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Study on Large-Capacity Lithium-Ion Cells Simulated Spacecraft's Operation at JAXA

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Development status in JAPAN

Manufacturer	Cell	Spacecraft	Note
GYT, GYT/Melco,	10 - 190 Ah	SERVIS-1, Thaicom-4, H-IIA, HTV, QZSS, ASTRO-H	Balancing circuit. GEO satellite Transportation, Science Mission
MHI	15Ah		Commercial use
IA (HVE)	6.5 - 90 Ah	M-V (SERVIS-2)	Commercial use
Furukawa	13.2Ah 25 Ah	Hayabusa Planet -C	Science Mission
COTS*	1-3Ah	Reimei, (Piggyback)	Small Satellite Commercial use

To be launched near future

*Commercial off-the-shelf

History of large lithium-ion cells at JAXA

Fiscal year	19 94	96	98	20 00	02	04	06	08	10	12
Flexibility investigation	1.0 Ah-class commercial cells Max. cycle life: LEO 23,000 ↔									
Development Evaluation				10-100 Ah-class space cells Max. cycle life: LEO 46,000, GEO 1,800 ←						
Application								LEO satellite, HTV, Rocket ←		

HTV: H-IIA transfer vehicle

Purpose of this Study

1) Assess the lightweight large lithium-ion cells
2) Conduct cycle-life testing of high-capacity lithium-ion cells simulated LEO and GEO operations
3) Find the optimum operation conditions (taper voltage, charge current, temperature, storage duration)

Design principle

Active material	Type	Parameter
Cathode	$LiCoO_2$, $LiNi_{1-x-y}Co_xAl_yO_2$	Thickness
Anode	Graphite,	Thickness
Electrolyte	Alkyl carbonate mixed solvent	Additives, composition

Cell Design	Mechanical modification	Safety vent, welding Process

Main samples evaluated at JAXA

(@Tsukuba Space Center)

Sample type		Testing condition	Status
Graphite/ $LiCoO_2$	10 Ah cell	LEO, DOD: 25%, 40%@15ºC	14,000
	40 Ah cell (High rate)	LEO, DOD: 40%@15ºC	13,000
	50 Ah cell	LEO, DOD:25%@15℃	12,000
	100 Ah cell	LEO, DOD: 25%, 40% @15ºC GEO, DOD: 80% @15ºC HTV, DOD: 40% @35ºC	46,000 1,800 (EOL) 3,300 stopped
	100 Ah battery	GEO, DOD: 40-70% @15ºC	36 seasons
Graphite/ $LiNi_{1-x-y}Co_xAl_yO_2$	50 Ah cell	GEO, DOD: 80% @15ºC	20 Seasons

Topics in this presentation

(1) Progress in long-term cycle-life testing of lithium-ion cells (batteries) simulated spacecraft operation

(2) High-rate design with thin electrode layer for LEO applications

(3) Performance comparison of lithium-ion cells with different electrode materials

(1) Typical life performance

100-Ah cell with graphite anode and $LiCoO_2$ cathode

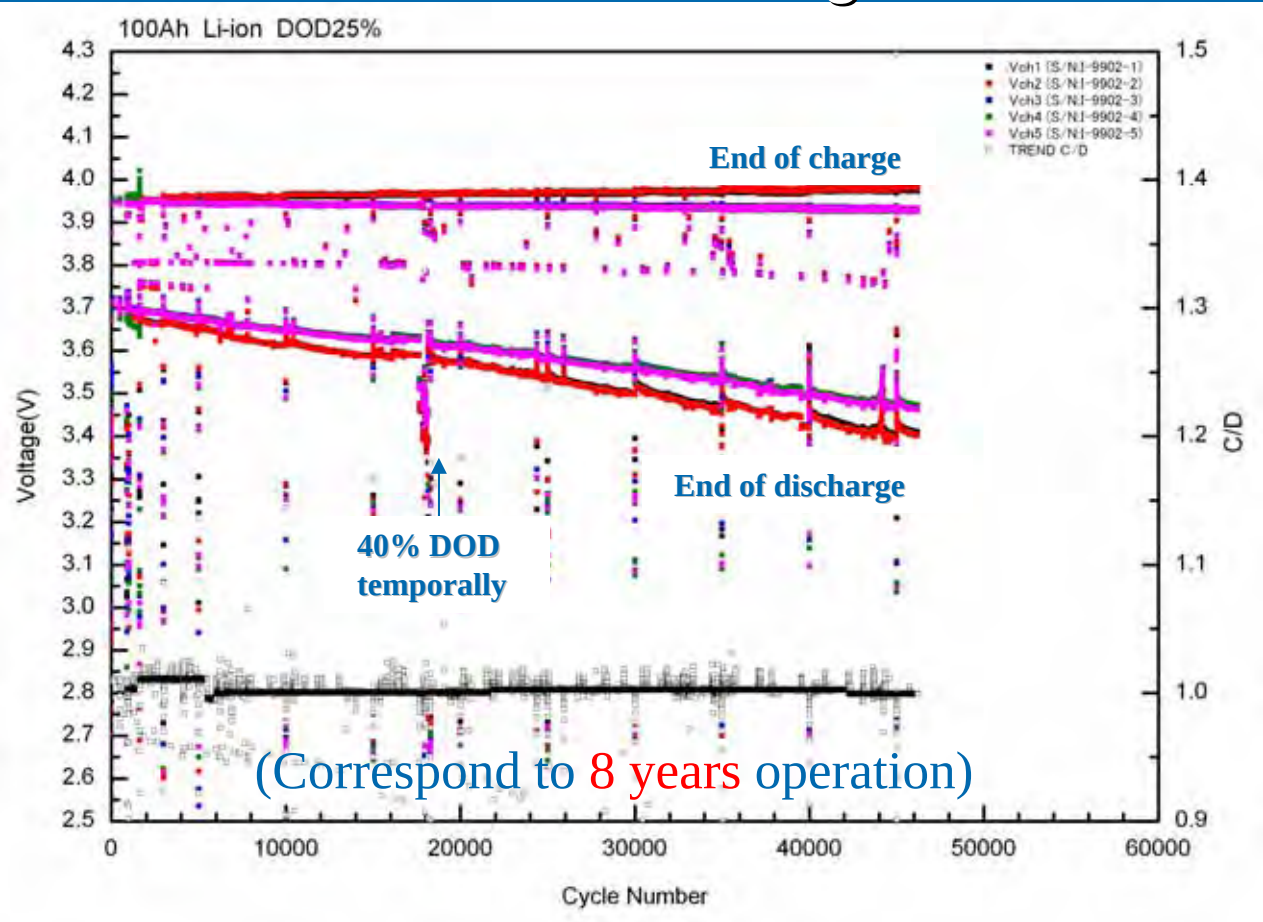
Manufactured by
GS-Yuasa Technology Ltd.

Cell type		Elliptic cylinder
Cathode		$LiCoO_2$
Anode		Graphite
Capacity	Rated	100
	Nominal	110
Nominal voltage, V		3.7
Weight, g		2,800
Dimensions, mm	Width	50
	Length	130
	Height	208
Energy density*	Wh/kg	132
	Wh/l	273

