Development of generation IV large format Li-ion cells for space applications

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Abstract

GS Yuasa Technology has developed new generation IV 160 Ah cells for space application in cooperation with Japan Aerospace Exploration Agency. Its specific energy of 180 Wh kg^{-1} is the highest class in large format space use cells. Despite its high energy, low temperature discharge performance was drastically improved compared to generation III cells. Life prediction and actual test results also revealed that generation IV cells are capable of powering spacecraft for more than 20 years for geostationary earth orbit mission, and for more than 7 years for low earth orbit mission. In addition, the cells demonstrated tough mechanical environmental durability required for the launch event with the proven structure design.

Key words : Li–ion cells for space application ; High specific energy ; Long life ; Mechanical environmental durability

1　Introduction

The year when GS Yuasa Technology (GYT) first qualified the 100 Ah cells for space application was 1998. In the last two decades, GYT pursued technology, quality and reliability to offer the best solution to customers who pioneer the space. To date, space qualified GYT lithium ion cells have the honor of being selected by more than 160 spacecrafts, including the H–II Transfer Vehicle and the ISS battery cells replacement.

The demand of higher specific energy with superior life has been growing in recent years. Therefore, GYT started the development of new generation cells to meet it in cooperation with Japan Aerospace Exploration Agency (JAXA) following the previous generation III.[1–3] As the results, they have succeeded in releasing generation IV 160 Ah cells that are planned to power Japanese Engineering Test Satellite, ETS–IX. This paper describes its excellent electrochemical characteristics and tough environmental durability.

2　Cell specification overview

Key changes from generation III to IV are summarized in table 1. The specifications of generation IV 160 Ah cells are shown in table 2. The cell appearance is shown in figure 1. The use of modified $LiCoO_2$ and binder contributed to higher density of positive and negative electrodes than that of generation III, respectively. In addition to it, the use of thinner separator increased nominal capacity from 161 Ah to 178 Ah. Furthermore, the composition optimization of each electrode and superior permeability performance of separator increased nominal discharge voltage to 3.72 V. As results of their improvements, the cells

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Table 1 Key changes from generation III to IV.

Component	Changed contents
Positive electrode	Use of modified $LiCoO_2$.
	Decrease binder ratio.
Negative electrode	Use of modified binder.
	Decrease of binder ratio.
Separator	Use of thinner microporous polyolefin film with ceramic layer.
Electrolyte	Optimization of amount of additive.

Table 2 Specifications of generation IV 160 Ah cells.

Model		Generation IV 160 Ah cells	Generation III 150 Ah cells
Nominal capacity / Ah		178	161
Rated capacity / Ah		160	145
Nominal voltage / V		3.72	3.70
Dimensions / mm	H*	263	263
	W	130	130
	T	50	50
End-of-charging voltage / V		4.1	4.1
Mass / kg		3.69	3.55
Energy density / Wh/kg		180	168

* Without terminal bolts

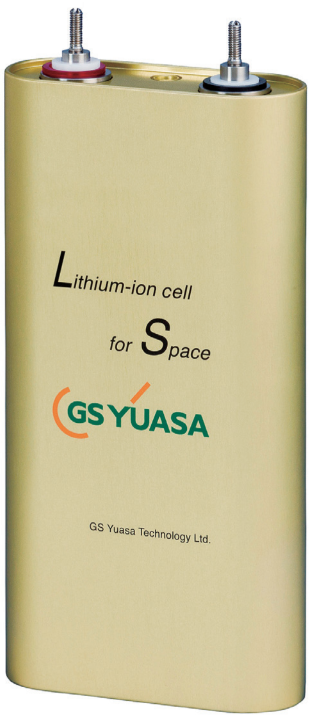


Fig. 1 Appearance of generation IV 160 Ah cells.

achieved a high specific energy of 180 Wh kg^{-1}. No modification change of structure was made since it was proved to be very reliable by the past launched heritages.

3 Test description

3.1 Initial discharge performance

In order to evaluate initial discharge performance, the cells were subjected to the testing below.

