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Thin Film Users Group:

Alternative Energy Symposium

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JSR Micro

MATERIALS INNOVATION

JM Energy's Lithium Ion Capacitor:

The Hybrid Energy Storage Advantage

Outline

1. Introduction to: JSR Corp, JSR Micro Inc, JM Energy.
2. Lithium Ion Capacitor: Concept, Features, Assembly, Applications.
3. Performance Characteristics.
4. Safety.
5. LIC Packs and Modules
6. Reliability.
7. Improvement Plans
8. Summary.

JSR Corp, Overview

- JSR Corp, was founded in 1957, HQ in Tokyo, Japan
- Annual revenues of over $4.2 billion.
- 5,122 employees
- Major Facilities:
  - Japan: Yokkaichi, Yamanashi, Kyushu, Tsukuba, Chiba and Kashima
  - US: Sunnyvale, CA
  - Europe: Leuven, Belgium
- Major Subsidiary Companies:
  - JM Energy, dedicated to the development and production of Lithium Ion Capacitors.
  - JSR Micro Inc, the US division of JSR Corp.
    - ✓ Distributor for JM Energy and all JSR Corp products.
  - JSR Micro NV, the European division of JSR Corp.

JM Energy's New HQ and Production Plant

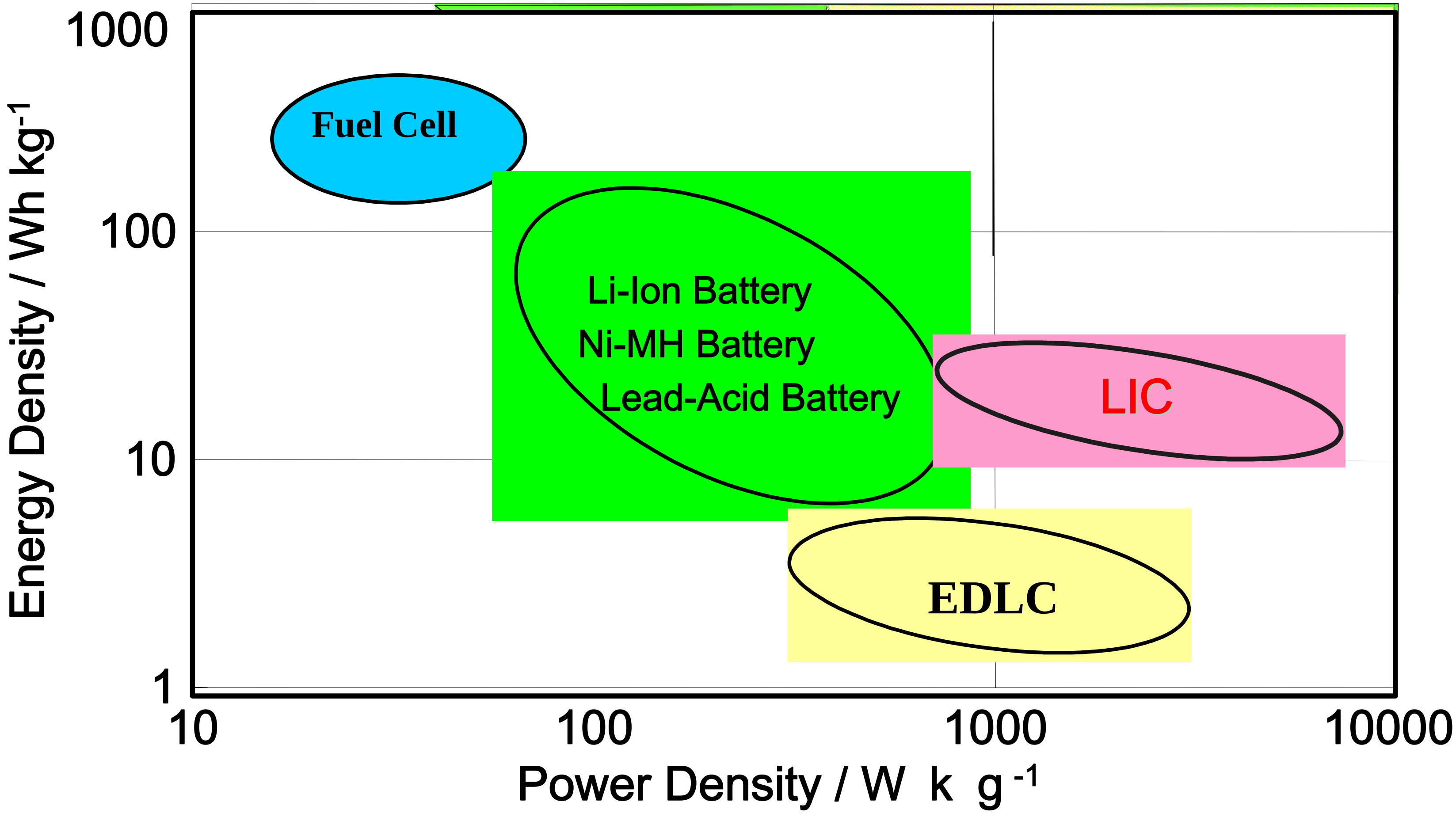
- JM Energy's Yamanashi HQ plant.
  - Construction completed in October 2008; production started in January 2009
  - Investment: $18.9 million
- Production Capacity.
  - January 2009 — 300K cells/year
  - 2009 — 600K cells/year
  - 2010 — 1.2 million cells/year
  - 2011 — 2.4 million cells/year

LIC Performance Overview

Highly reliable, safe, high power, and high energy density capacitor

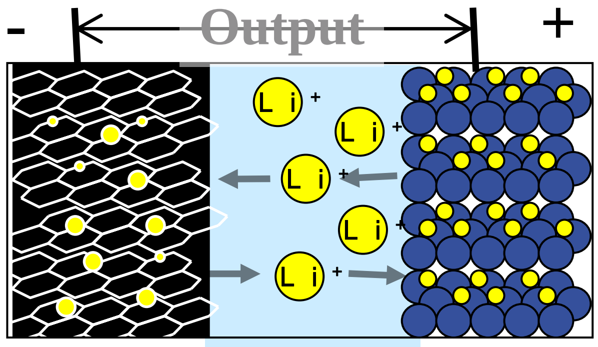
About 4 times higher energy density than conventional EDLC,

More than 2 times higher power density than conventional secondary batteries.



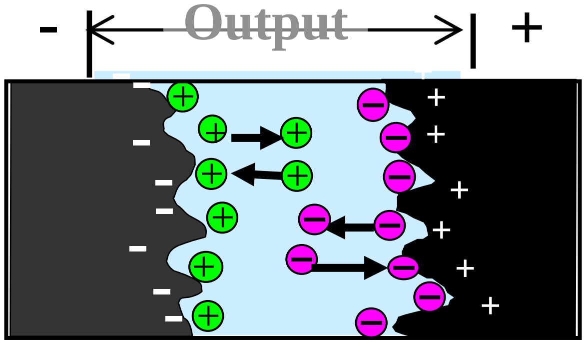
The Lithium Ion Capacitor is a Hybrid Device

Lithium-ion Battery



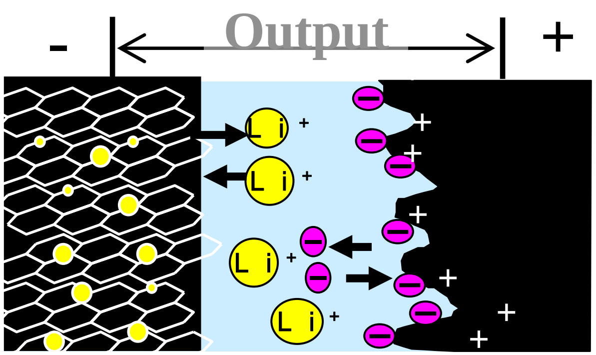
Graphite Electrolyte $LiCoO_2$

EDLC



Activated Carbon Electrolyte Activated Carbon

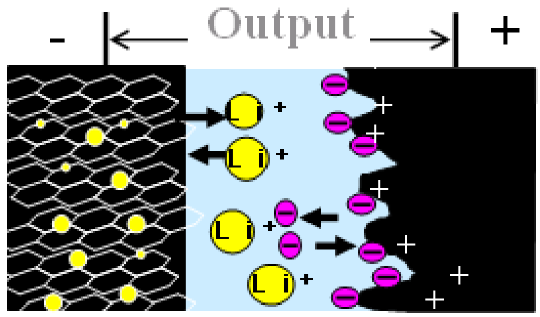
Lithium-ion Capacitor



Li-doped Carbon Electrolyte Activated Carbon

Key technology:
Pre-doping of Li
to the carbon anode

Lithium-ion Capacitor

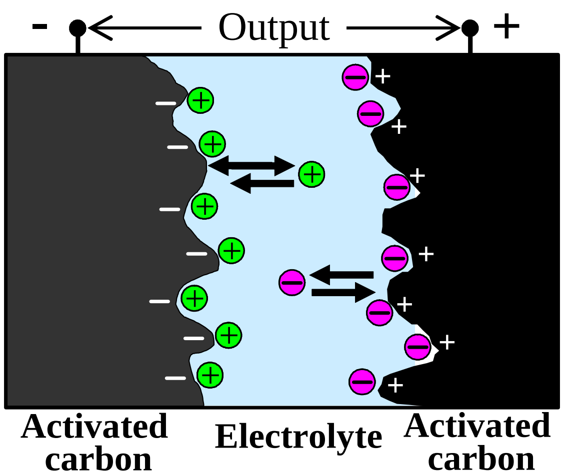


- Hybrid construction summary:
  - The activated carbon cathode is a capacitor cathode.
    - ✓ In a Lithium Ion Battery thermal runaway occurs at the cathode when the Li spinel decomposes and reacts with the electrolyte.
  - Since LIC has an activated carbon cathode, thermal runaway will not occur.
  - The Li-doped carbon anode is a battery anode, undergoing Li doping during charge and de-doping during discharge
  - The electrolyte contains a Li salt and is a battery electrolyte.

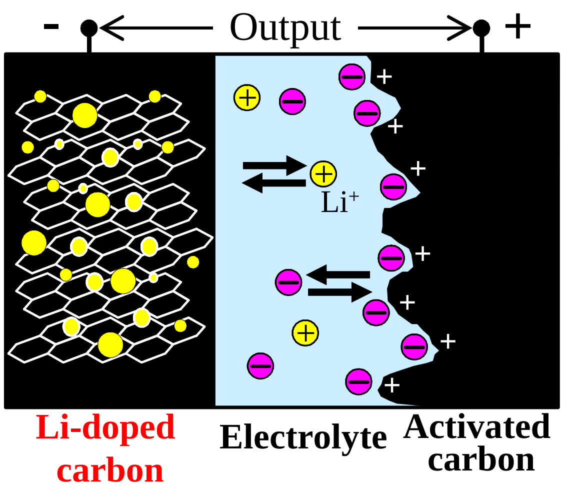
- Hybrid construction creates a capacitor which yields the best performance features of batteries and capacitors