*Calculated using rated capacity

(1) Typical life performance

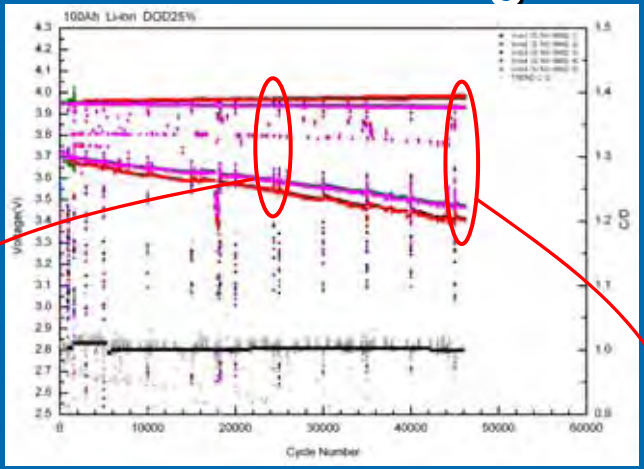
LEO simulation testing: 25% DOD

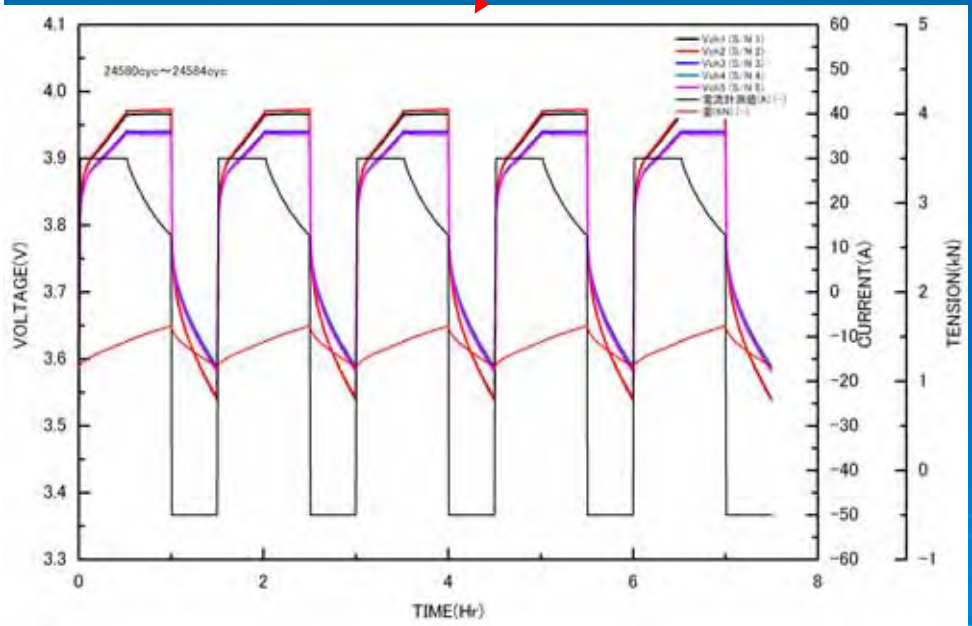


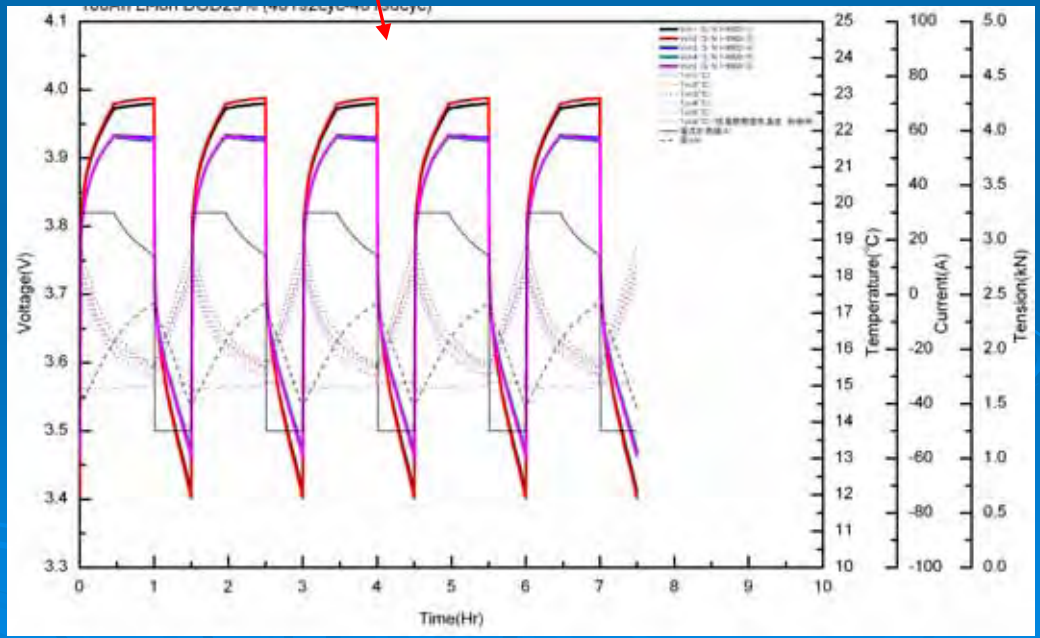
Discharge ---- CC: 50 A (0.5C), 30min. (25.0%DOD)
Charge ----- CC-CV: 30 A (0.3C), 3.95 V, 60min.
Ambient temp. ------- 15 degree-C
5 cells in series