Charge: 0.2 CA, 4.10 V, CC/CV, 8 h

Discharge: 0.5 CA to 2.75 V

Temperature: 15℃

3.2 Multiple temperature test

In order to evaluate the effect of temperature, the cells were discharged according to the following procedure.

Charge: 0.1 CA, 4.10 V, CC/CV, 15 h

Discharge: 0.2 CA to 2.75 V

Temperature: −10, 5, 15, 30, and 45℃

In order to measure DC resistance, pulse current of 0.5 CA for 30 seconds was imposed at 32 Ah, 80 Ah, and 128 Ah discharged states during 0.2 CA discharge.

3.3 Life test

In order to evaluate the life performance in short term, the cells were subjected to DOD 100% cycle life testing as an accelerated test. The cells were also subjected to DOD 80% and DOD 25% cycle life testing for the evaluations of semi-accelerated geostationary orbit (GEO) and real time low earth orbit (LEO) uses, respectively. Each life test procedure is shown below.

(1) DOD 100% cycle life test

Charge: 0.5 CA, 4.10 V, CC/CV, 4 h

Discharge: 100 A* to 2.75 V

Temperature: 25℃

* The current of 100 A corresponds to 0.63 CA and 0.67 CA for 160 Ah and 150 Ah cells, respectively.

(2) DOD 80% cycle life test

Charge: 0.2 CA, 4.10 V, CC/CV, 10.8 h

Discharge: 0.67 CA for 1.2 h

Temperature: 15℃

(3) DOD 25% cycle life test

Charge: 0.3 CA, 4.10 V, CC/CV, 1 h

Discharge: 0.5 CA for 0.5 h

Temperature: 15℃

3.4 Mechanical environmental test

In order to evaluate mechanical environmental durability, the cells were subjected to sine and random vibrations, shock, and acceleration tests. Their conditions are shown in tables 3 to 6, respectively. The cells were discharged at 0.25 CA during each test in consideration the case that they supply power to the satellite components while in the launch event.

4 Results and discussion

The cells showed superior electrochemical characteristics together with long life performance and demonstrated tough mechanical environmental durability. Their details are described below.

4.1 Initial discharge performance

Figure 2 shows initial 0.5 CA discharge profiles of generation IV 160 Ah cells and generation III 150 Ah cells. It is found that the former shows about 10% higher capacity than the latter. In addition, the former shows 0.02 V higher discharge voltage than the latter because of DC resistance improvement. It is achieved by the composition optimization of each electrode and superior permeability performance of separator.

Table 3 Sine vibration test condition.

Axis	Frequency / Hz	Levels
X, Y, Z	5–27.9	6.4 mm (Single Amplitude)
	27.9–100	20 g

* Sweep rate : 2 octave / minutes

Table 4 Random vibration test condition.

Axis	Frequency / Hz	Levels	Period / m	Grms
X, Y, Z	20–58	+6 dB / octave	3	23.63
	58–700	0.5 g^2 / Hz		
	700–2000	−6 dB / octave		

Table 5 Shock test condition.

Axis	Frequency / Hz	Levels
± X, ± Y, ± Z	200	40 G
	200–2000	+9.296 dB / octave
	2000–7000	1400 G

* Number of shock is 3 per axis.

Table 6 Acceleration test condition.

Axis	Levels / G	Period / m
± X, ± Y, ± Z	25	5

4.2 Multiple temperature performance

Figure 3 shows the effect of temperature on DC resistance. As described in paragraph 4.1, 160 Ah cells show smaller DC resistance than 150 Ah cells. Furthermore, its improvement becomes more clear at low temperature range. It mitigates the risk of lithium