LIC vs. EDLC: Capacitance Comparison

EDLC



Lithium Ion Capacitor



$$\frac{1}{C_{cell}} = \frac{1}{C-} + \frac{1}{C+}$$

$C- = C+ = C$

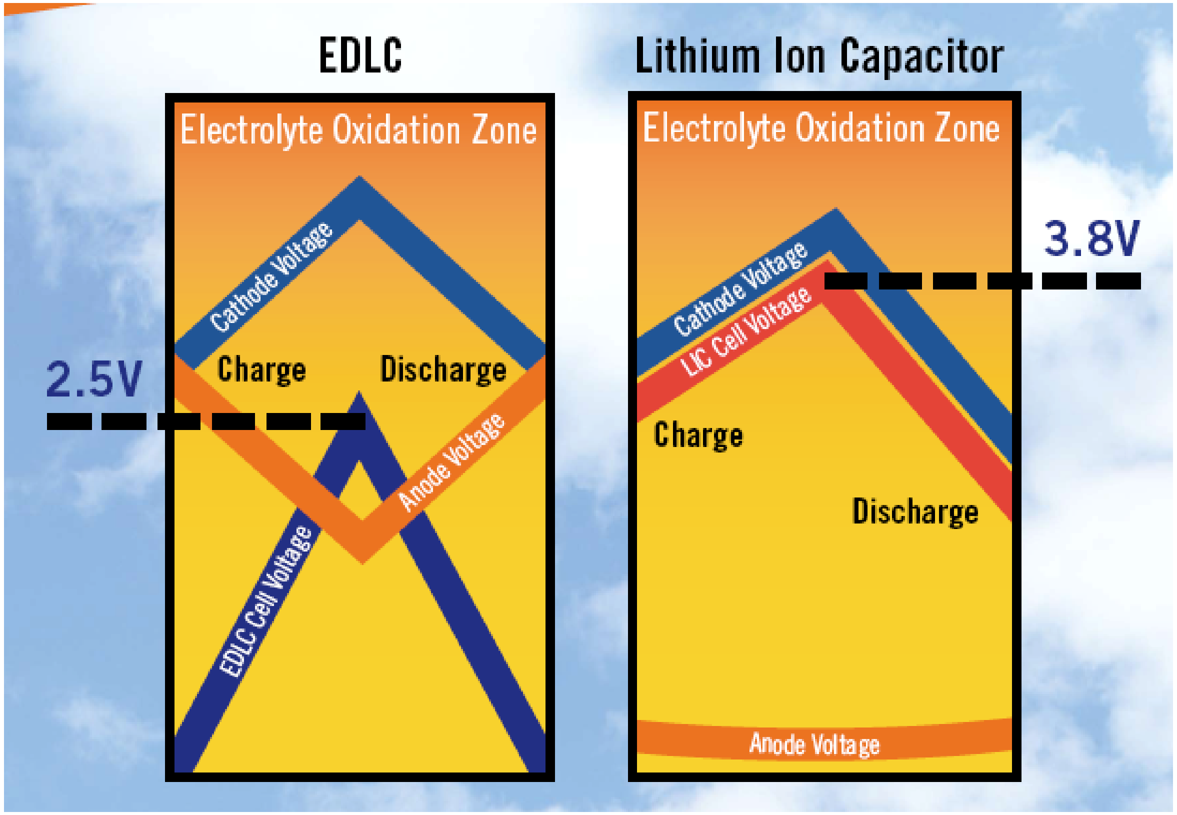
$C_{cell} = 1/2C$

LIC's Capacitance is twice as high

$C- >> C+$

$C_{cell} = C+$

LIC vs. EDLC: Charge-Discharge Cycles



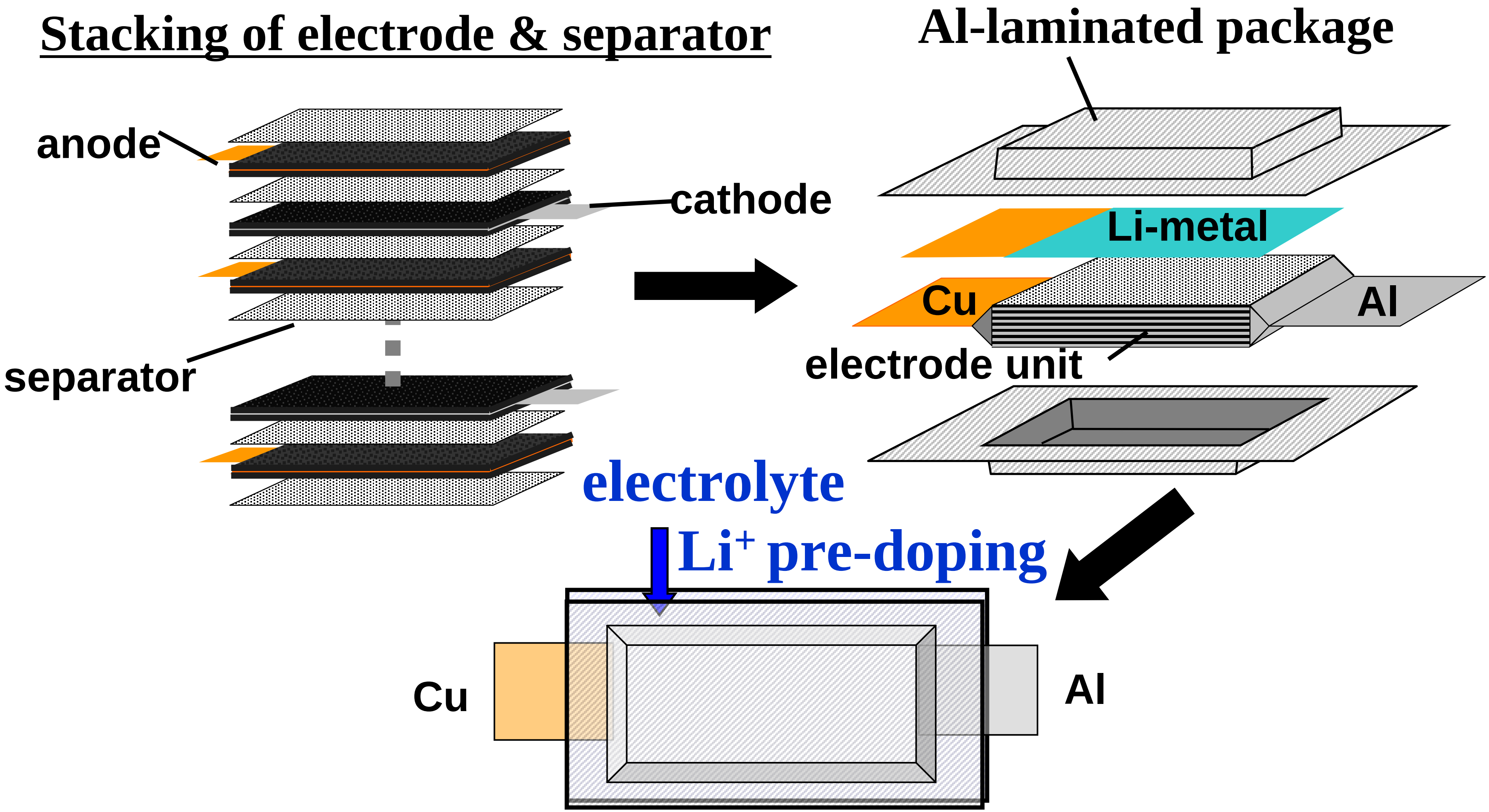
- For EDLC the anode and cathode potentials change symmetrically and the maximum cell voltage is 2.5 to 2.7v.
- For LIC the anode's potential stays almost constant due to the lithium doping and the maximum cell voltage is 3.8v

Hybrid Performance Advantages

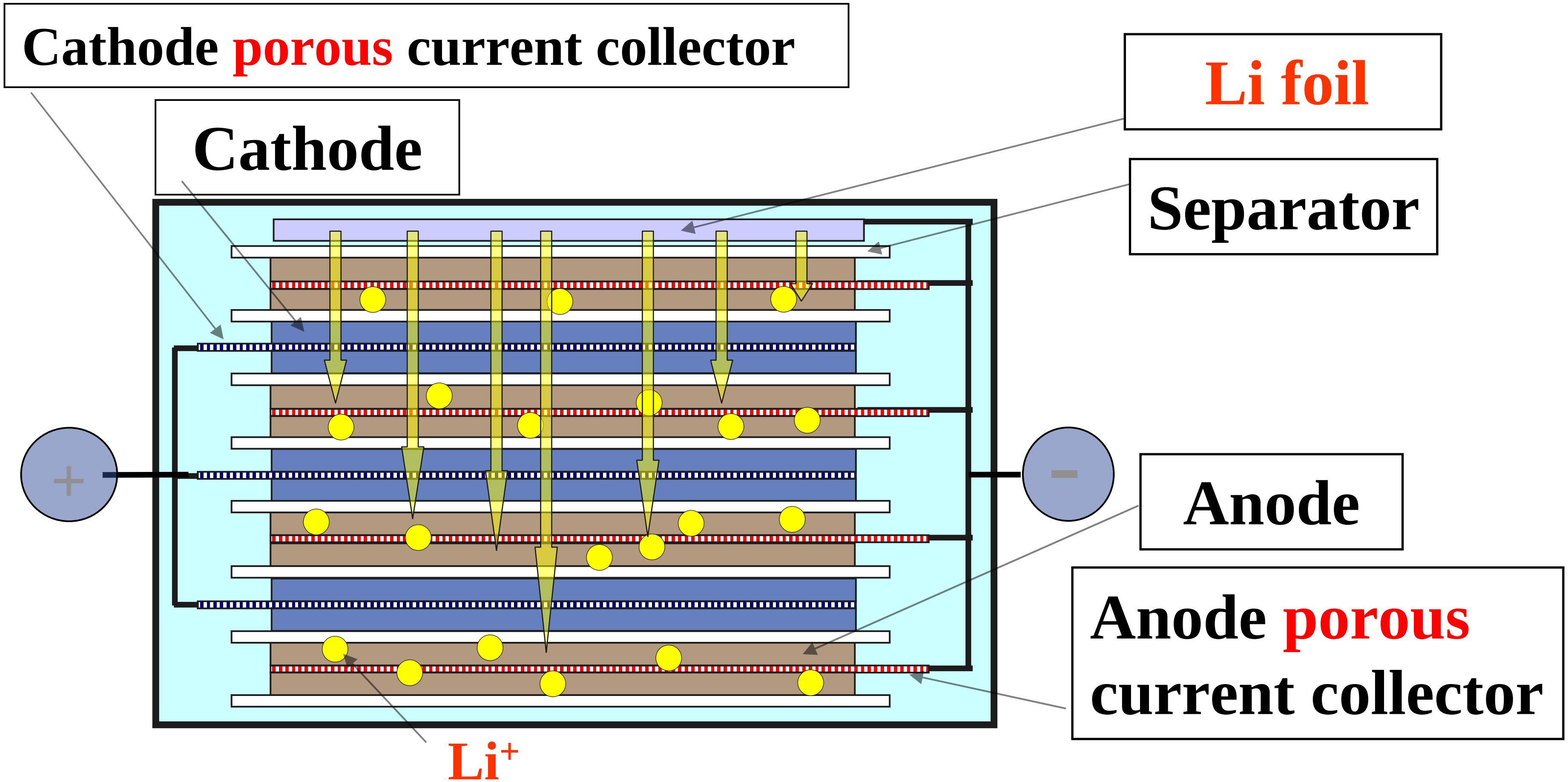
- **Battery-Like Advantages**
  - High Energy Density
    - ✓14-15 Wh/kg
  - High Voltage
    - ✓3.8v to 2.2v discharge range
    - ✓When connected in series, 1/3 fewer LIC cells are needed compared to a conventional EDLC supercapacitor
  - Low Self-Discharge Rate
    - ✓Will hold 95% of its charge after 3 months

- **Capacitor-Like Advantages**
  - **Safety: No Thermal Runaway**
    - ✓Since the cathode does not contain Li spinel, thermal runaway cannot occur
  - High Power Density
    - ✓>1000 W/kg
  - Can be charged/discharged quickly.
  - High Reliability
    - ✓Estimated life is 1 million charge/discharge cycles
  - Wide Temperature Range
    - ✓-20°C to 70°C

Assembly of Laminated LIC Cell



Schematic figure of Li pre-doping



Li+ Pre-dope start after electrolyte is impregnated

Features of JM Energy's-LIC

Environmentally friendly materials
C, Al, Cu, Li

High performance
High energy density
High Voltage

Key technology:
Lithium pre-doping
Electrode/cell design

Mass- producible
(Conventional mass production technology is applicable)

Highly reliable
(Less degradation of positive electrode)
Less self discharge
Long life