(1) Typical life performance

LEO simulation testing: 25% DOD

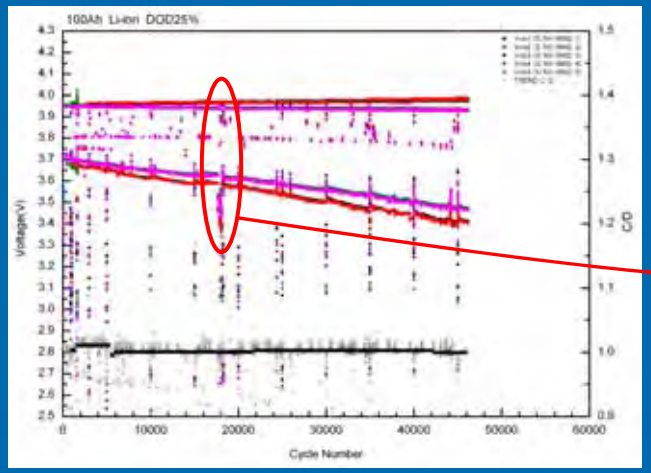


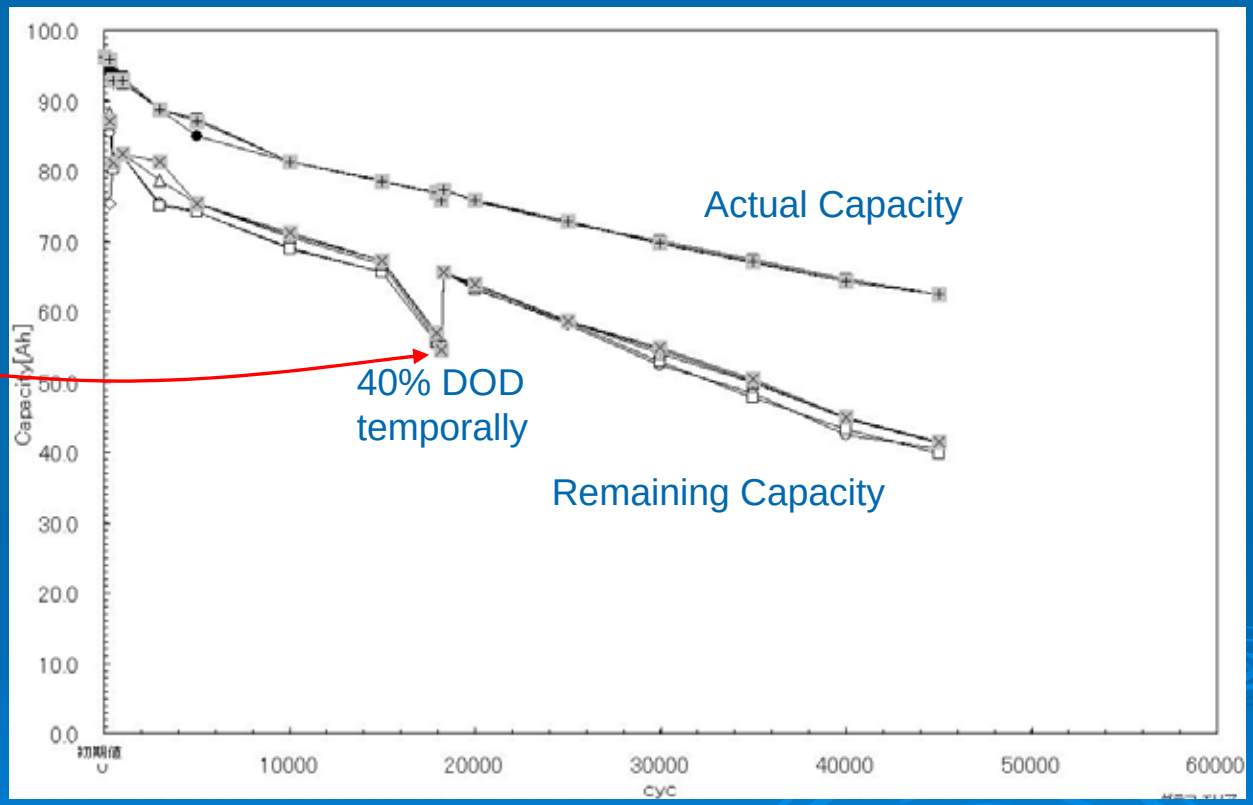




(1) Typical life performance

LEO simulation testing: 25% DOD

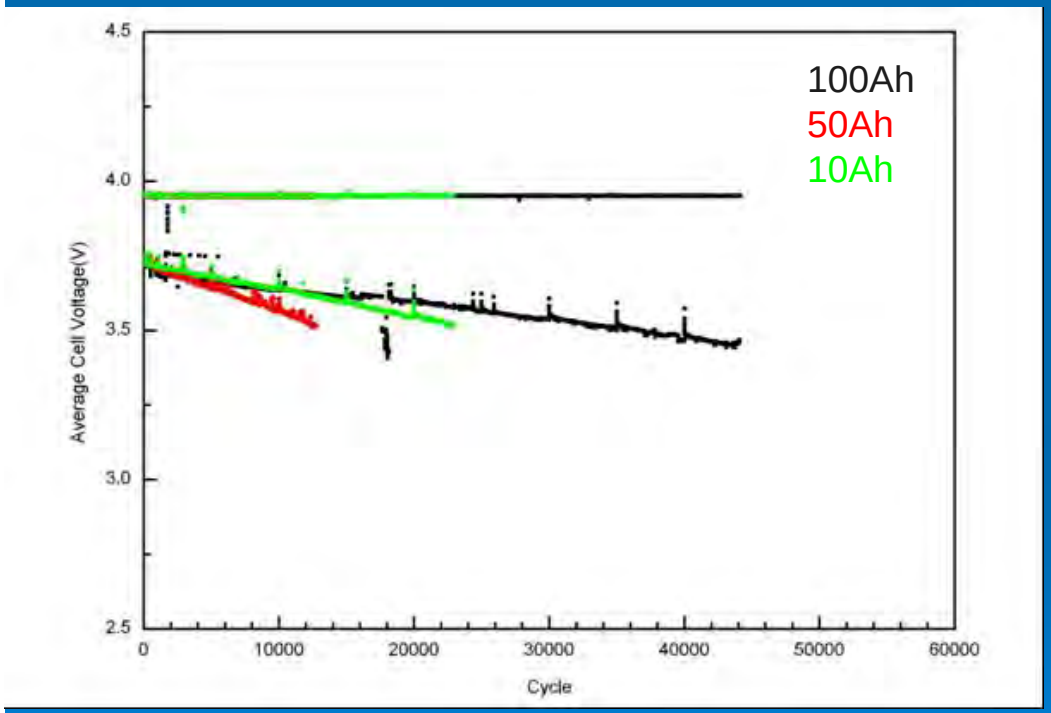


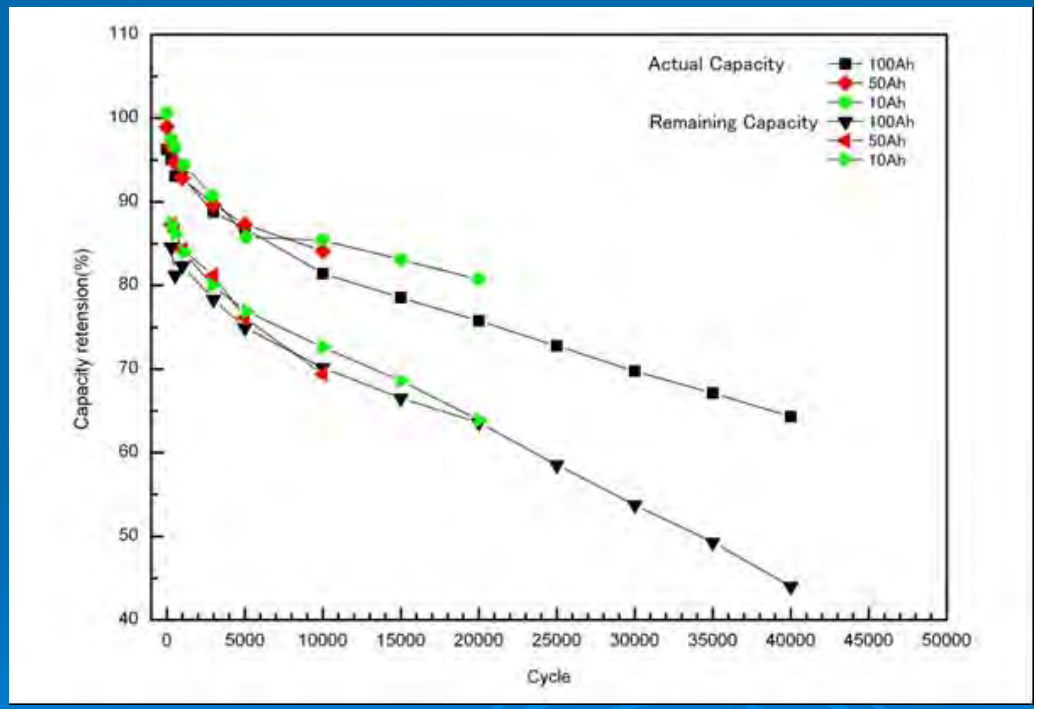


Capacity retention

(1) Typical life performance

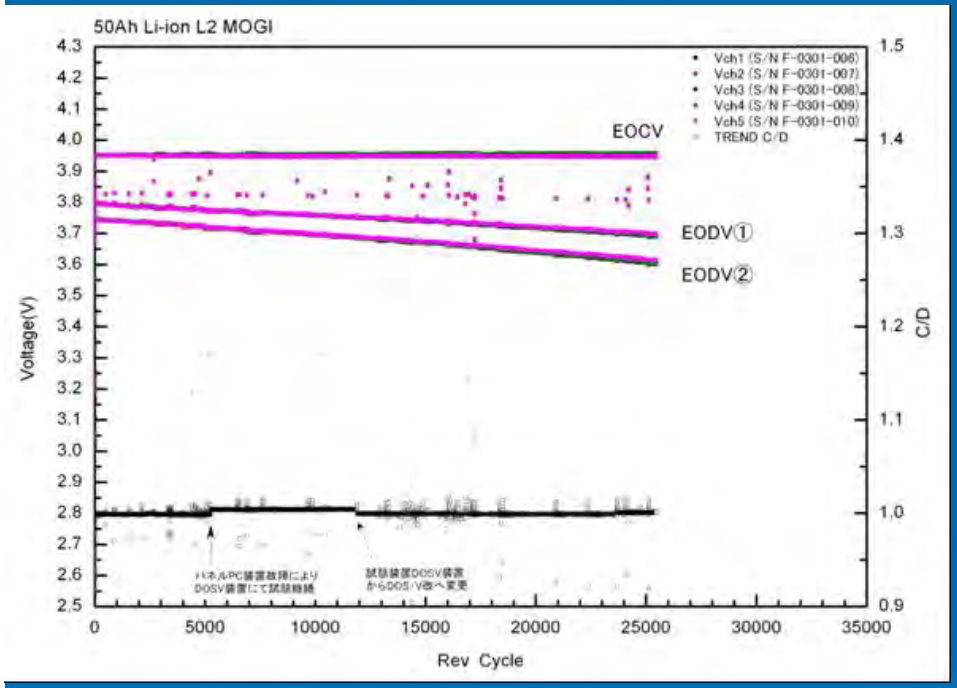
LEO simulation testing: 25% DOD
Comparison with the Cell Rated Capacity