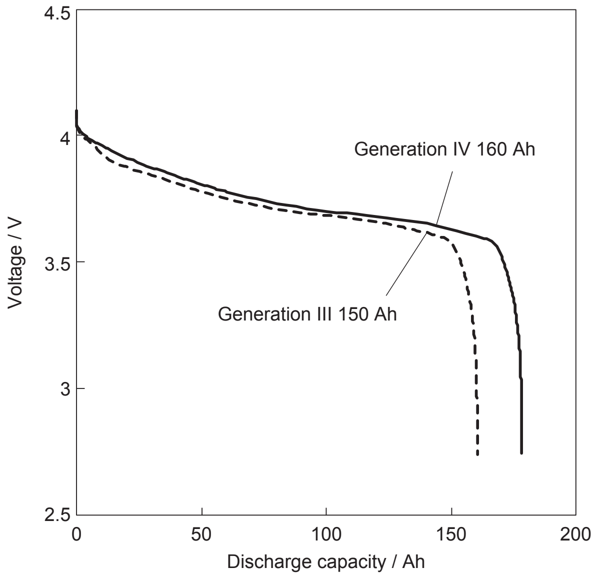


Fig. 2 Representative discharge performance of generation IV 160 Ah cells and generation III 150 Ah cells. Cells were discharged at 0.5 CA to 2.75 V at 15℃ after they were charged at 0.2 CA to 4.10 V followed by constant voltage for 8 hours in total.

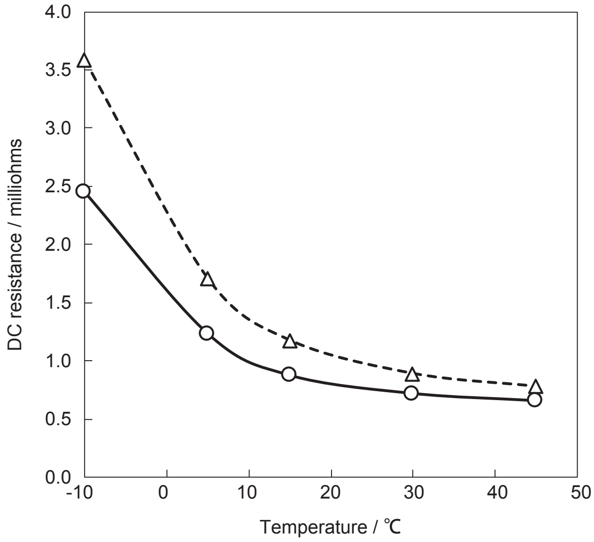


Fig. 3 Effect of temperature on DC resistance of generation IV 160 Ah cells.

plating caused by low temperature and high rate charging.

4.3 Life performance

(1) DOD 100% cycle life test

Figure 4 shows DOD 100% cycle life performance of the cells. The average capacity loss ratio of 160 Ah cells are only 15% after long cycling of 2,000 cycles. Figure 5 shows changes in discharge performance caused by cycling. There is almost no performance change except small capacity fades for both 160 Ah and 150 Ah cells. It is notable that the former shows the superior long cycle life performance as the latter does even while specific energy is increased to 180 Wh kg^{-1}.

(2) DOD 80% cycle life test

Figure 6 shows changes in charge and discharge characteristics for the 160 Ah cells caused by cycling. It shows almost no characteristics change to 1,000 cycles. In other words, discharge energy is constant from initial to 1,000 cycles as shown in figure 7. The degradation mechanism of generation IV is the same as that of generation III since the basic chemistry of both cells is identical.[4,5] Some parameters of the life model were modified based on the various life test results of 18 Ah class sub scale cells with generation IV chemistry. Figure 8 shows predicted changes in discharge capacity and end of discharge voltage. It shows that actual test results of 160 Ah cell fit well with the prediction. Furthermore, the prediction estimates