LIC Applications

Energy generation & storage

- Wind Turbine
- Solar Cells
- LED Display

Transportation

- Trains/Trams
- Cars
- Buses/Trucks
- Airplanes

UPS

- Voltage sag compensation
- Bridge power

Industrial Machines

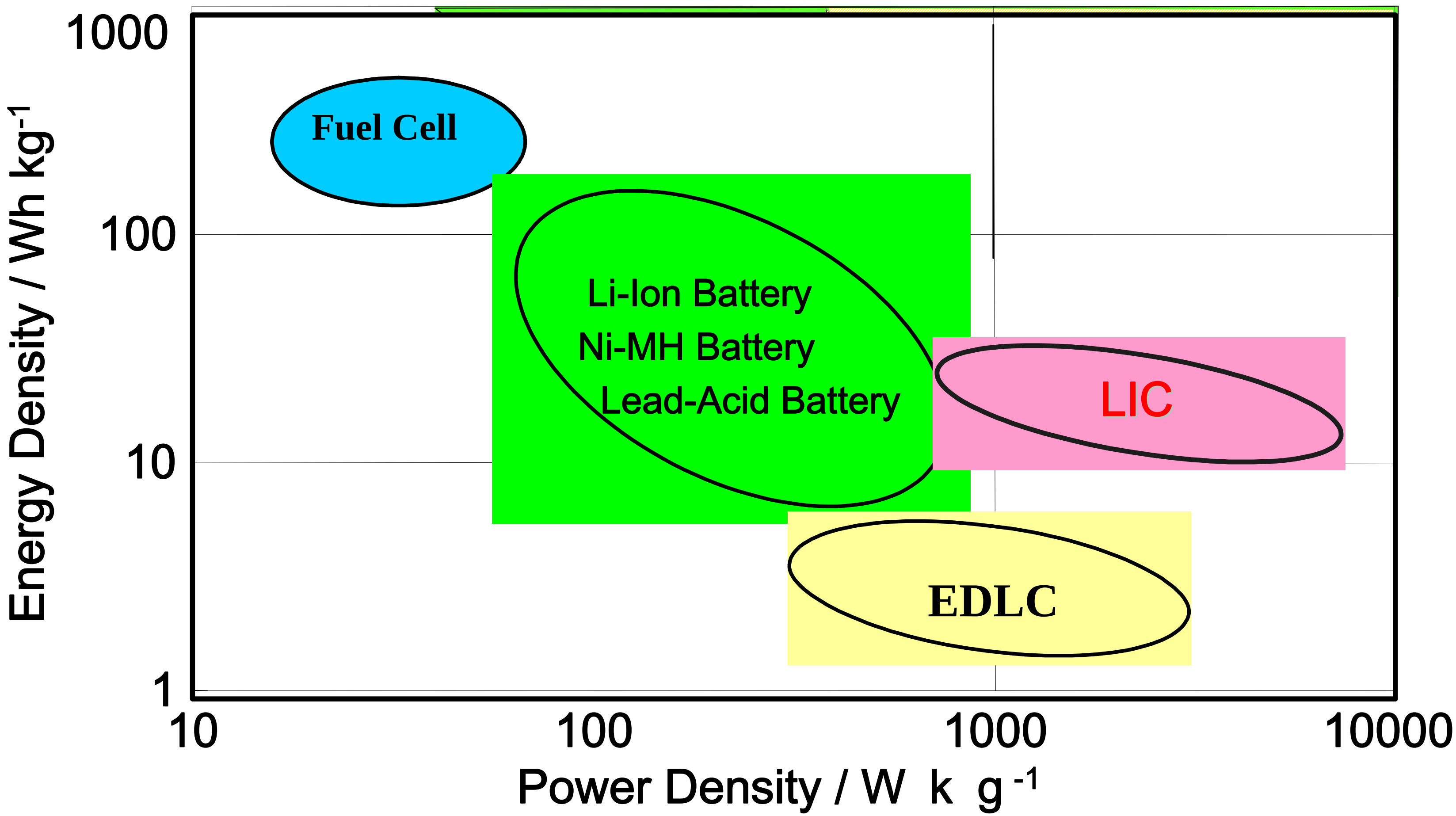
- Forklift
- Power shovel
- Cranes
- AGV

Medical Equipment

- CT, MRI, etc.

LIC Performance Overview

Highly reliable, safe, high power, and high energy density capacitor
About 4 times higher energy density than conventional EDLC,
More than 2 times higher power density than conventional secondary batteries.



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Advantage of LIC against EDLC

	JM Energy - LIC	E D L C
		
Capacitance (F)	2000	2000
Volume (mL)	124	373
Weight (g)	208	400
Internal resistance (mΩ)	1.4	0.4
Max operation voltage (V)	3.8	2.7
Volume Energy density (Wh/L)	25	5
Weight Energy density (Wh/kg)	14	4.5

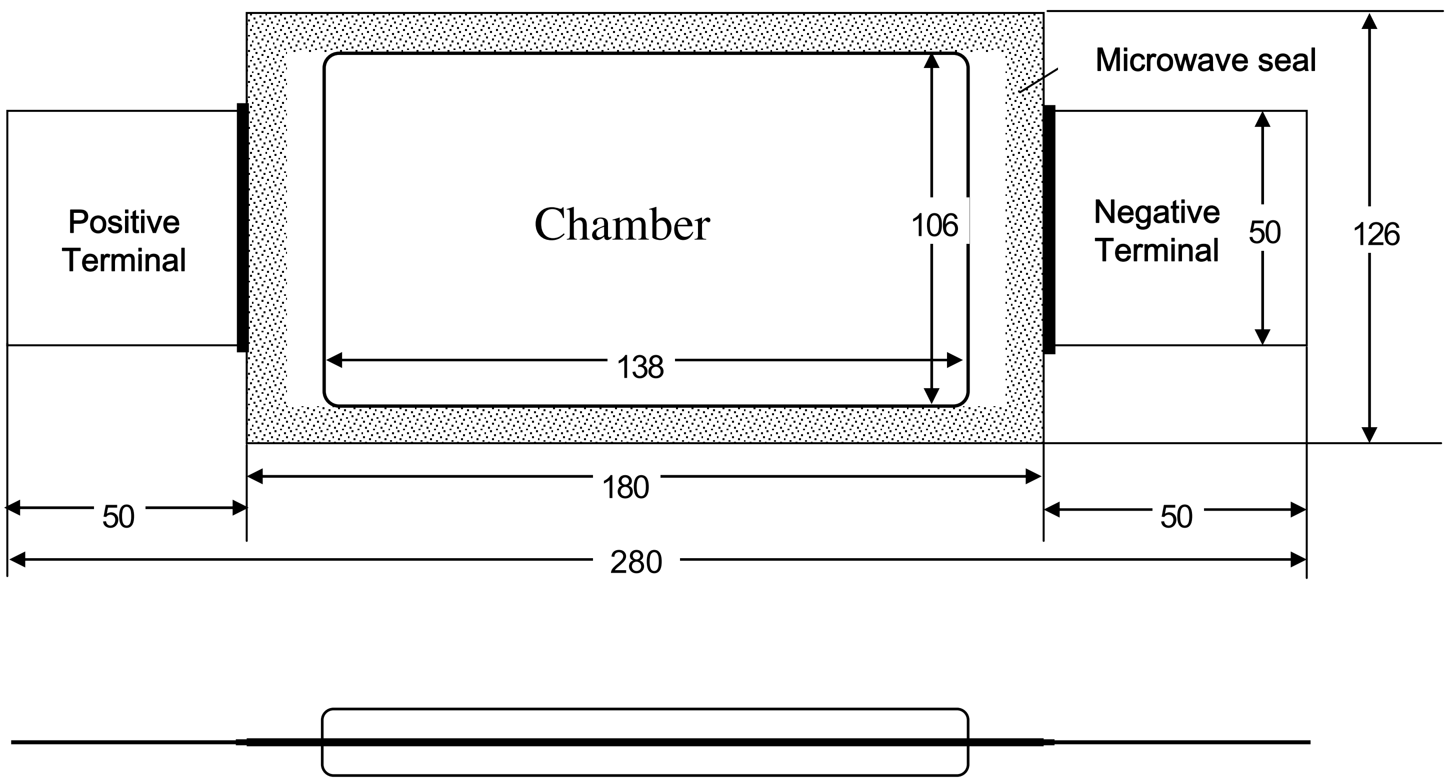
LIC Cell Performance (1000F, 2000F)

Measurement Items			Unit	1000F Standard	2000F Standard	2000F Low -resistance	Conditions
Operating Temp.		Range	C	- 20 ~ + 70	- 20 ~ + 70	- 20 ~ + 70	
Rated Voltage		Max	V	3.8	3.8	3.8	
		Min	V	2.2	2.2	2.2	
Initial Properties		Capacitance	F	1100±100	2200±200	2200±200	10CA, C.C. Discharge at 25℃
		DC-IR	mohm	4.5±0.6	2.3±0.3	1.4±0.3	
		ESR	mohm	2.8±0.6	1.4±0.3	1.0±0.3	1kHz
		Energy Density (weight)	Wh/kg	12	14	11	10CA, C.C. Discharge at 25℃
		Energy Density (Volume)	Wh/L	21	25	19	
Temp. Dependence	-20℃	Capacitance	F	850±150	1700±300	1700±300	10CA, C.C. Discharge
		DC-IR	mohm	46±6	23±3	19±3	
	70℃	Capacitance	F	1150±150	2300±200	2300±200	
		DC-IR	mohm	2.4±0.8	1.4±0.3	0.8±0.3	
High Temp. Load Life		Capacitance	F	1000±150	2000±300	2000±300	3.8V, 70℃, 1000h
		DC-IR	mohm	5.0±0.8	2.6±0.4	1.6±0.4	
Cycle Test Performance		Capacitance	F	1000±150	2000±300	2000±300	100CA at 25℃, 100k Cycle
		DC-IR	mohm	5.0±0.8	2.6±0.4	1.6±0.4	
Self Discharge		Voltage Drop	%	<1%	<1%	<1%	24h at 25℃
				<5%	<5%	<5%	3 Month at 25℃
Cell Dimension			mm	138×106×5	138×106×9	138×106×11	Active Size
Cell Weight			g	113±4	208±4	270±6	

LIC Cell Performance (350F, 500F)

			Unit	350F	500F	Condition
Operating Temperature		Range	C	-20° ~ 70°	-20° ~ 70°	
Rated Voltage		Maximum	V	3.8V	3.8V	
		Minimum	V	2.2V	2.2V	
Initial Property		Capacitance	F	370F	550F	10CA constant current discharge at 25°C
		E S R	mΩ	5.6	3.9	1kHz
		DC-IR	mΩ	10.4	7.5	
		Energy Density by Weight	Wh/kg	15	15	10CA constant current discharge at 25°C
		Energy Density by Volume	Wh/L	26	26	
Capacitance	-20°	from 25°	%	75	75	10CA constant current discharge
	70°	from 25°	%	105	105	10CA constant current discharge
Heat Resistance		from Initial	%	90	90	3.8V, 70°C, 100 h
Cycle Test Performance		from Initial	%	90	90	100CA constant current discharge 25°C、100K Cycles
Self Discharge		ΔVoltage	%	< 5	< 5	3 months at 25°C
Dimensions		Convex	mm	52×66×6.5	52×66×9.0	

Cell Dimensions (2000F, 1000F)