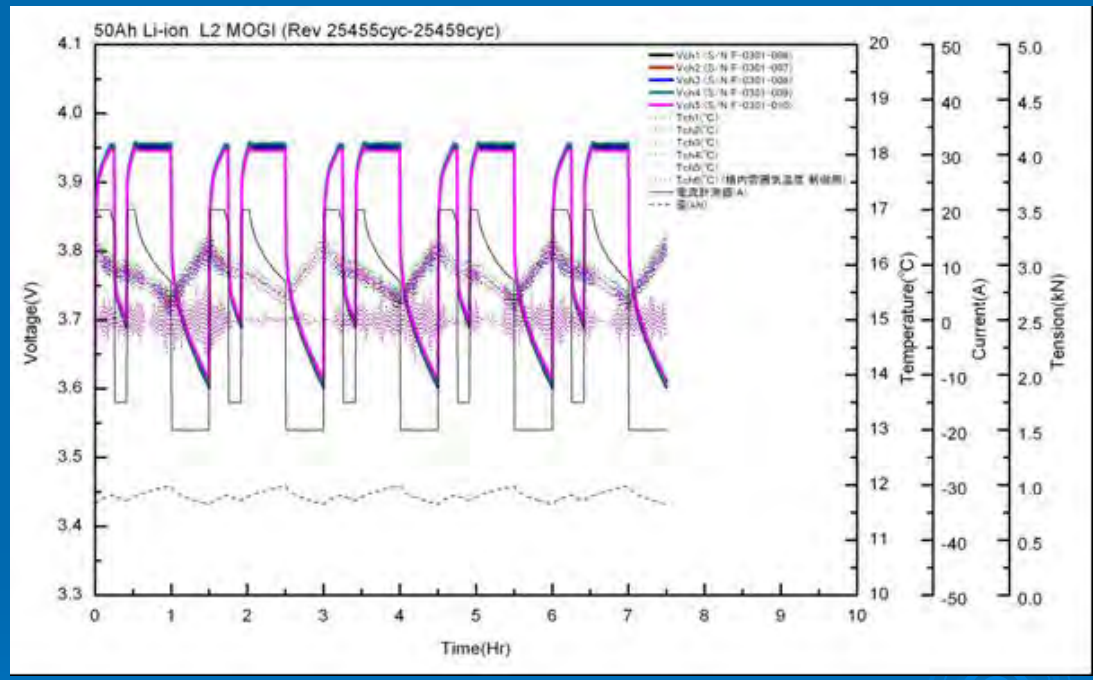




(1) Typical life performance

LEO simulation testing: Discharge during Shining period





Discharge(1) ---- CC: 15 A (0.3C), 10min. (5.0%DOD)
Charge(1) ---- CC-CV: 20 A (0.4C), 3.95 V, 35min.
Discharge(2) ---- CC: 20 A (0.4C),30min. (20.0%DOD)
Charge(2) ---- CC-CV: 20 A (0.4C), 3.95 V, 15min
Ambient temp ----- 15 deg-C
5 cells in series

(1) Typical life performance

10 cells in series for GEO simulation testing

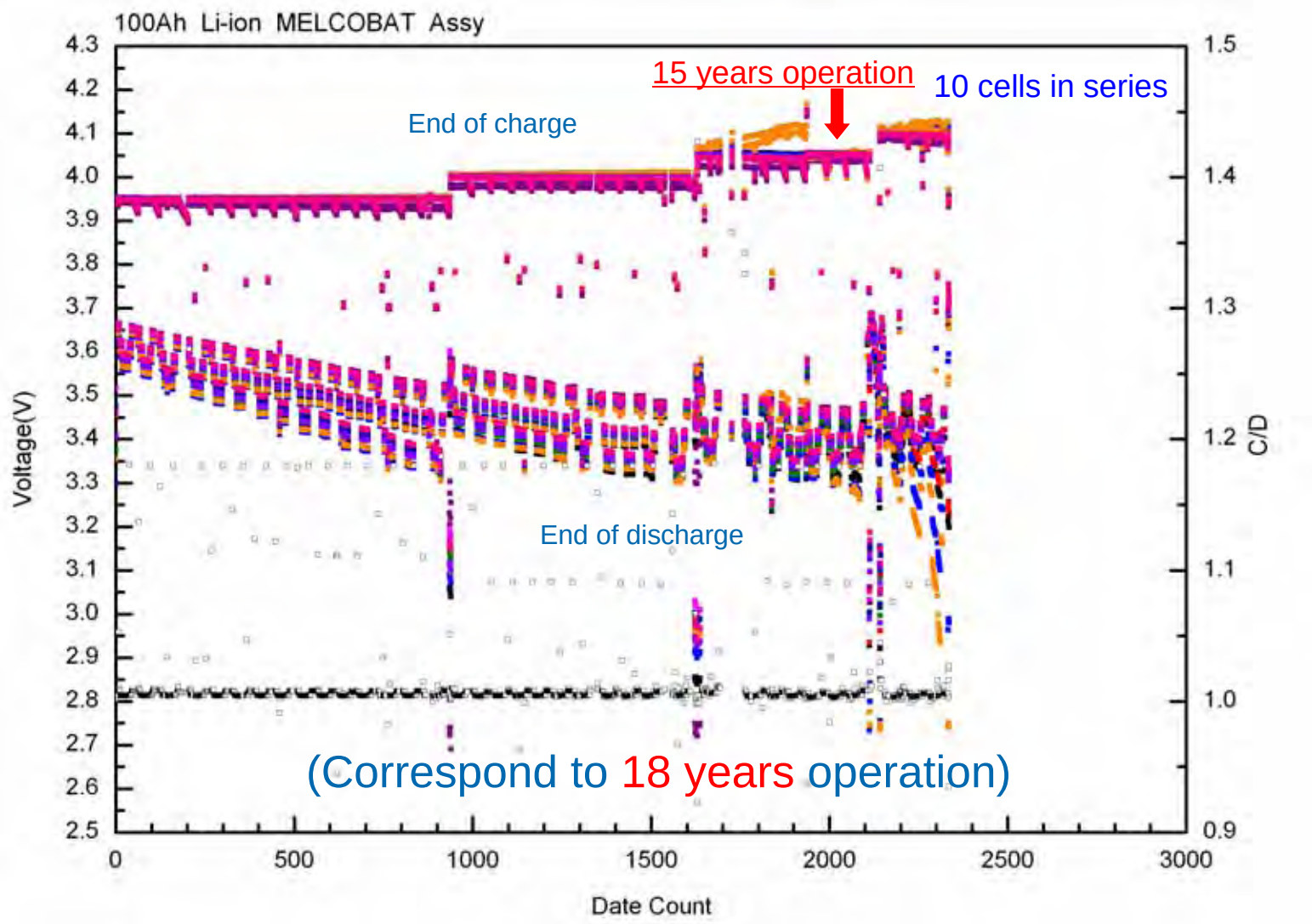
Manufactured by GS-Yuasa Technology Ltd.
Assembled by Mitsubishi Electric Co.

