C



### Test procedure

Temperature : 60 °C

Charge current : 1C

End-of-charge current : 0.001C

End-of-charge voltage : 3.8V

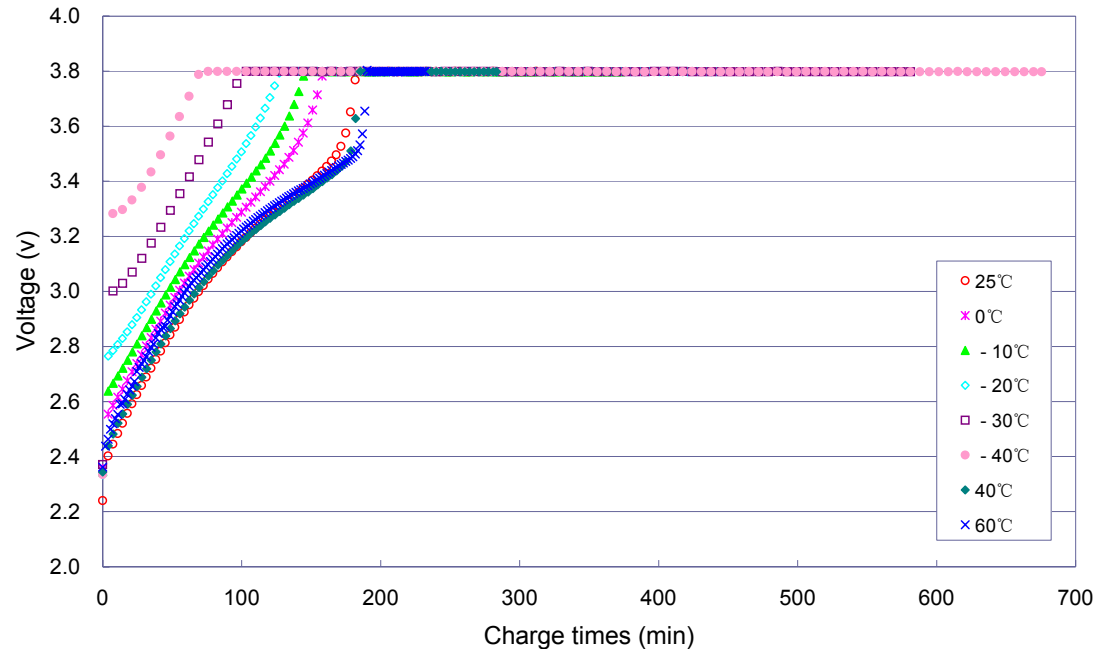
Dimension : 28\*100\*330mm

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

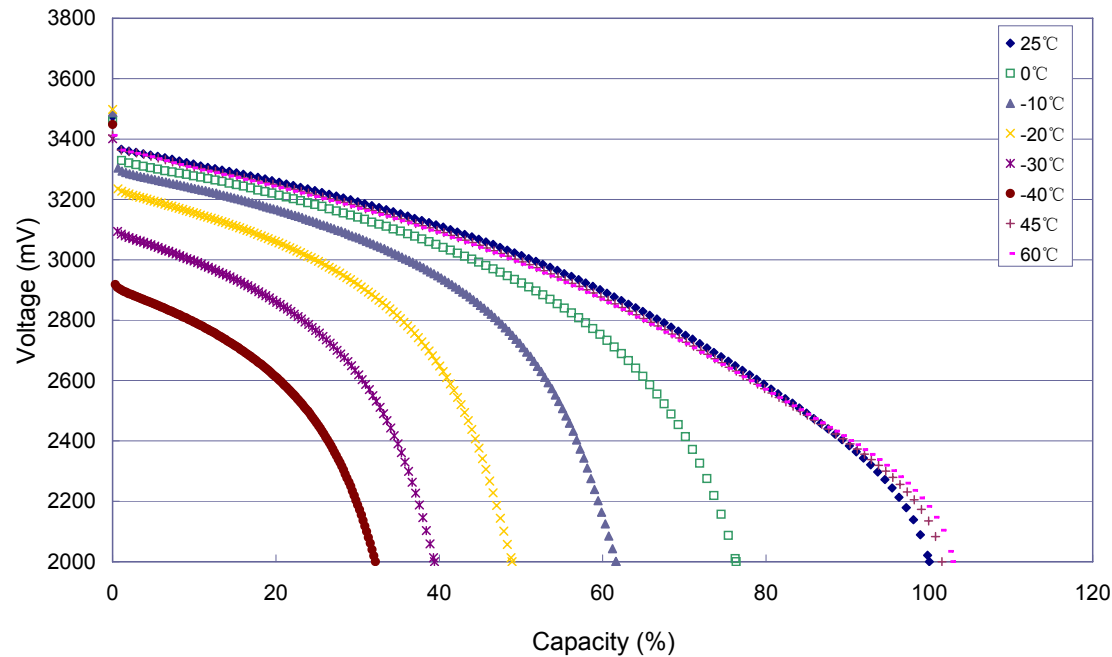
Dimension : 28\*100\*330mm

Charge temp. : -30~60 °C



## 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

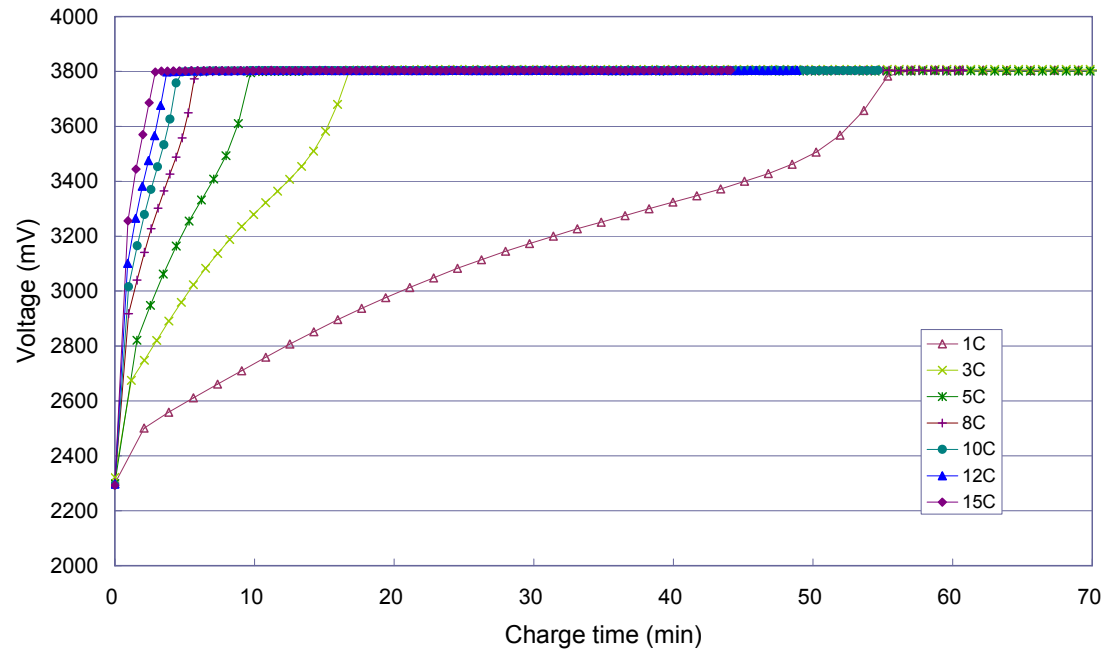