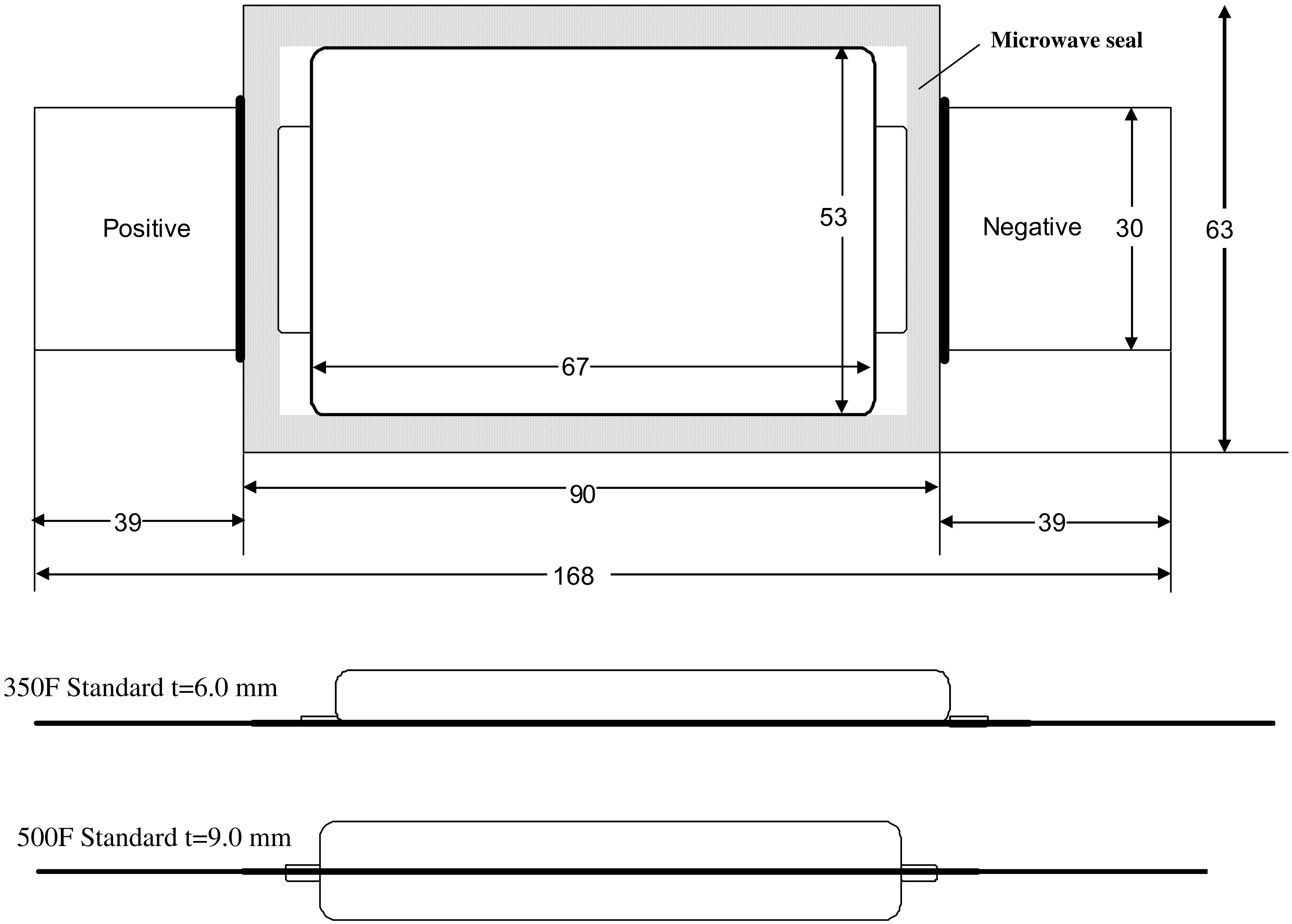


Cell thickness: 2000F Low Resistance 10.5 ± 1.0mm

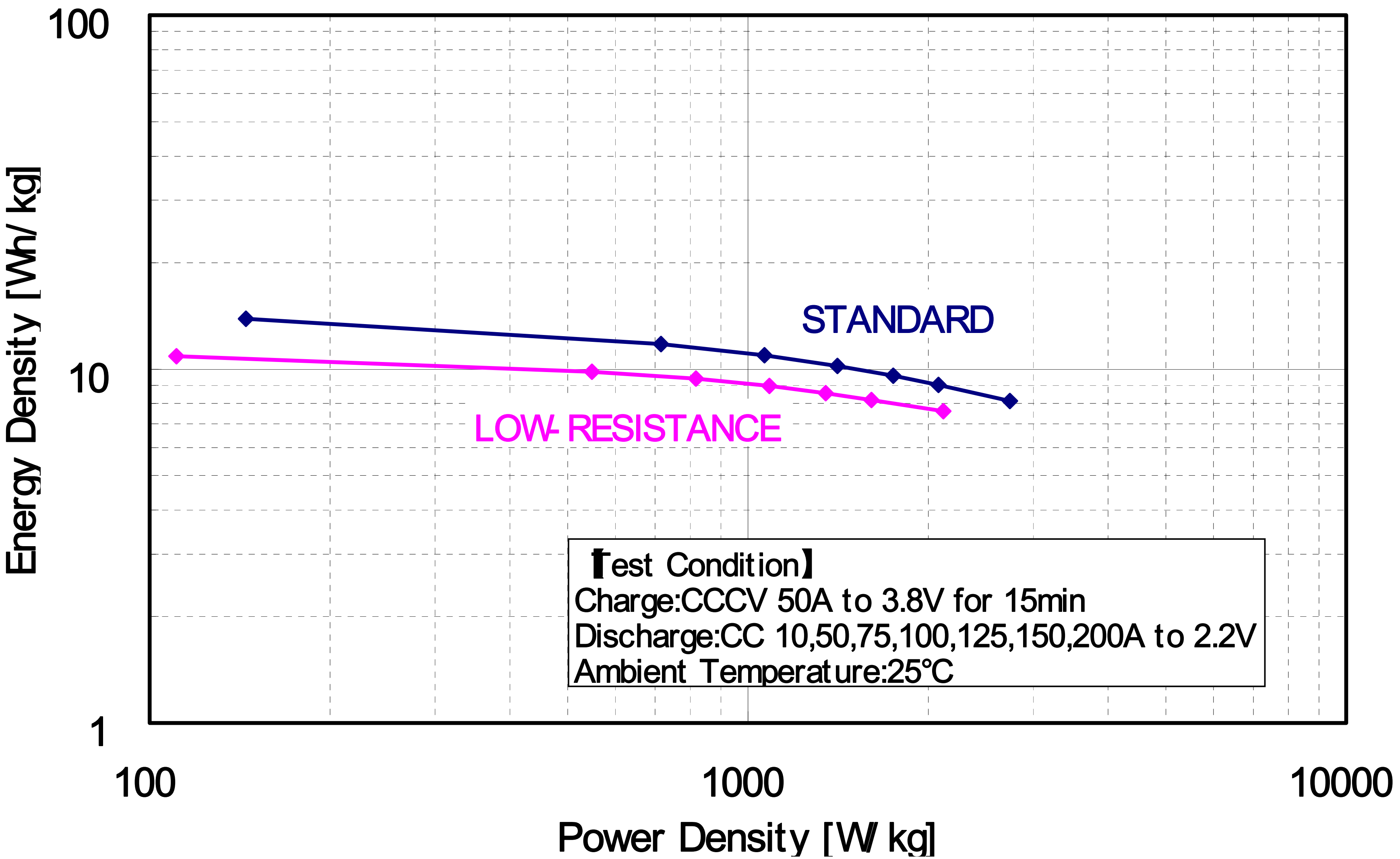
2000F Standard 8.5 ± 1.0mm

1000F Standard 5.0 ± 1.0mm

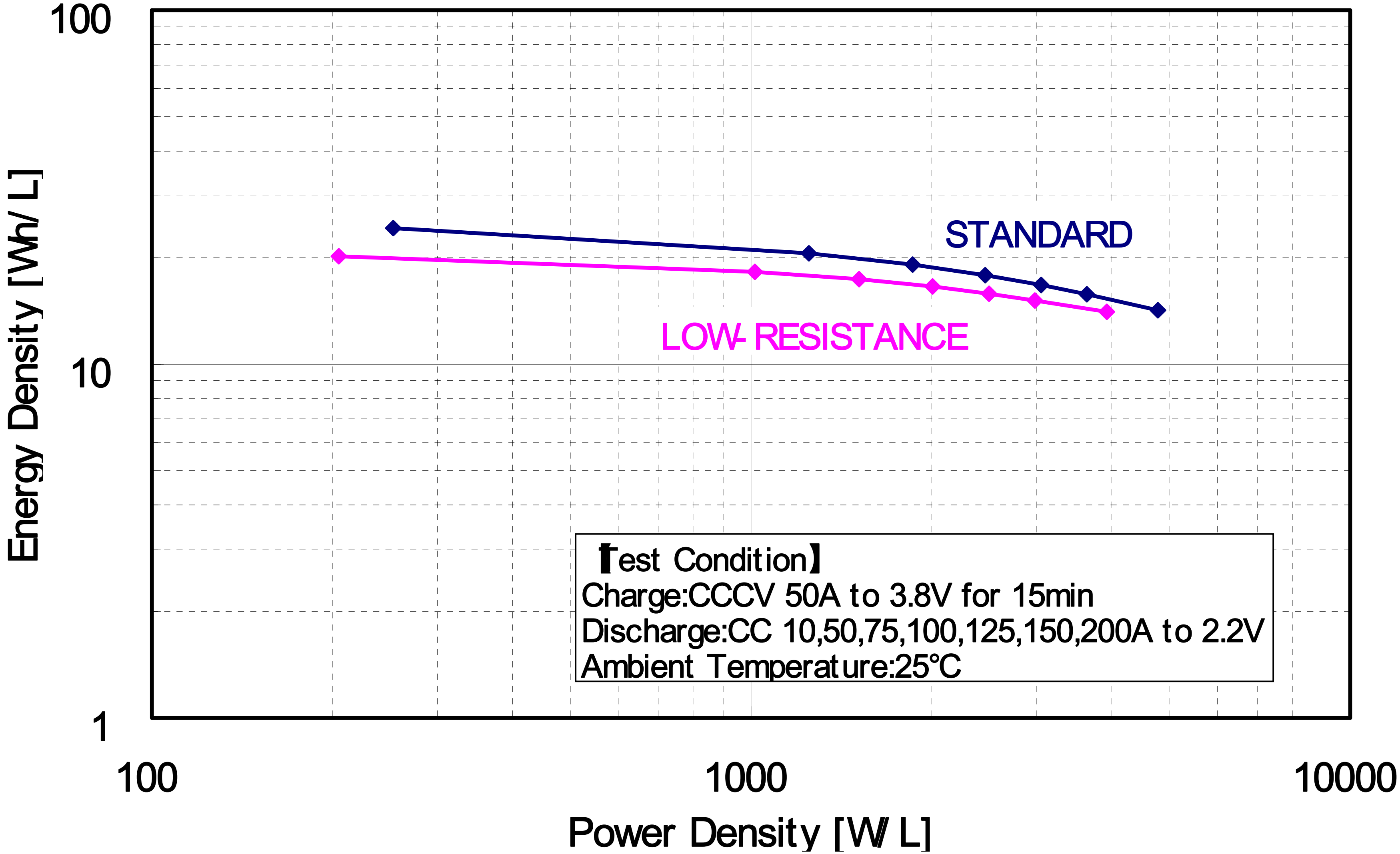
Cell Dimensions (350F, 500F)