Eclipse period
Real-time testing with 40%, 60%, 70.5% DOD (total 45days)
Ambient Temp.: 15℃

Sun-shine period
Thermally-accelerated simulation for full-charge storage: 8 days at 25ºC to simulate a half of year at 0ºC

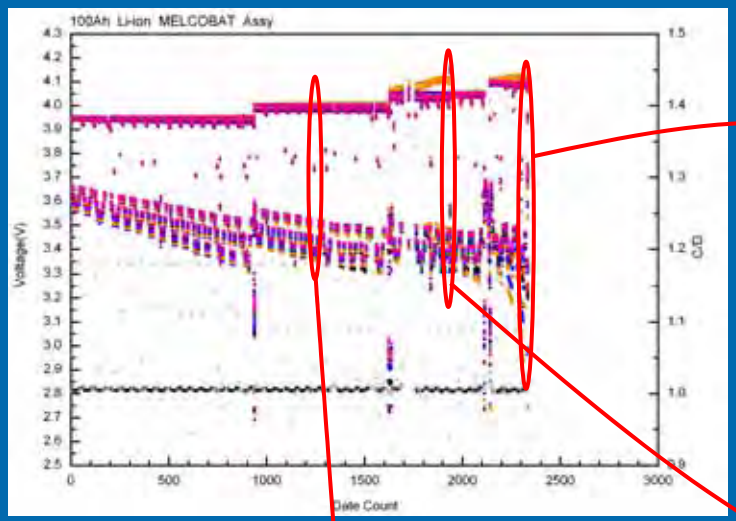
(1) Typical life performance

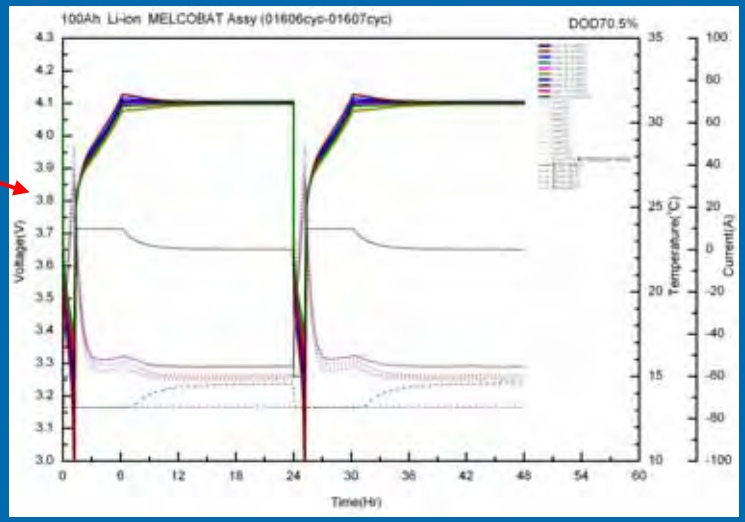
GEO simulation testing: max. 70% DOD

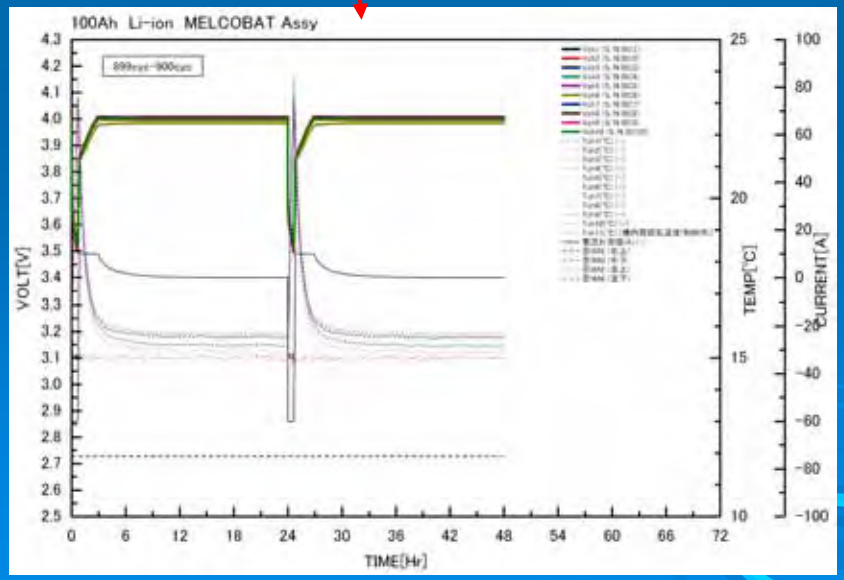


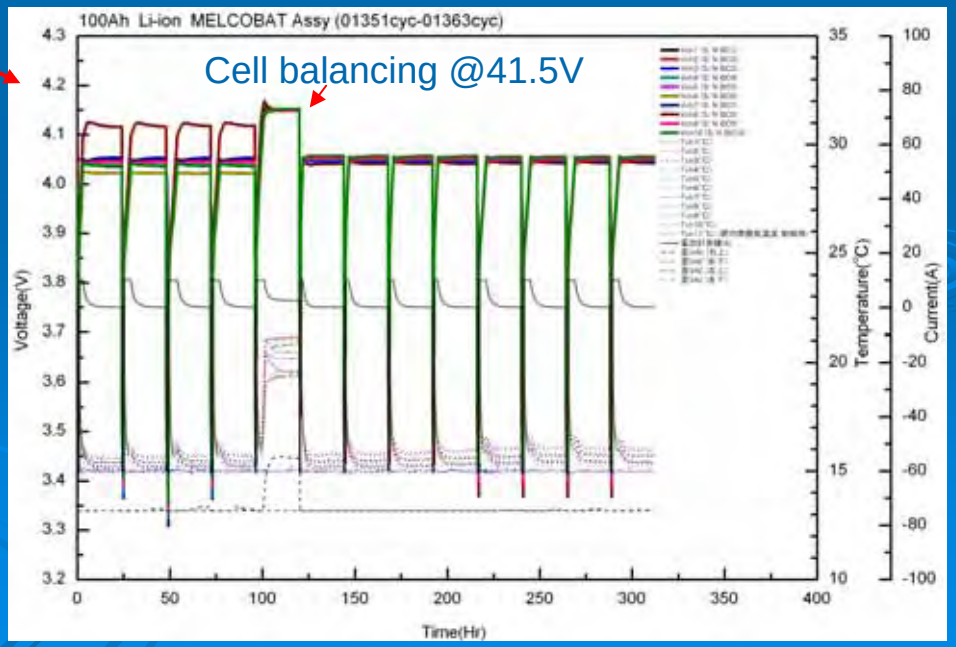
(1) Typical life performance

GEO simulation testing: max. 70.5% DOD



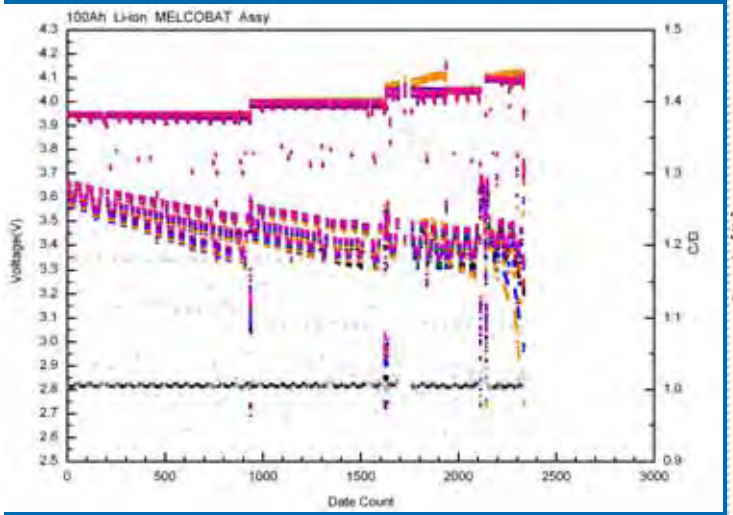


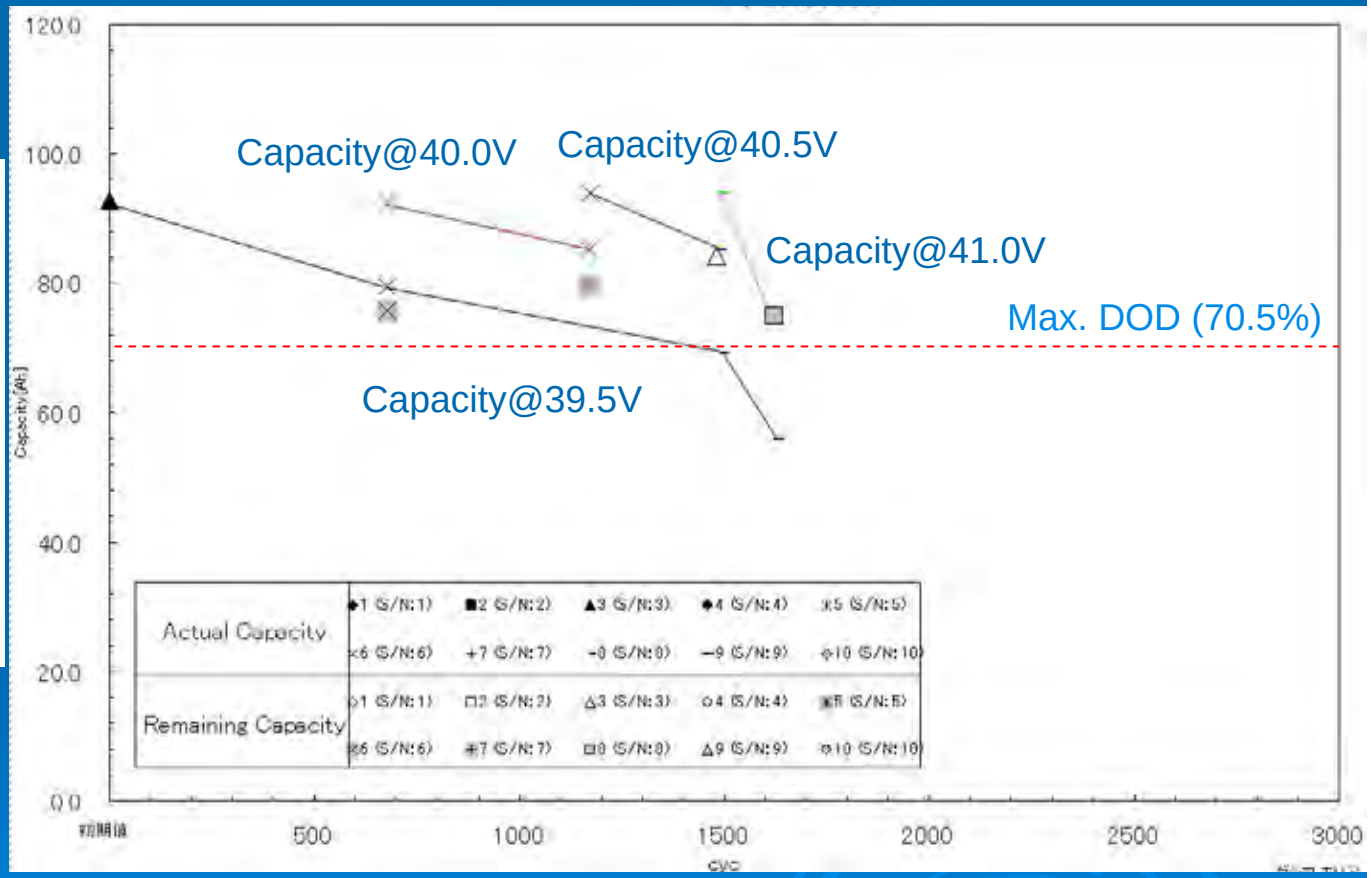




(1) Typical life performance

GEO simulation testing: max. 70% DOD





(1) Typical life performance

Summary

Large Lithium-ion cells evaluated at JAXA
with $LiCoO_2$ cathode and graphite anode

Meet the general requirements for LEO and GEO missions