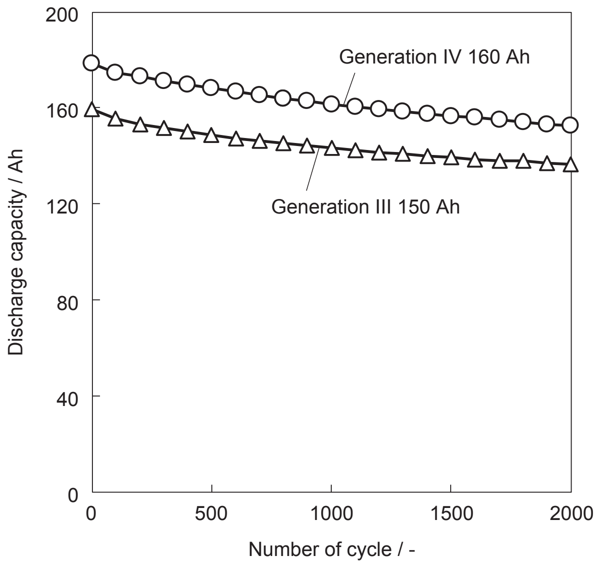
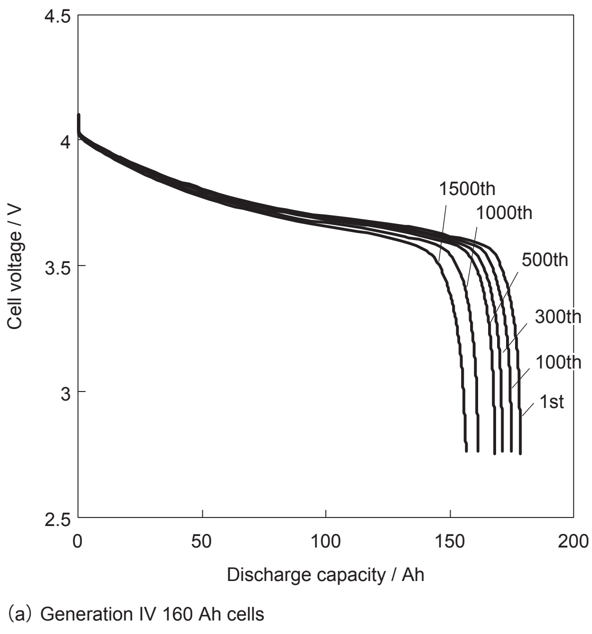


Fig. 4 Changes in discharge capacity during DOD 100% cycle life test for 160 Ah (○) and 150 Ah (△) cells at 25℃. The cells were discharged at 100 A to 2.75 V after charged at 0.5 CA to 4.10 V followed by constant voltage for 4 hours in total.



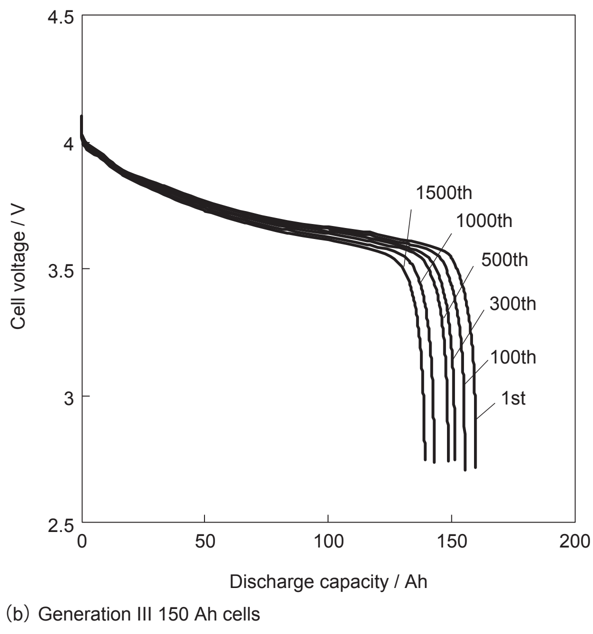


Fig. 5 Changes in discharge performance caused by DOD 100% cycling on generation IV 160 Ah cells and generation III 150 Ah cells at 25℃. The cells were discharged at 100 A to 2.75 V after charged at 0.5 CA to 4.10 V followed by constant voltage for 4 hours in total.

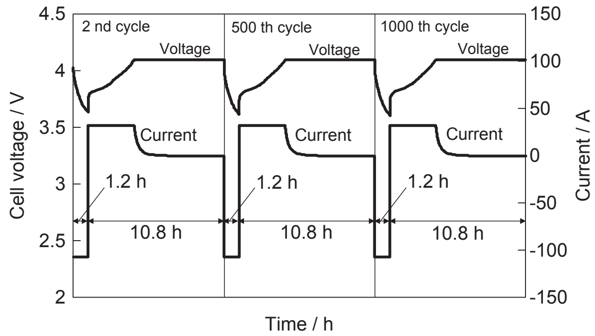


Fig. 6　Changes in charge and discharge characteristics during DOD 80% cycle life tests for 160 Ah cells at 15℃. The cells were discharged at 100 A for 1.2 hours after charged at 0.2 CA to 4.10 V followed by constant voltage for 10.8 hours in total.

