Development of High Power Li-ion Cell "LIM25H" for Industrial Applications

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Abstract

GS Yuasa has developed an improved high power Li-ion cell (LIM25H) and its battery module (LIM25H-8) for use in industrial applications. The LIM25H's size has been reduced by 23% while volumetric energy density has increased 9% compared to the previous generation cell (LIM30H). The LIM25H can be quick charged up to 90% of SOC within 10 minutes at 25℃. Additionally, the LIM25H retains 70% of its discharge capacity even at very high rate discharge (600 A; 24 CA) at 25℃ and the LIM25H retains 90% of its original capacity after 5000 cycles at 25℃ with 120 A (4.8 CA). High power and high durability performance have been achieved as a result of the introduction of new electrolyte and cell design. GS Yuasa has begun the mass production of the LIM25H cells and modules from March, 2015.

Key words : Li-ion battery ; Industrial applications ; High power

1 Introduction

In recent years, the effective use of energy storage systems to store clean energy provided by renewable sources such as wind or photovoltaic power has been accelerating in an effort to address global environmental and energy issues. Energy storage systems are also being used to efficiently store energy from regenerative power systems. Electric double layer capacitors, flywheels and various rechargeable batteries have all been considered as energy storage media. Li-ion batteries are an attractive solution as an energy storage system due to their ability to reliably provide high energy density and high rate performance while requiring minimal maintenance.[1–4] GS Yuasa developed the LIM30H as a large-format Li-ion battery for storing regenerative energy.[3, 4] Since 2007 the use of the LIM30H has steadily spread for hybrid industrial applications such as railway systems and cranes which enables efficient capture regenerative energy. However, to achieve further improvement in fuel consumption for hybrid systems, it was necessary for GS Yuasa to advance the technology by improving the energy density and high rate capabilities of the LIM30H. For these reasons GS Yuasa has developed the new LIM25H cell which has increased energy density and improved high rate capabilities. In this report, GS Yuasa will introduce the benefits of the LIM25H for energy storage systems used in industrial applications.

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2 Cell and module design

2.1 Cell

The LIM25H electrochemical system consists of a spinel-type lithium manganese oxide cathode with non-graphitic carbon anode. The electrolyte solution composition has been optimized and improved relative to the one for existing LIM30H. The improvements in the cell chemistry have reduced the internal resistance of the cell. Fig. 1 and Table 1 show the appearance and specifications of LIM25H. The optimized cell design of the LIM25H has led to an increase of the volumetric energy density by 9% and allows for a 23% reduction in cell size while maintaining the same rate capabilities of the LIM30H.

2.2 Module

Fig. 2 and Table 2 show the appearance and specifications of battery module "LIM25H-8". The nominal capacity is 25 Ah (1 CA). The module consists of 8 cells connected in series with an Advanced Cell Sensor (ACS) circuit board. The ACS monitors individual cell voltages, module temperature and performs cell balancing.

Due to avoiding hazardous phenomena even if a lithium ion battery is allowed to be operated under the condition of outside of its specifications, a Lithium-ion Battery Management System (LIBM) is employed in systems using the LIM25H-8 modules. The LIBM monitors all module performance parameters and status signals received from the connected ACSs and acts to prevent the batteries from operating in an unsafe manner.

3 Charge and discharge performance

The performance requirements of the cell for an energy storage system are as follows:

(1) Managing the state of charge (SOC) judging from the voltage.

(2) Providing high power performance at low-temperature.

(3) High durability performance at high rate cycle.

(4) High capacity retention and low self-discharge.

3.1 Management of SOC

The primary purposes of an industrial energy storage system involve intelligently storing regenerative energy and providing voltage of system during periods of high demand. Therefore, it is vital for the sys-

Table 1　Specifications of LIM25H and LIM30H Li-ion cell.