1) high voltage retention
2) small cell voltage dispersion
3) low cell-temperature rising

(2) High-rate design

Design concept

Impedance increase with cycling is responsible for performance fading of a lithium-ion cell with $LiCoO_2$ cathode in our know-ledge. To improve cycle-life performance of the cell, we should suppress cell impedance by

- increasing electrode surface area
- decreasing electrode thickness.

(2) High-rate design

40-Ah cell with graphite anode and $LiCoO_2$ cathode: thinner and larger electrode layer than that of 100-Ah cell

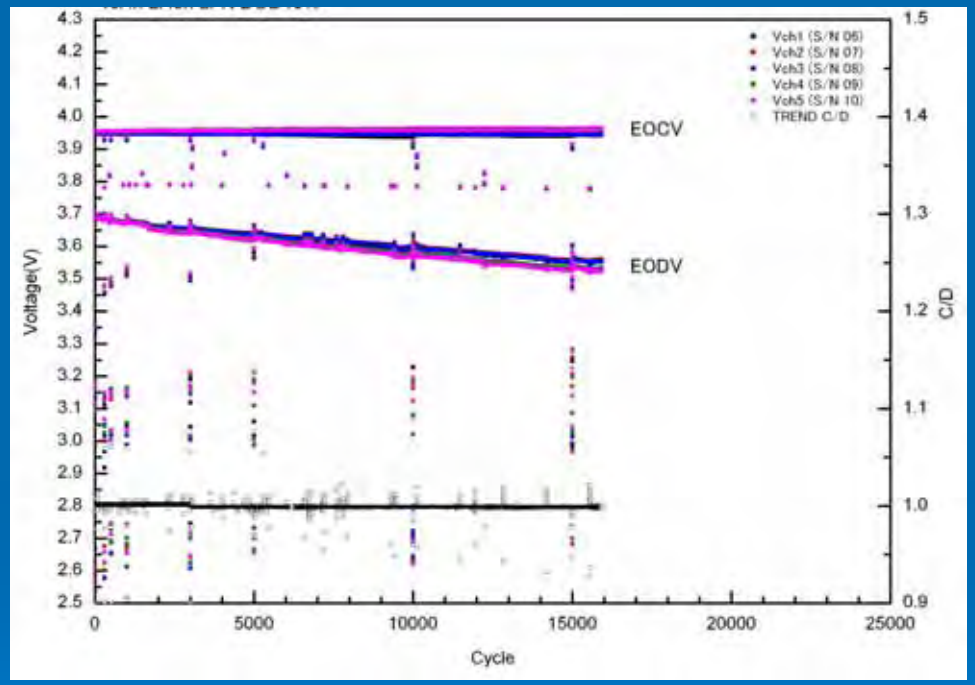
Manufactured by
GS-Yuasa Technology Ltd.

Cell type		Elliptic cylinder
Cathode		$LiCoO_2$
Anode		Graphite
Capacity	Rated	40
	Nominal	45
Nominal voltage, V		3.7
Weight, g		1,500
Dimensions, mm	Width	50
	Length	130
	Height	123
Energy density	Wh/kg	111
	Wh/l	