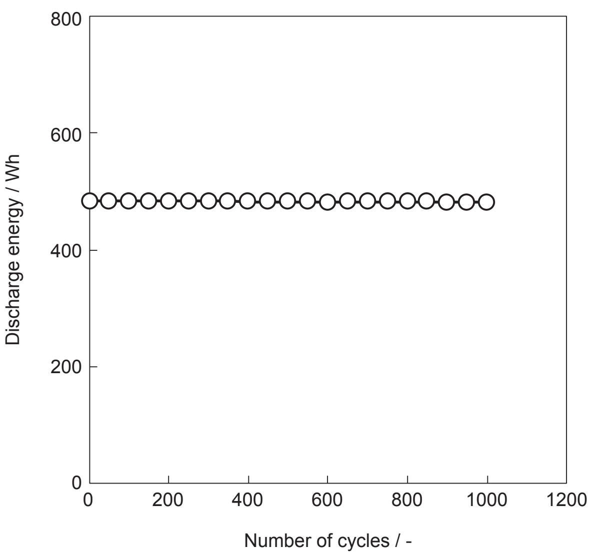


Fig. 7　Changes in discharge energy of 160 Ah cells during constant DOD 80% cycle life test at 15℃. The cells were discharged at 100 A for 1.2 hours after charged at 0.2 CA to 4.10 V followed by constant voltage for 10.8 hours in total.

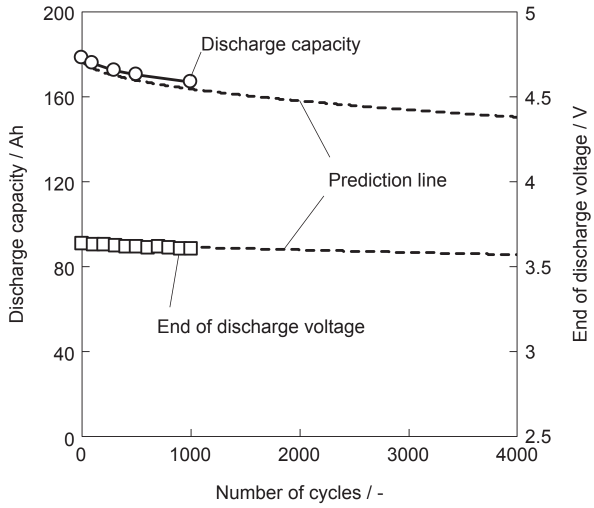


Fig. 8　Predicted changes in discharge capacity and end of discharge voltage of 160 Ah cells during constant DOD 80% cycle life test at 15℃.

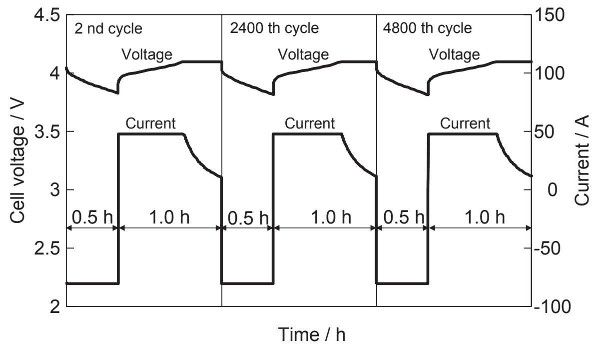


Fig. 9　Changes in charge and discharge characteristics during DOD 25% cycle life test for 160 Ah cells at 15℃. The cells were discharged at 0.5 CA for 0.5 hours after charged at 0.3 CA for 1 hour in total.

that the cells still have sufficient energy margin to continue DOD 80% cycling after typical required cycling number of 2,000.