Model	LIM25H	LIM30H
Nominal capacity / Ah	25	30
Nominal voltage / V	3.6	3.6
Dimension (W×L×H) / mm	44×171×111	47×170×136
Mass / kg	1.5	2.1
Specific energy / Wh kg^{-1}	60	51
Energy density / Wh L^{-1}	108	99

Table 2　Specifications of LIM25H-8 and LIM30H-8 Li-ion battery module.

Model	LIM25H-8	LIM30H-8
Nominal capacity / Ah	25	30
Nominal voltage / V	28.8	28.8
Dimension (W×D×H) / mm	219×440×128	231×414×147
Mass / kg	17.5	19.5
Max current / A	600 (24 CA)	600 (20 CA)

Fig. 1　Appearance of LIM25H Li-ion cell.

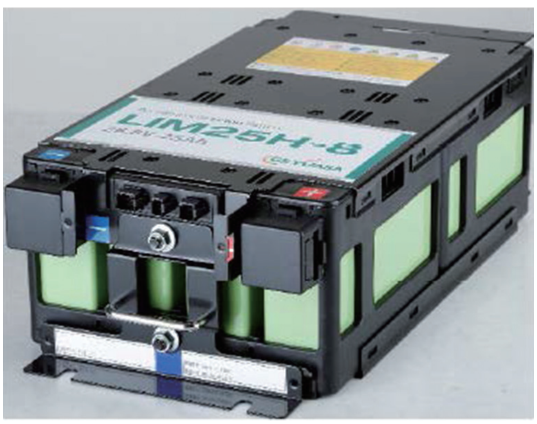

Fig. 2　Appearance of LIM25H-8 battery module.

tem to understand how much currents are allowable at any given state of charge (SOC) to prevent overvoltage or under voltage of the system. Fig. 3 shows the relation of the depth of discharge (DOD) and the cell voltage of LIM25H. The cell was discharged from a fully charged state to an end voltage of 2.75 V with a constant current of 25 A (1 CA) at 25℃. Next, the cell was charged using a constant current of 25 A to 4.15 V followed by constant voltage for a total of 180 minutes (CC/CV method). The charge and discharge curves of LIM25H have the large slope of voltage. Therefore, it is considered that the DOD (or SOC) of each cell in the system can be detected easily by voltage.

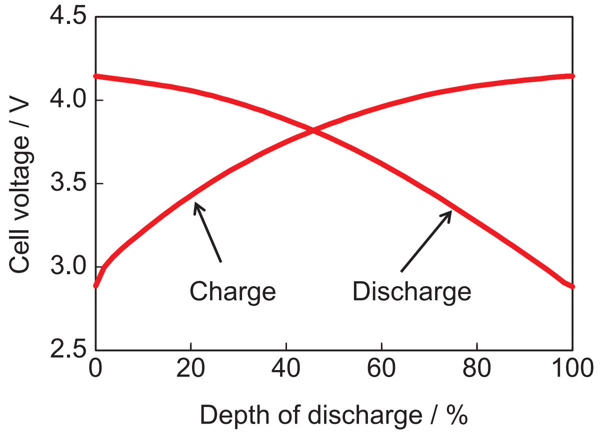

Fig. 3　Charge and discharge characteristics of LIM25H at 25℃. The cell was discharged to 2.75 V with a constant current of 1 CA at 25℃ after charged for 180 minutes in total with 1 CA at a constant voltage of 4.15 V.

3.2　Internal resistance

Fig. 4 shows the internal resistance of the LIM25H as a function of temperature compared to the existing LIM30H. Internal resistance was calculated using the voltage change during charge (a) and discharge (b) at 12.5 A (0.5 CA), 25 A (1 CA), and 50 A (2 CA) for 10 seconds at 50% SOC. The internal resistance of the LIM25H at 0℃ has been reduced by approximately 25% compared to LIM30H while the internal resistance at 25℃ and 45℃ is nearly equal to LIM30H, which is a significant characteristic due to the LIM25H's smaller form factor. The improvement at low temperature is attributed to the improved electrolyte. This results in improvement of power acceptance and supplying rate in cold environments for the LIM25H.