End-of-discharge voltage : 2.0V

Dimension : 28\*100\*330mm

Discharge temp. : -40~60 °C

## 3

## Charge at Different Current



## Test procedure

Temperature :  $20 \pm 5$  °C

Discharge current : 0.2C

End-of-discharge voltage : 2.0V

Rest time after discharge : 6h

End-of-charge voltage : 3.8V

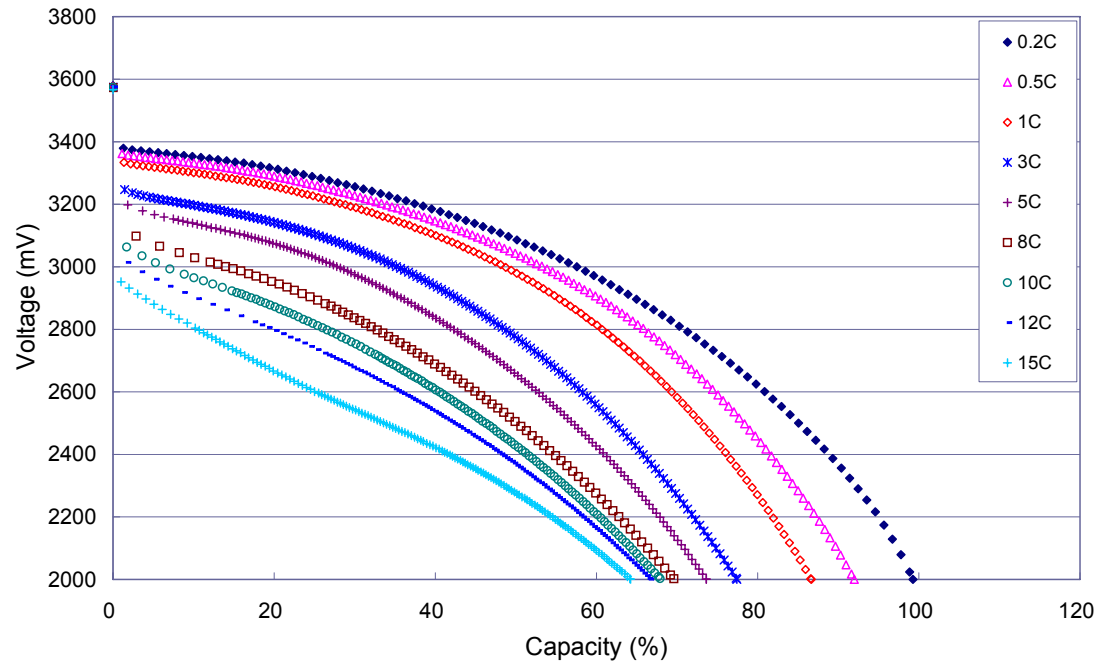
End-of-charge current : 0.02C

Dimension : 28\*100\*330mm

80% capacity can be charged  
in 10mins .