(3) DOD 25% cycle life test

Figure 9 shows changes in charge and discharge characteristics for the 160 Ah cells caused by cycling. It shows almost no characteristics change to 4,800 cycles. Discharge energy is also constant from initial to 4,800 cycles as is the case with the result of DOD 80% cycling. Figure 10 shows predicted changes in discharge capacity and end of discharge voltage. It shows that actual end of discharge voltage of 160 Ah cells fit well with the prediction. Actual capacity of 160 Ah cells is about 2.4% greater than the prediction at 4,800 cycles. However, it is found that the cells still have energy margin to supply power for more than typical required cycling number of 40,000.

4.4 Mechanical environmental performance

No abnormal discharge voltage behavior was observed through all the environmental tests. No appearance change and AC impedance increase were also confirmed after the completion of the tests. Fig-

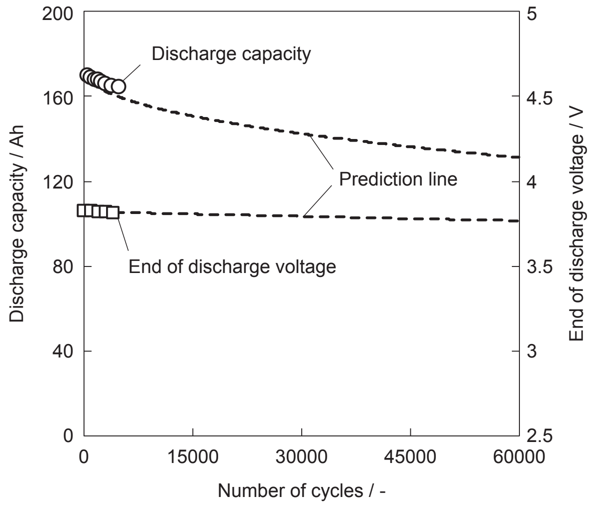


Fig. 10 Predicted changes in discharge capacity and end of discharge voltage of 160 Ah cells during constant DOD 25% cycle life test at 15℃.

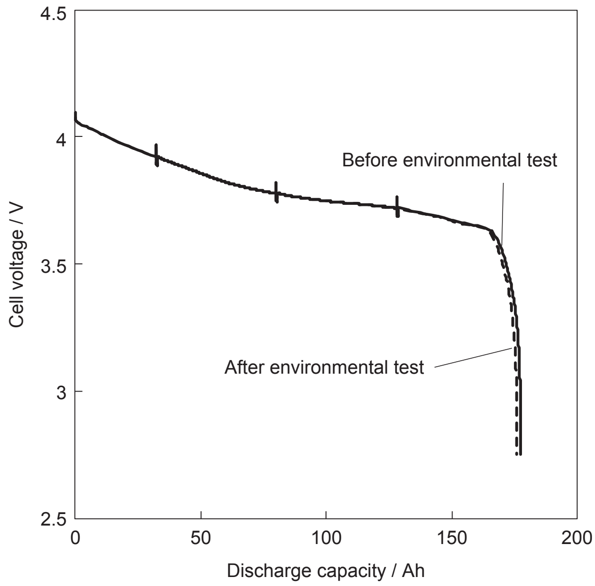


Fig. 11 Representative post environmental discharge profiles of 160 Ah cells at 15℃. The cells were discharged at 0.2 CA to 2.75 V after charged at 0.1 CA to 4.10 V followed by constant voltage for 15 hours in total. The cells were left open for 1 hour and then discharged at 0.5 CA for 30 seconds at 32 Ah, 80 Ah, and 128 Ah discharged states.

ure 11 shows post environmental discharge profiles of 160 Ah cells. There is no performance change except a slight capacity decrease of less than 1%. It was not caused by the environmental loads but by the natural calendar effect. From these results, it is clear that the cells survive from tough environmental of the launch. Furthermore, the cells are able to operate normally on orbit after its event.

5 Conclusions

GYT has developed the new generation IV 160 Ah cells for space application in cooperation with JAXA. The cells show better discharge performance than existing generation III cells. Cycle test results and the life model predictions revealed that the cells have enough capabilities of supplying power to the satellite for more than 2,000 cycles in GEO mission use, and for more than 40,000 cycles in LEO mission use. The cells have also demonstrated the tough mechanical environmental durability.

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