3.3　High rate performance

Fig. 5 shows the high rate charge characteristics of the LIM25H compared to LIM30H at 25℃. For this test the cells were charged using constant current of 25 A (1 CA) to 4.15 V followed by constant voltage for a total charge time of 90 minutes. Cells were discharged and the test was repeated using additional

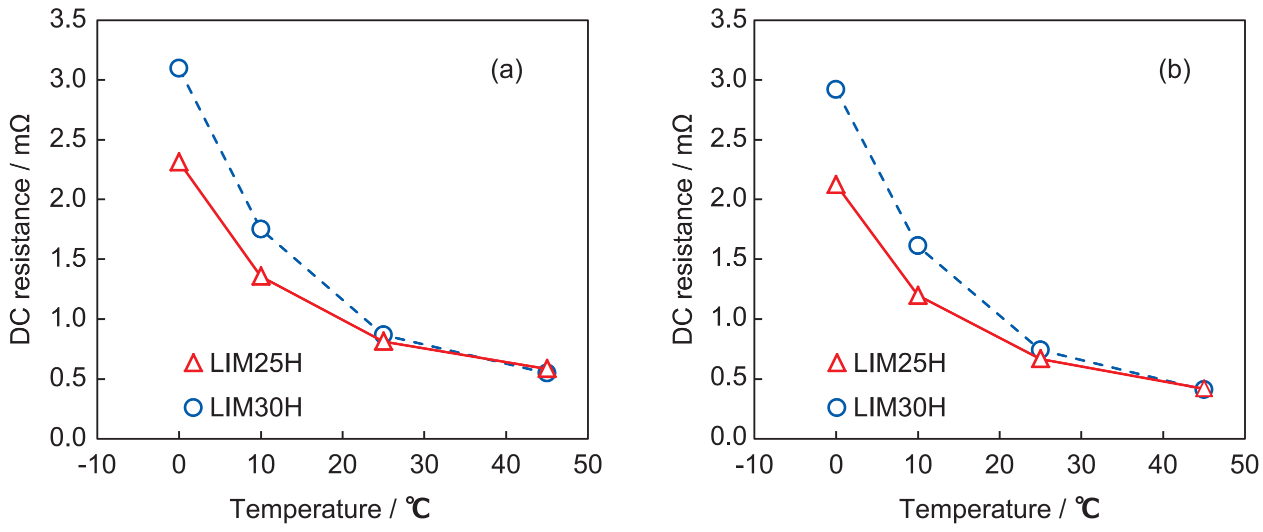

Fig. 4　The internal resistance of LIM25H as a function of temperature compared to conventional LIM30H. Internal resistance was calculated by the voltage after charge (a) and discharge (b) at 0.5 CA, 1 CA, and 2 CA for 10 seconds at 50% SOC.

charge currents of 250 A (10 CA) and 600 A (24 CA). The LIM25H can be rapid charged up to approximately 90% SOC within 10 minutes at 25℃. LIM25H quick charging performance is equivalent to one of the LIM30H.

Fig. 6 shows the high rate discharge characteristics of the LIM25H compared to LIM30H at 25℃. The cell was discharged with a constant currents of 25 A, 250 A, and 600 A at 25℃ after being charged using constant current of 25 A (1 CA) to 4.15 V followed by constant voltage for a total charge time of 180 minutes. The voltage polarization during high rate discharge has improved compared to LIM30H. Furthermore, the maximum discharge capacity for LIM25H is 70% even at a very high discharge rate (600 A, 24 CA). The ability to supply a majority of the stored energy at very high rates is a desirable characteristic for high power industrial applications.