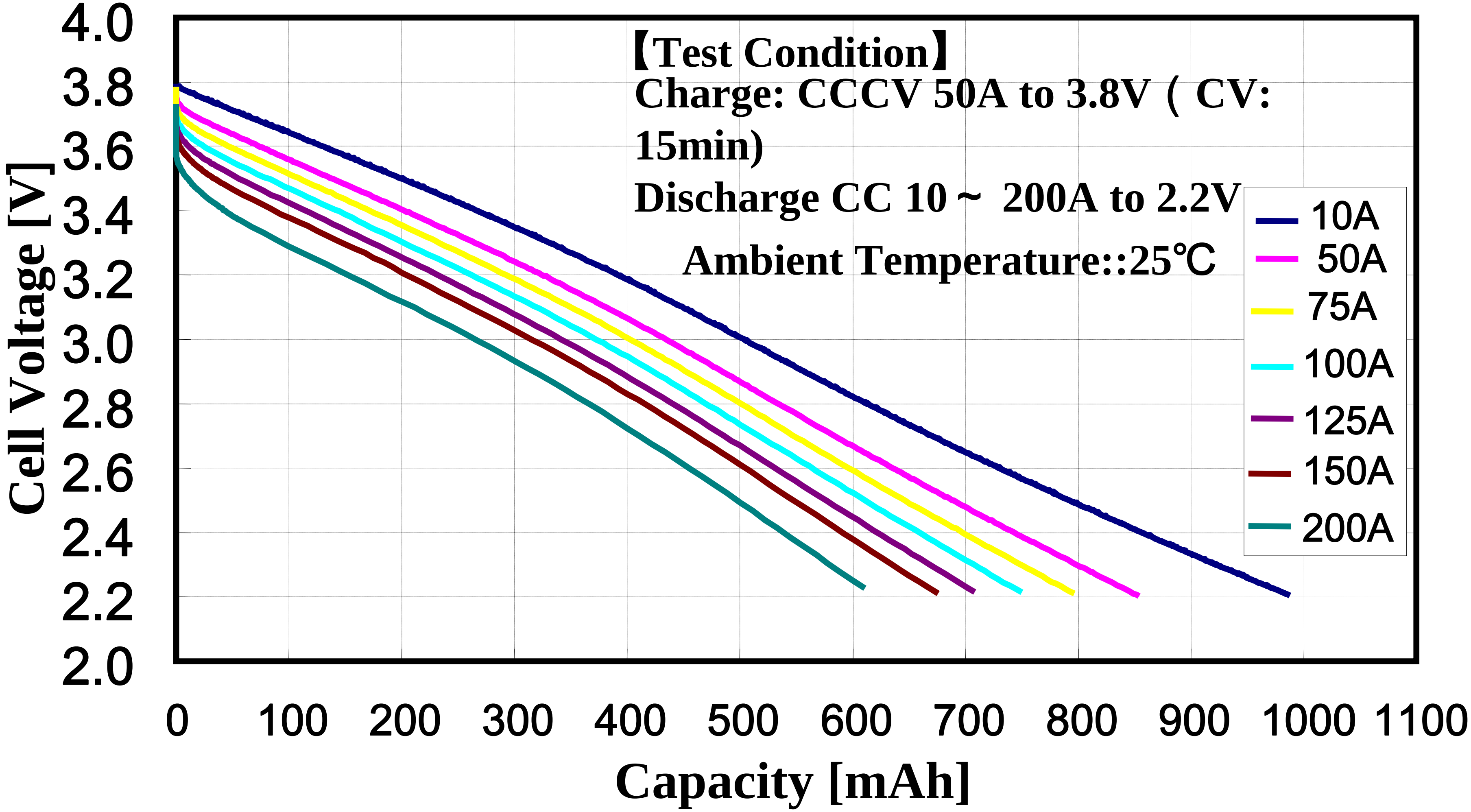
Ragone Plots (Weight), 2000F



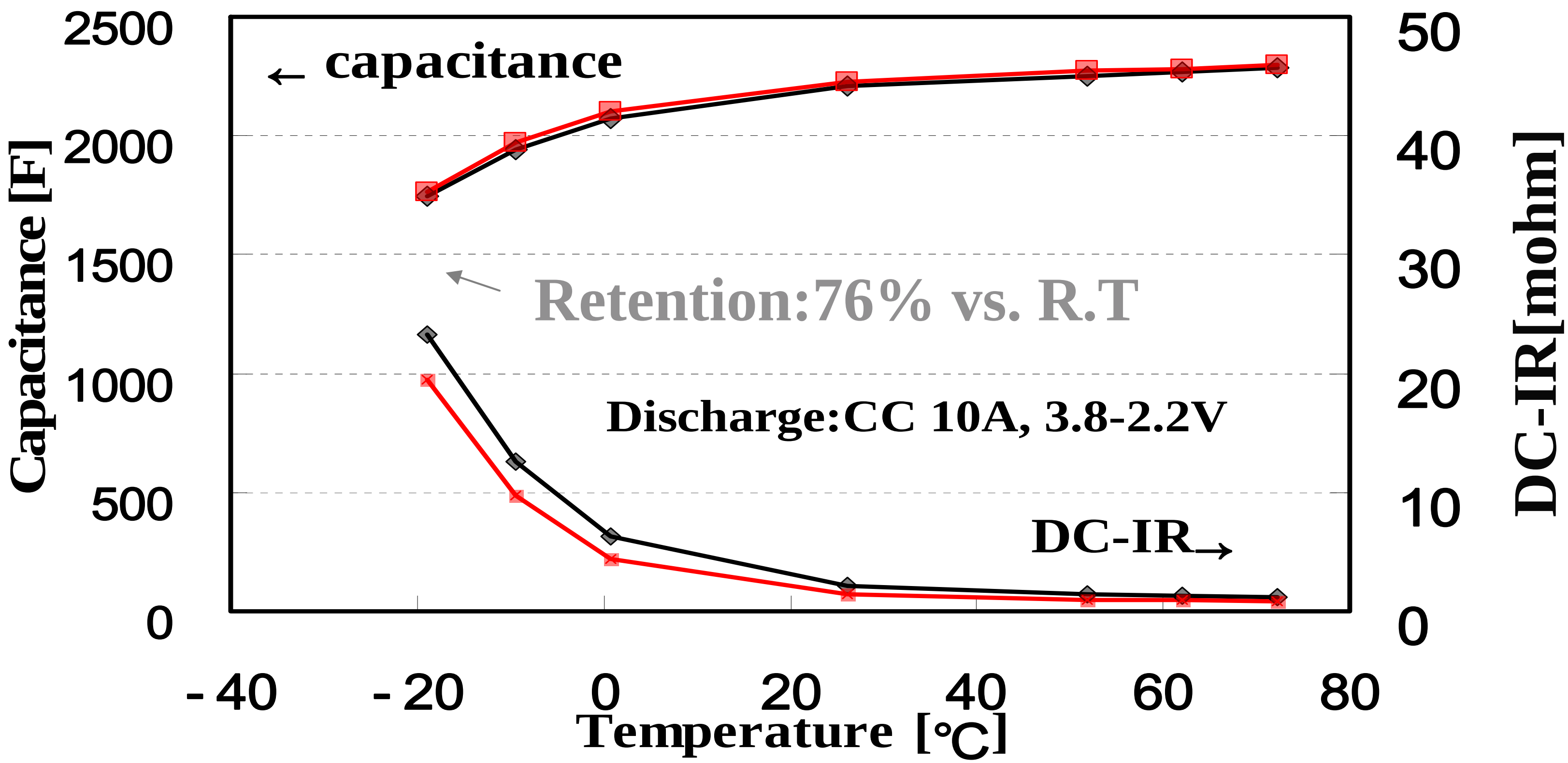
Ragone Plots (Volume), 2000F



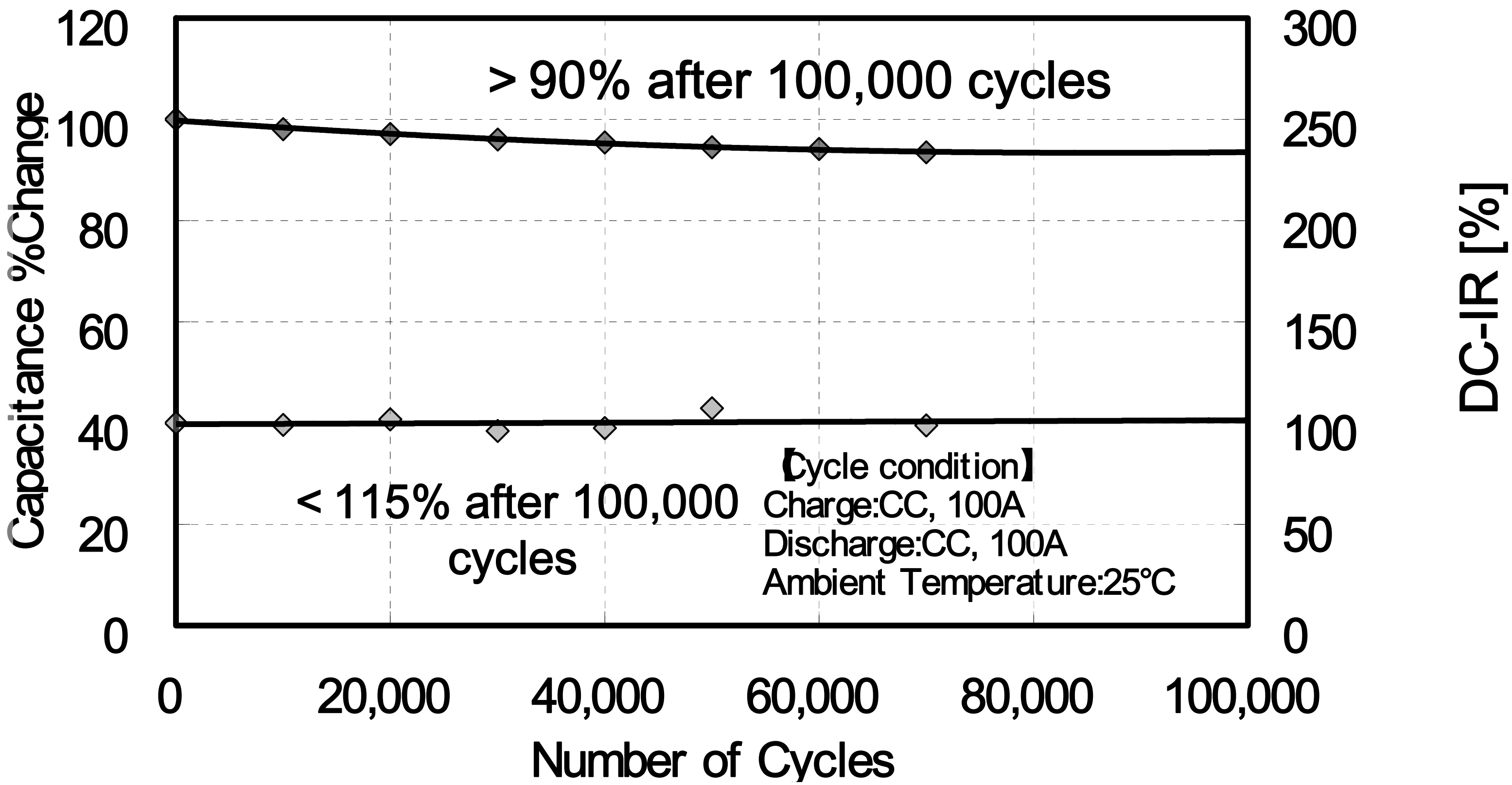
Discharge Curve (2000F, Standard Type)