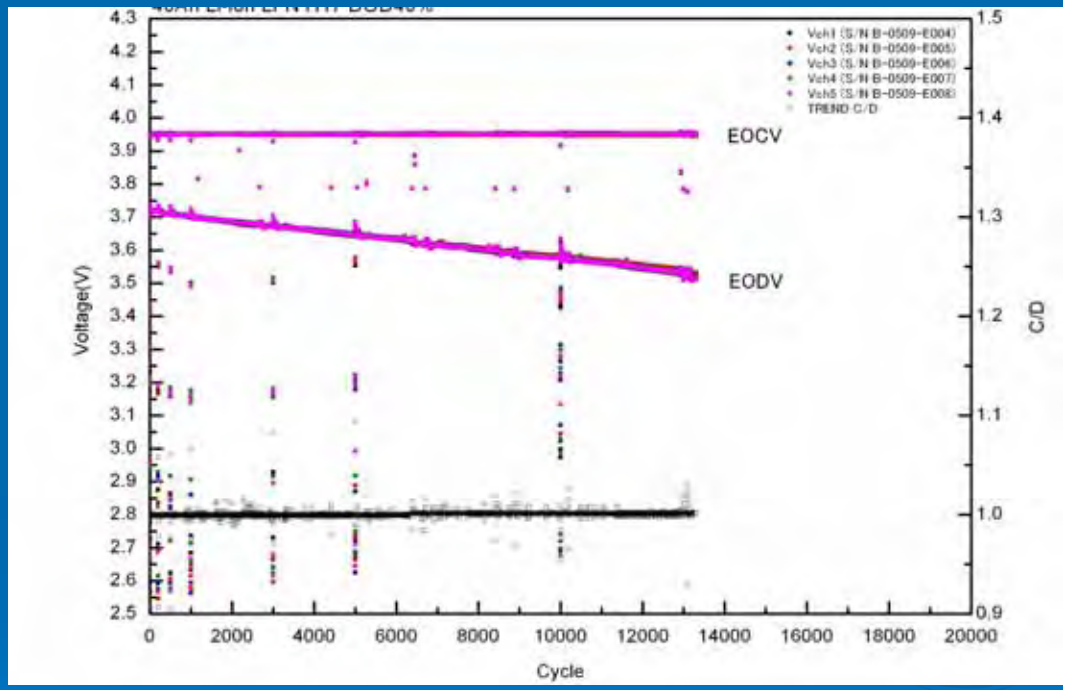
(2) High-rate design

LEO simulation testing: 40% DOD

Ambient temp. 15ºC, taper voltage 3.95 V

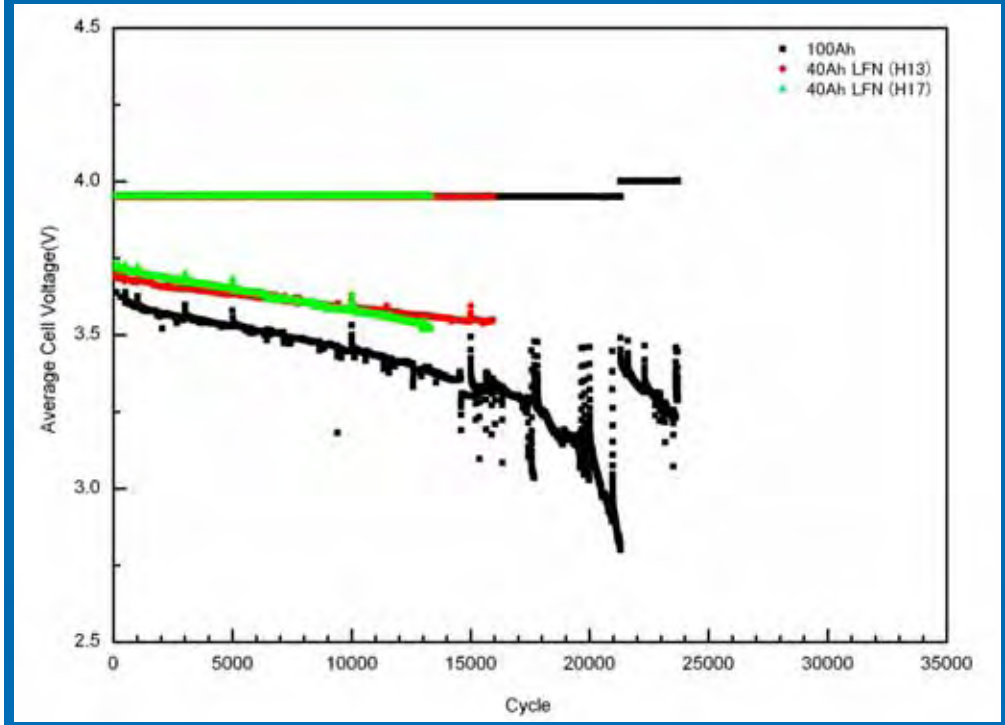


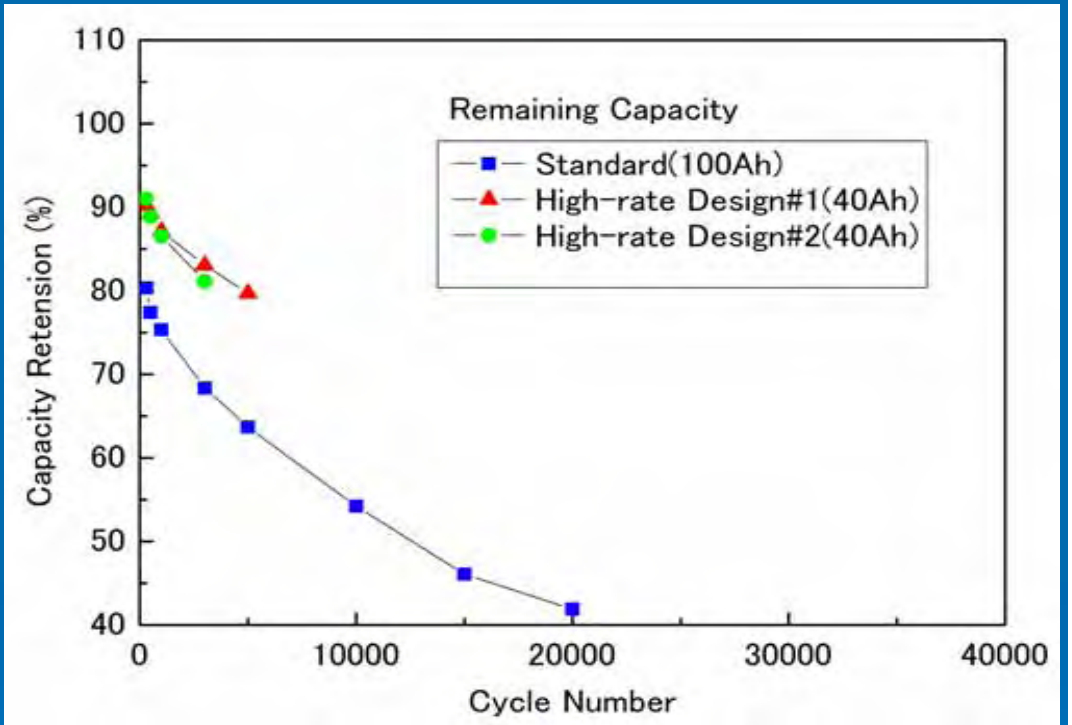
High-rate design #1



High-rate design #2

(2) High-rate design





Voltage comparison at charge and discharge

(2) High-rate design

Summary

High-rate designed lithium-ion cells
with $LiCoO_2$ cathode and graphite anode

Promising for LEO operation
due to lower impedance compared with that of standard cell and slow impedance increase with cycling

(3) Alternative cathode materials

50-Ah cell with graphite anode and $LiNi_{1-x-y}Co_xAl_yO_2$ cathode

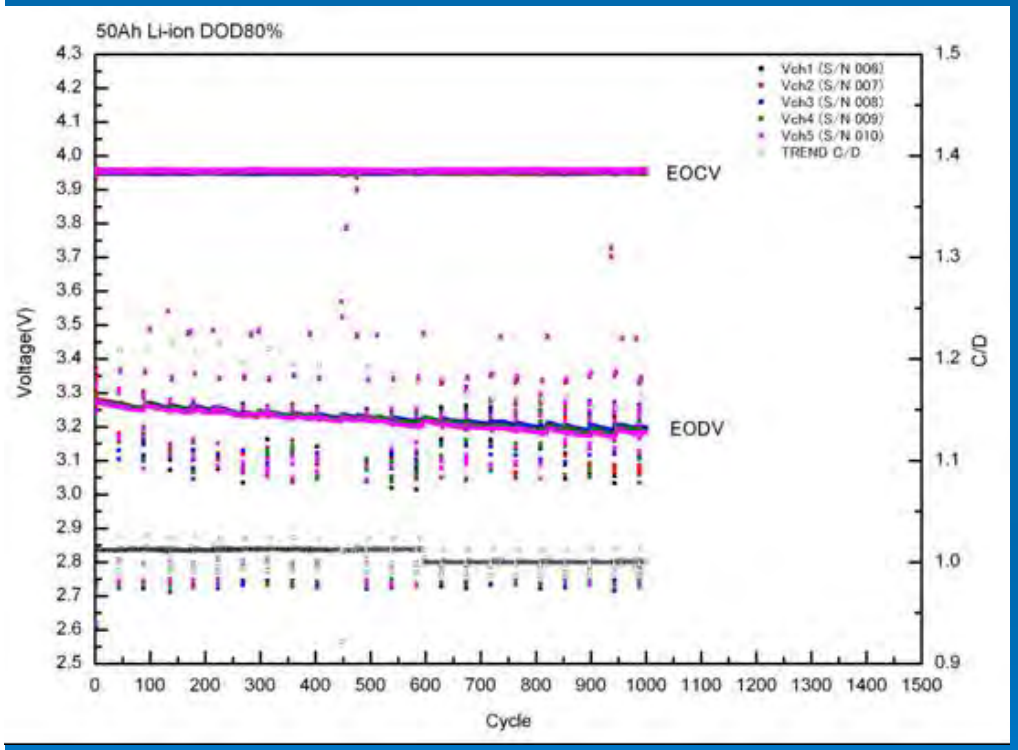
Manufactured by
GS-Yuasa Technology Ltd.