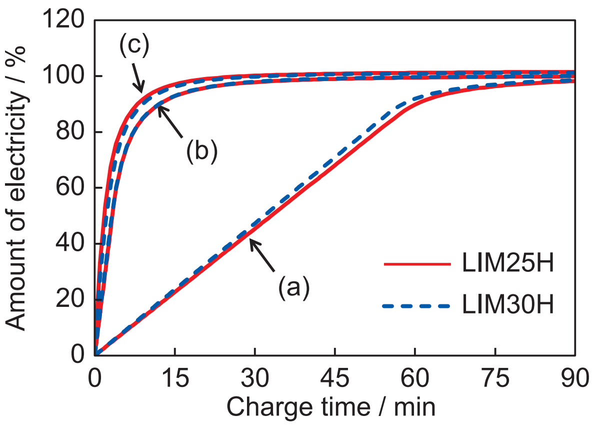

Fig. 5　Charge characteristics of LIM25H at high rate current compared to LIM30H at 25℃. The cell was charged for 90 minutes in total with (a) 1 CA, (b) 10 CA, and (c) 600 A (24 CA) at a constant voltage of 4.15 V.

3.4　Low temperature performance

Fig. 7 shows the continuous discharge characteristics compared to LIM30H at low temperature. After charging for 180 minutes in total at 25℃ the cells were discharged with constant current of 25 A (1 CA) at −25℃, 0℃, and 25℃. As indicated in Fig. 7, the LIM25H is able to deliver 86% of its stored capacity even at −25℃.

4　Life performance

4.1　Cycle performance

Most of the battery in a regenerative energy storage system is cycling within a limited SOC range. For example, many demanding regenerative energy storage systems have cycling patterns with average currents of 120 A (4.8 CA) and operate in the 20−80% SOC region. Fig. 8 and Fig. 9 show the discharge capacity retention and DC resistance change for LIM25H at 45℃ and 25℃ tests respectively. The resistance was calculated from the voltage differences after 10 seconds

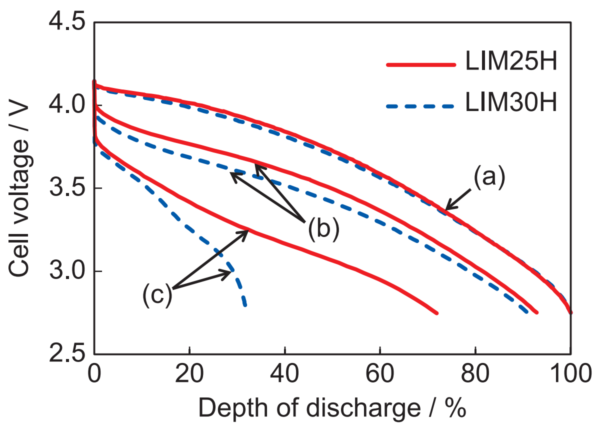

Fig. 6　Discharge characteristics at various currents of (a) 1 CA, (b) 10 CA, and (c) 600 A (24 CA) at 25℃ of LIM25H and LIM30H. The battery were discharged to 2.75 V after charged at 1 CA to 4.15 V for 180 minutes in total at 25℃.

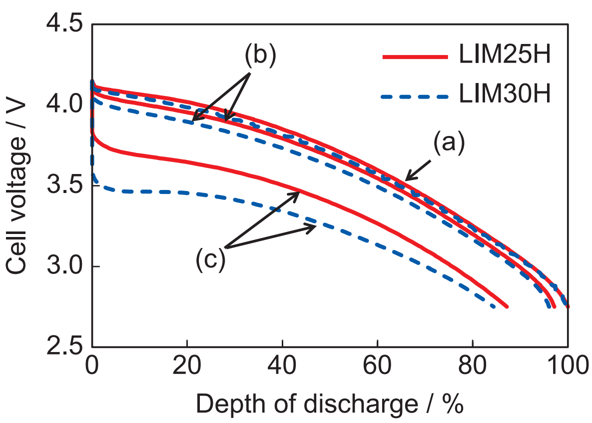

Fig. 7　Continuous discharge characteristics at low temperature compared to LIM30H. The cell was discharged with constant current of 1 CA at (a) 25℃ , (b) 0℃ , and (C) −25℃ after charged at 25℃ for 180 minutes in total at a constant voltage of 4.15 V.