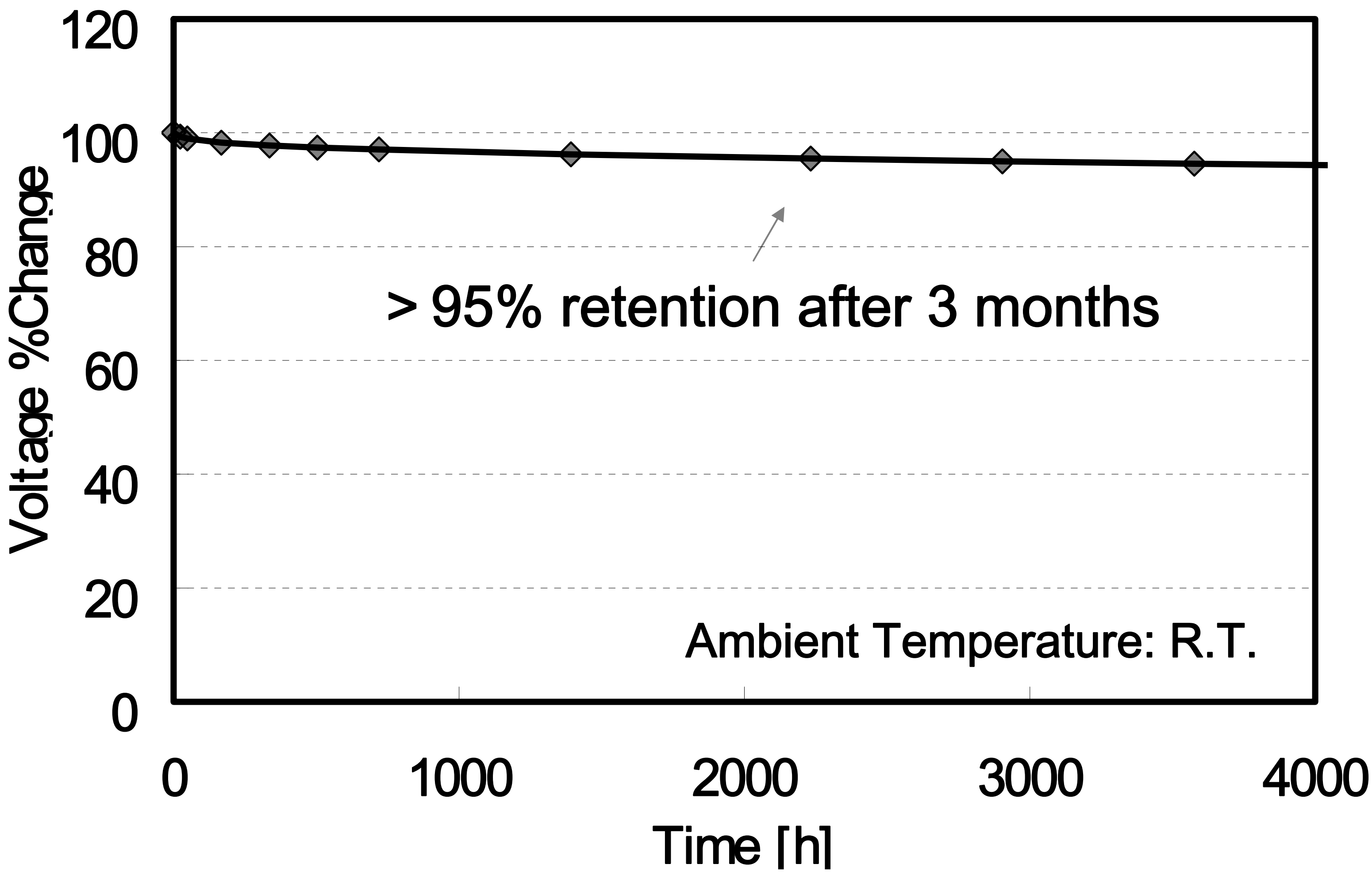
Temperature Dependence (2000F)



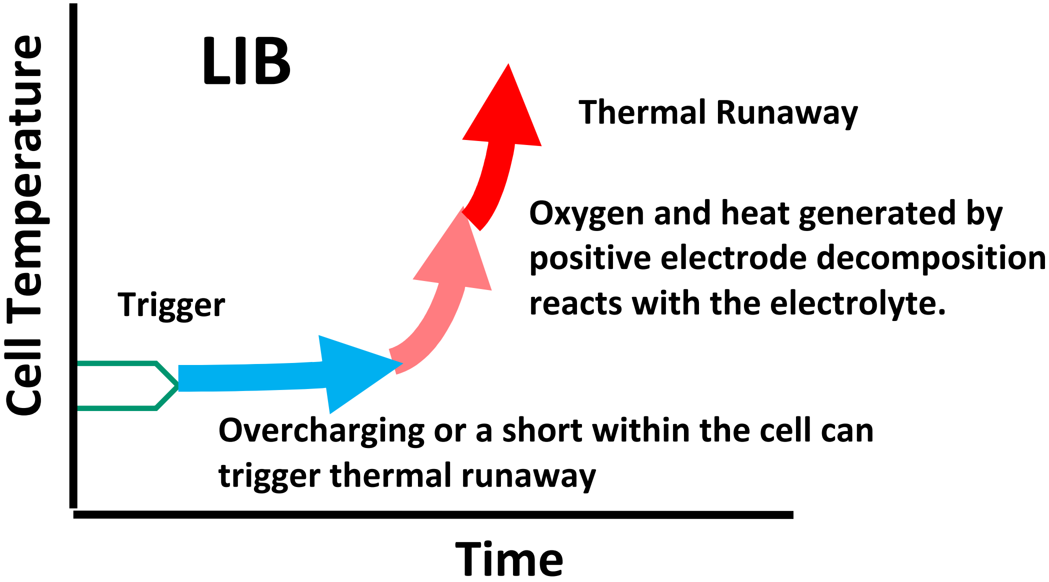
Cycle Test Performance (2000F, Standard Type)



Self Discharge Performance, (2000F, Standard type)



Thermal Runaway Model of Li-ion Battery

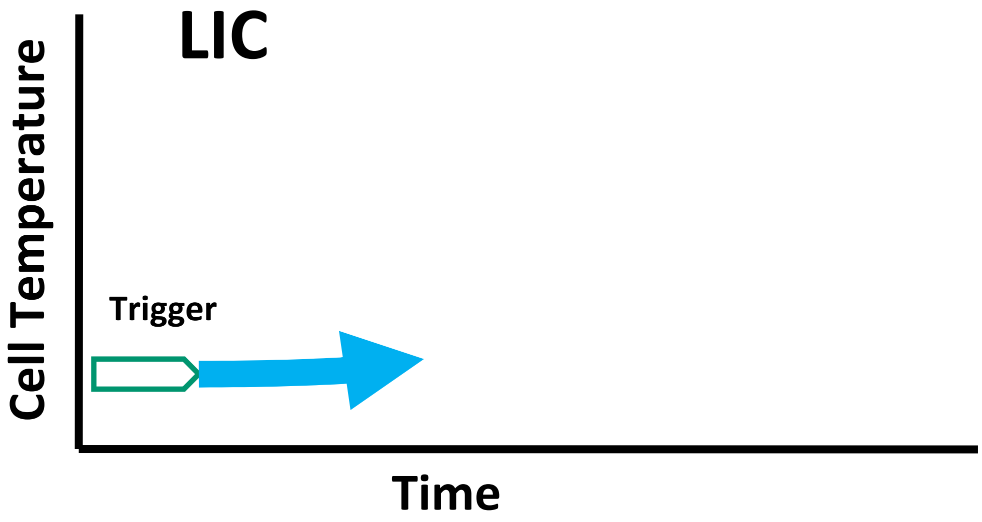


Composition of Electrodes

Negative Electrode	Positive Electrode
Carbon Material	$LiCoO_2$, $LiMn_2O_4$, etc

Thermal runaway cannot be stopped once decomposition of the lithium spinel in the cathode occurs.

Thermal Stability Model of JME-LIC



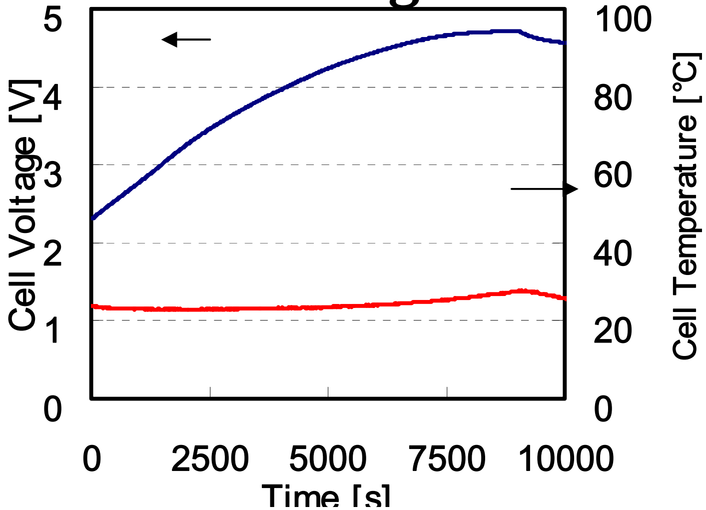
Composition of Electrodes

Negative Electrode	Positive Electrode
Li-doped Carbon	Activated Carbon

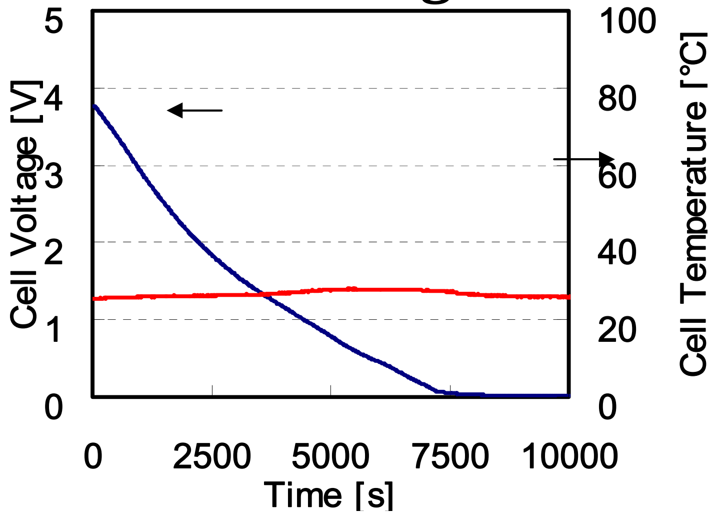
No thermal chain reaction occurs, since the positive electrode does not contain any lithium spinel.

Safety Test of LIC Cells

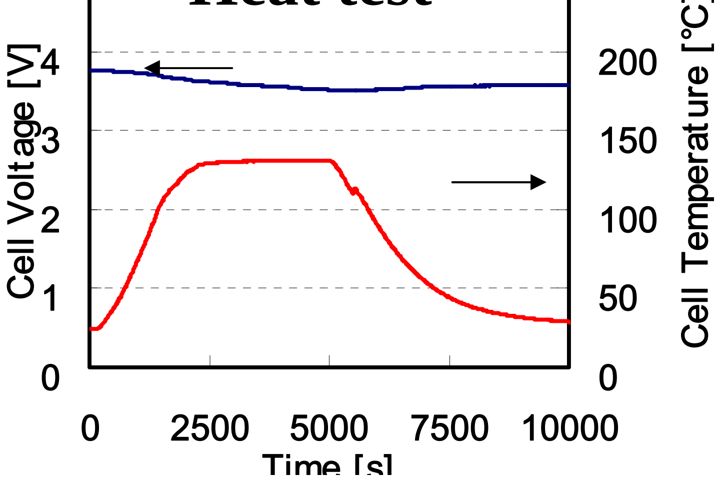
Over Charge test



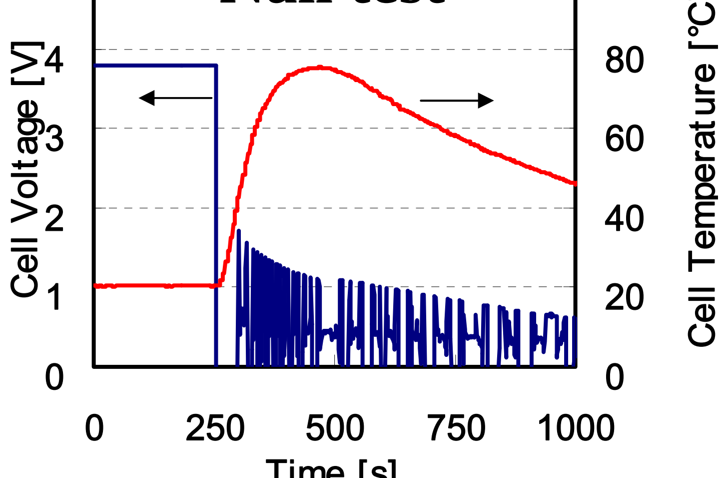
Over Discharge test



Heat test



Nail test



Summary of Safety Test

Items	Test Methods	Test Results	
		Fire	Explosion
Over Charge Test	Charge up to 250% of rated capacitance with 1A constant current	pass	pass
Over Discharge Test	Discharge to 0V with 1A constant current	pass	pass
Heat Test	Heat by 5C/min and kept at 130C×1h	pass	pass
Nail Test	Vertical penetration by a nail of 2.5mmΦ through the center of the cell	pass	pass

Equivalent Lithium Content

- Due to its low lithium content, LIC is not subject to the Class 9 transportation regulations.