## 3

## Discharging at Different Current



### Test procedure

Temperature :  $20 \pm 5$  °C

Charge current : 0.2C

End-of-charge voltage : 3.8V

Rest time after charge : 6h

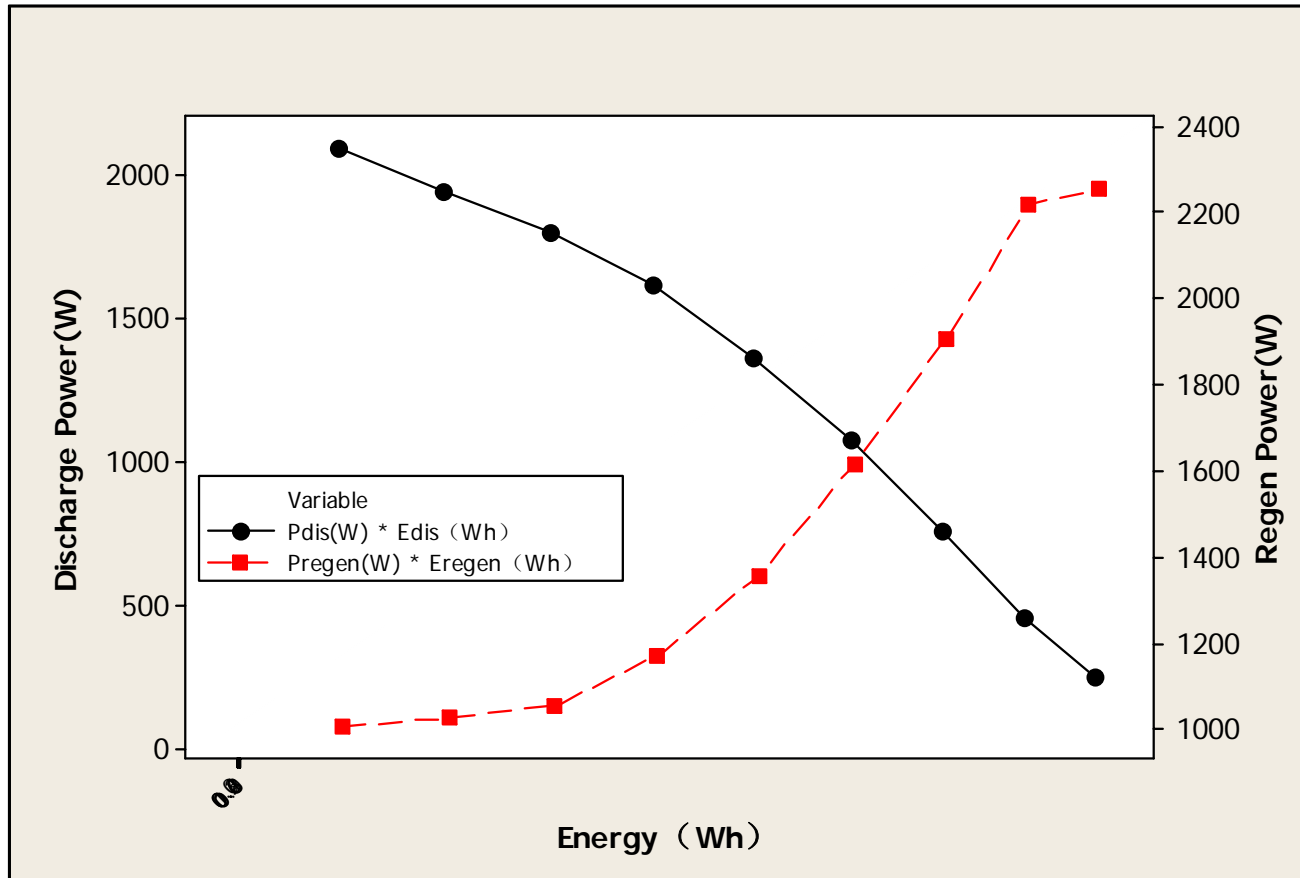
End-of-discharge voltage : 2.0V

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

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

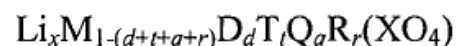
	QCT/743-2006 Lithium-ion Batteries for Electric Vehicles (2006)	Secondary Batteries for Electric Vehicles (Draft, 2009)
<b>Cell Performance</b>		
Storage	20°C, 90days, Residual Capacity>95%	55°C, 56days, Residual Capability>60%
Cycle Life	Residual Capacity>80% after 500 cycles	Residual Capacity>90% after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



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<sup>2+</sup>, Ni<sup>2+</sup>, [Co<sup>2+</sup>,] Zn<sup>2+</sup>, Cu<sup>2+</sup>, and Ti<sup>2+</sup>;



## 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!

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