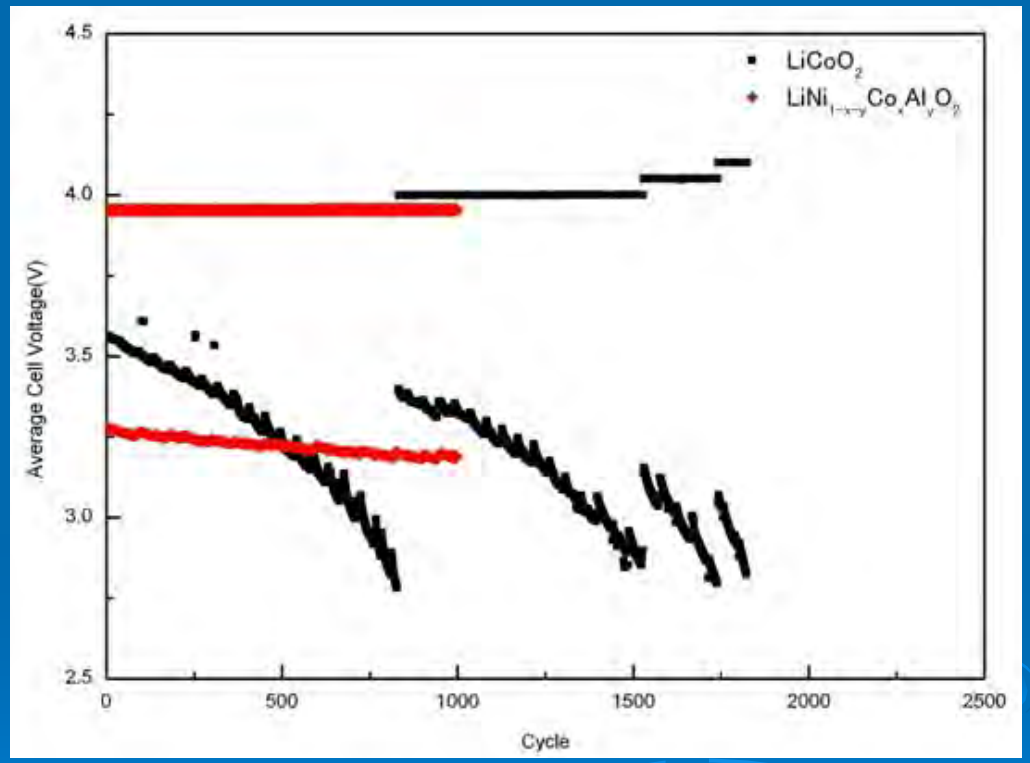
Cell type		Elliptic cylinder
Cathode		$LiNi_{1-x-y}Co_xAl_yO_2$
Anode		Graphite
Capacity	Rated	50
	Nominal	53
Nominal voltage, V		3.6
Weight, g		1,400
Dimensions, mm	Width	52
	Length	130
	Height	123
Energy density	Wh/kg	136
	Wh/l	254

(3) Alternative cathode materials

GEO simulation testing: 80% DOD

Ambient temp. 15ºC, taper voltage 3.95 V

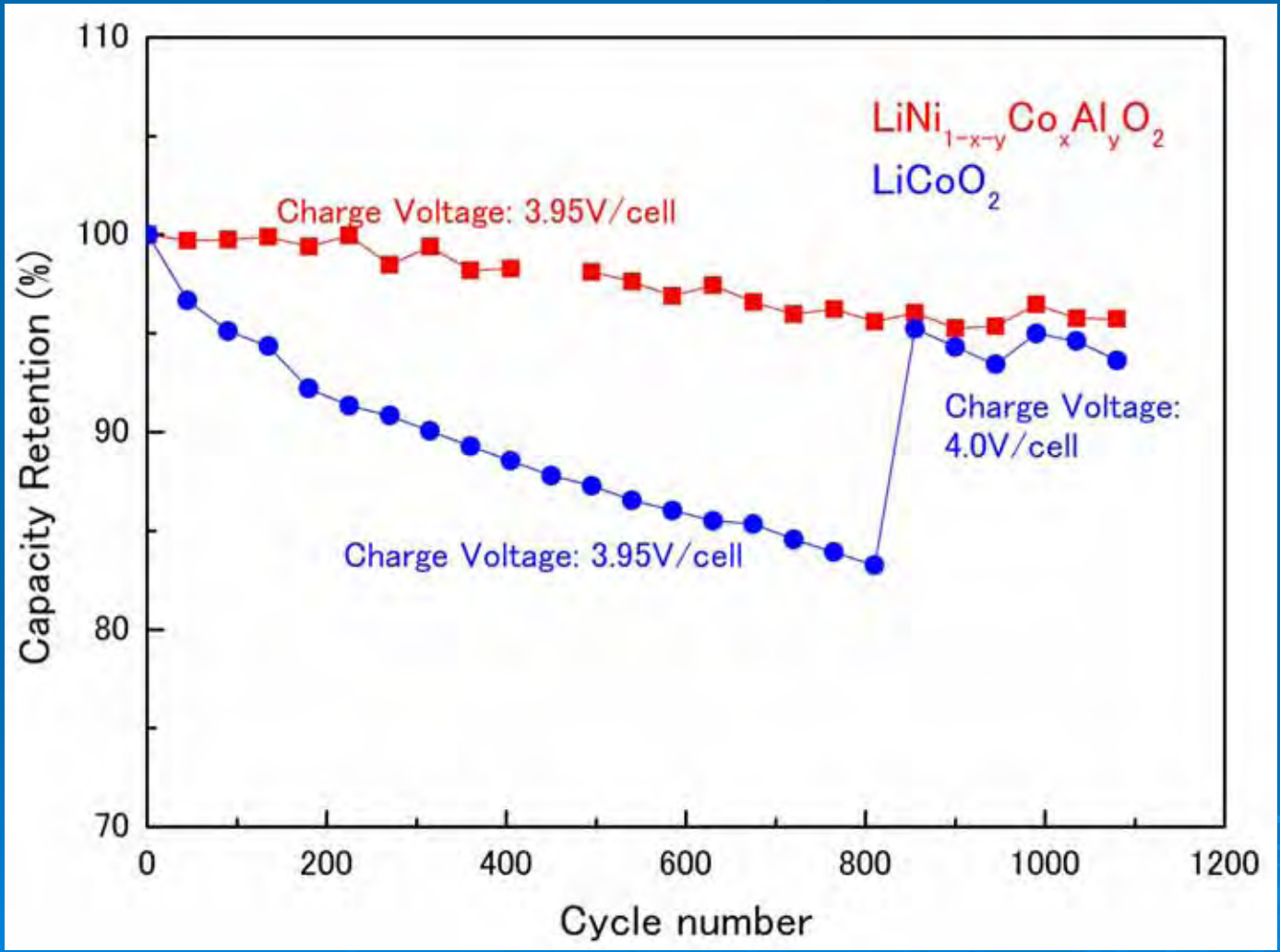




Voltage comparison

(3) Alternative cathode materials

GEO simulation testing: 80% DOD



Capacity-retention comparison

(3) Alternative cathode materials

Summary

Lithium-ion cells

with $LiNi_{1-x-y}Co_xAl_yO_2$ cathode material

Expected to be a candidate for one of the alternative of $LiCoO_2$ cathode for GEO mission

Prospect

Large capacity Lithium-ion cells

Under qualification for a few satellite- and rocket-projects at JAXA

(1) Continue on-ground real time cycle-life testing
(2) Optimize the operation conditions in a space environment
(3) Establish database with different electrode materials
(4) Design and development of higher energy density cell (>150Wh/kg for LEO and GEO satellite)
(5) Design and development of longer cycle-life lithium-ion cells (>7 years operation@LEO, >15 years operation@GEO)

Acknowledgments

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for
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for
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