- The equivalent lithium ion content of the 2000F cell is less than 0.30 grams.

- The equivalent lithium content is calculated in grams by multiplying the capacity in ampere hours by 0.3
  - The capacity of the 2200F cell is 0.980Ah.
  - 0.980 x 0.3 = 0,294

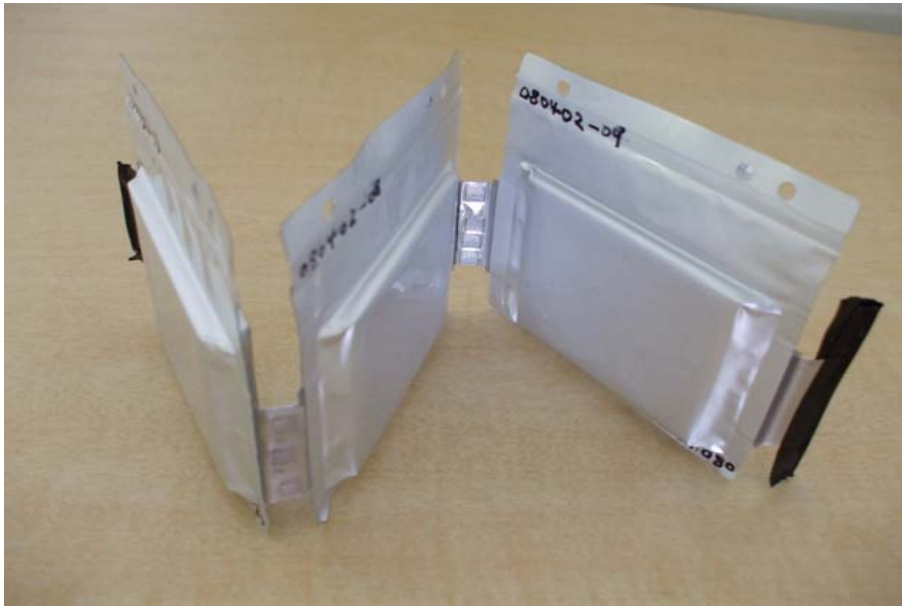
LIC Pack and Module Advantages

- Due to their higher energy density and voltage, LIC's provide a smaller, lighter power supply.
- The number of cells is reduced by 33%.
- The weight of the cells is reduced by 66%.
- The volume of the cells is reduced by 78%.

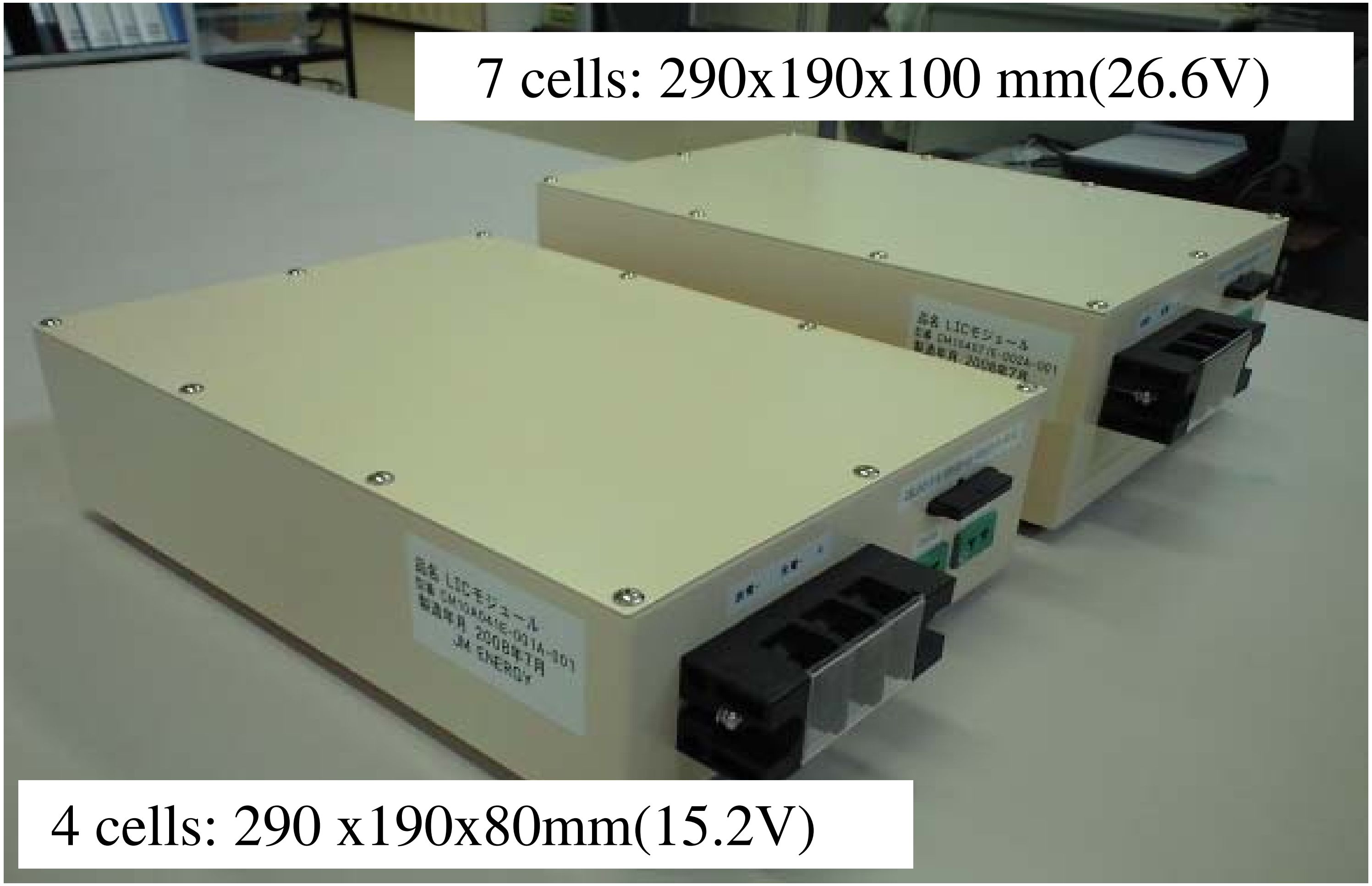
- The low self-discharge rate also provides faster start-up.
  - At room temperature, the cells will retain more than 95% of their charge for 3 months.

Welded Packs of LICs

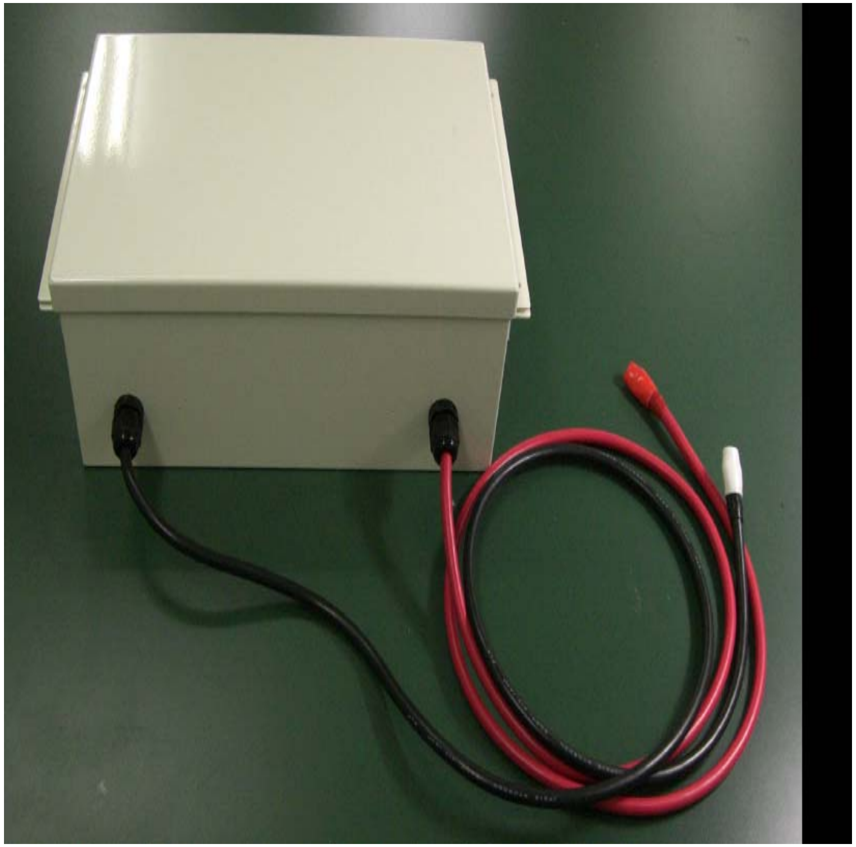
- Multiple cell packs:
  - The lead terminal of the LIC cell is combined together in series by ultrasonic welding to get high voltage as a pack.
  - Standard pack sizes are 4, 7 or 12 cells in series; 15.2v, 26.6v or 45.6v.



Prototype Modules (4 cells, 7 cells)



10 and 12 Cell Modules



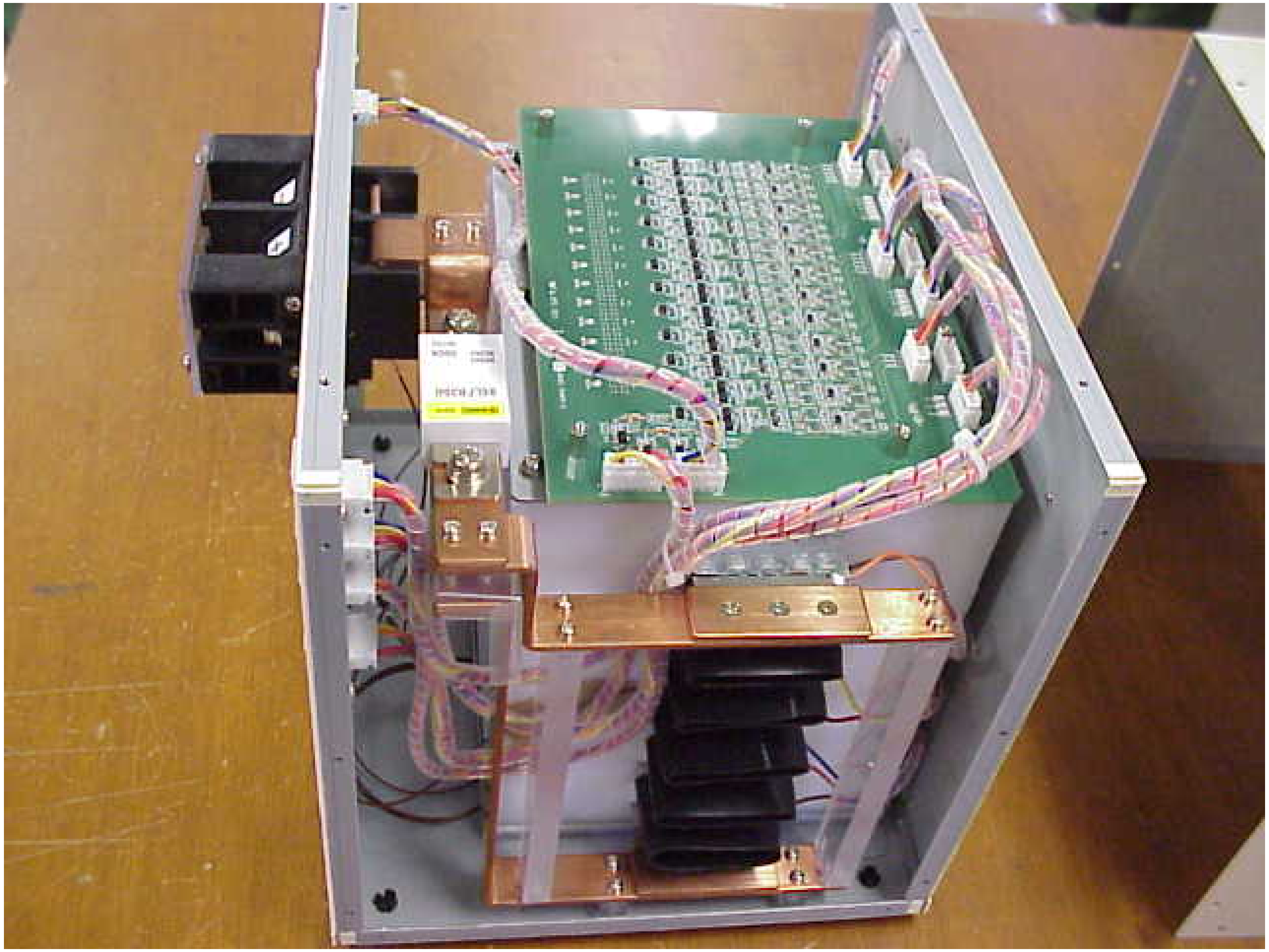
1000F×10 cells

(Commercial Module)

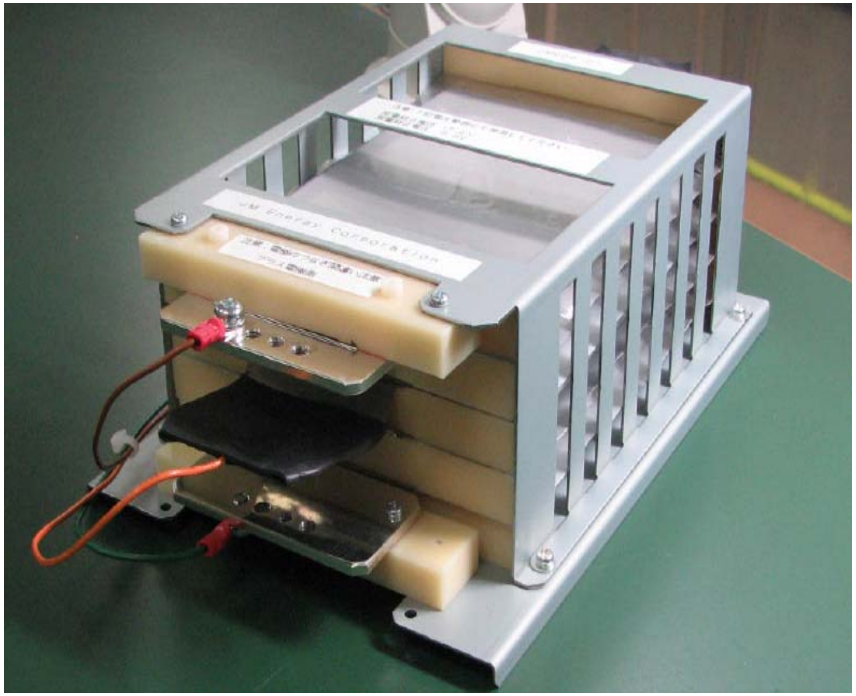
2000F×12 cells

(Test Module)

Inside a 12 Cell Prototype

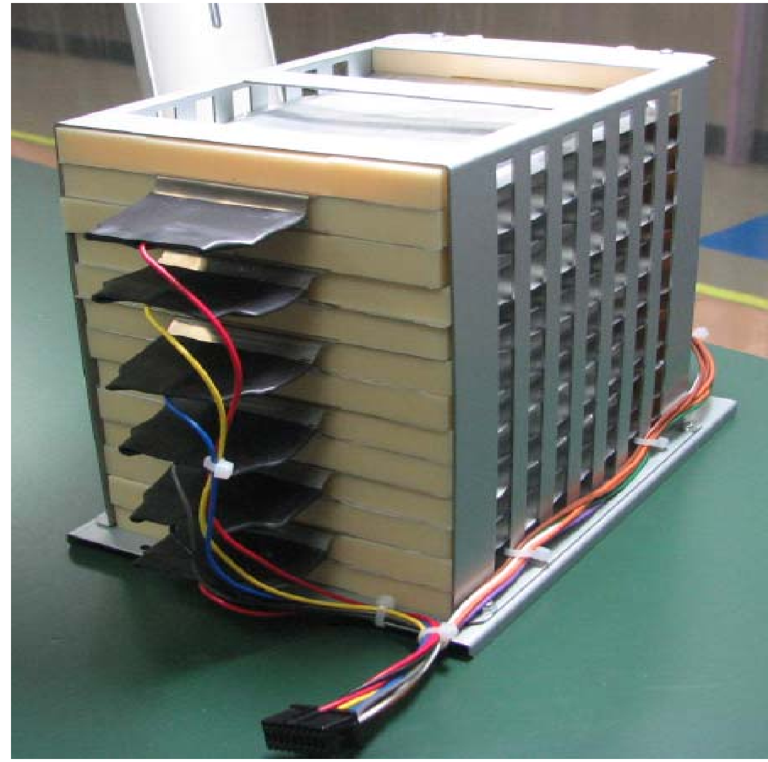


Examples of Open LIC Modules



1000F×4 cells

(Open module, with no control circuit)

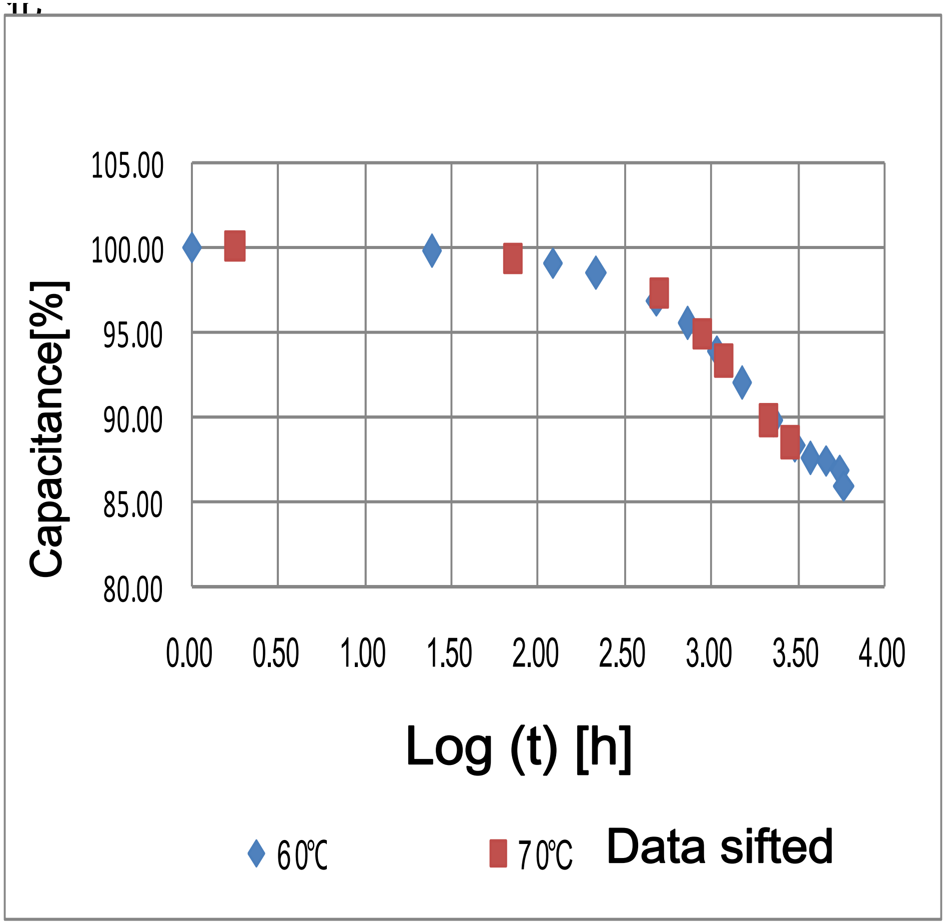


1000F×12 cells

(Open module, with no control circuit)

Estimated Life at 30℃ (1100F, Capacitance)

Capacitance Change



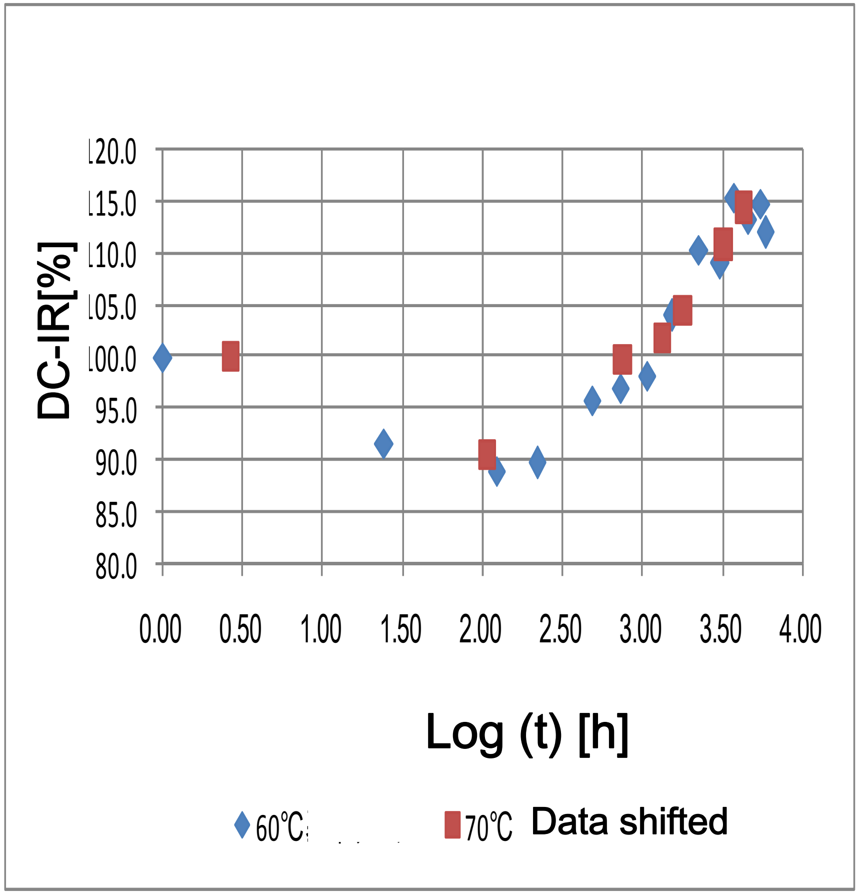
Sift Factor: 0.25

$10^{0.25} = 1.7783$

Ret. of Cap。	70℃ [h]	60℃ [h]	30℃ [h]	30℃ [Year]
C(90%)	1184	2106	11841	1.4
C(85%)	3172	5642	31725	3.6
C(80%)	**9023**	**16045**	**90229**	**10.3**
C(78.2%)	13358	23754	133581	15.2
C(75%)	27454	48820	274536	31.3

Estimated Life at 30℃ (1100F, DC-IR)

DC-IR Change



Sift Factor: 0.425

$10^{0.425} = 2.661$

DC-IR Change	70℃ [h]	60℃ [h]	30℃ [h]	30℃ [Year]
R(+10%)	1219	3244	61097	7.0
R(+15%)	**2110**	**5615**	**105768**	**12.1**
R(+17.1%)	2639	7021	132246	15.1
R(+20%)	3569	9496	178874	20.4

Performance Improvement Plans

1. Improvement of Internal Resistance (within 1 year)

    Target: less than 1mΩ at Room temp.

    less than 5 times at -20℃ compared to R. T.

2. Improvement of Energy Density (within 1-2 year)

    Target: First step; 20wh/kg (within 1 year)

    Second step; 30h/kg(within 2 year)

3. Development of Higher Capacitance Cell.

    Target: 3000F, prototypes in mid-2009.

Summary

- Lithium Ion Capacitor is a hybrid energy storage device.
  - It combines the best features of batteries and capacitors.
- LIC's energy density is 4 times greater than a conventional EDLC and its maximum voltage is 3.8 volts.
- LIC is a safe, reliable and has a very low self-discharge rate.
- Due to its higher energy and compact size it provides a smaller, lighter power supply.
- High volume manufacturing started in January 2009.
- Higher performance and capacity products are being developed.