discharge at 12.5 A, 25 A and 50 A at 50% SOC. After 2500 cycles at 45℃, the LIM25H exhibited discharge capacity retention of approximately 80% and an increase of internal resistance of approximately 32%. After 5000 cycles at 25℃, the LIM25H exhibited discharge capacity retention of approximately 90% and an increase of internal resistance of approximately 22%. These tests demonstrate the LIM25H's excellent cycle life performance at large currents and temperatures, which is a significant benefit for many regenerative energy storage systems.

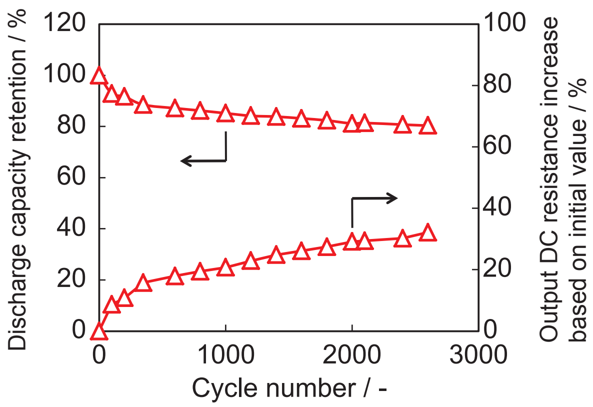

Fig. 8 Cycle life performance of LIM25H at 45℃ with 25 Ah (1 CA). Cell was discharged to 2.75 V after charged to 4.15 V for 180 minutes in total at 45℃. Capacity and DC resistance checks after cycling were performed at 25℃.

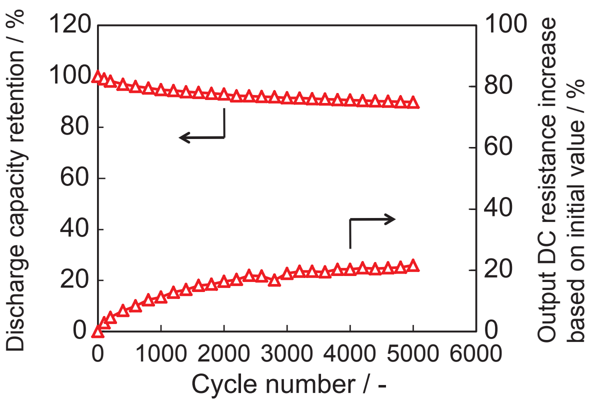

Fig. 9 Cycle life performance of LIM25H at 25℃ with 120 A (4.8 CA). Cell was discharged to SOC 20% after charged to SOC 80% at 25℃. Capacity and DC resistance checks after cycling were performed at 25℃.

4.2 Storage performance

4.2.1 Self-discharge

Fig. 10 shows the self-discharge amount as a function of the storage period for ambient temperatures of 25℃ and 45℃. The cells were charged to 20% SOC. Self-discharge based on initial amount of charged electricity of 20% SOC at 25℃ and 45℃ after 180 days is 10% and 35% respectively.

4.2.2 Effect of SOC on storage capacity retention performance

The decrease of recovery capacity with spinel-type lithium manganese oxide after storage at 20-50% SOC is documented to be relatively large.[5, 6] GS Yuasa investigated the storage performance of LIM25H at several SOC levels at temperatures of 25℃ and 45℃ to understand this effect. After setting the cell SOC, the cells were stored for a period of 180 days. A supplementary charge was applied to the cell every 30 days to maintain SOC and compensate self-discharge effects. Fig. 11 shows the recovery capacity retention and the increase of internal resistance as a function of SOC after storage for 180 days at 25℃ or 45℃. The retention of recovery capacity in the lower SOC region is almost the same as the higher SOC region. Moreover, the increase of internal resistance is small at less than 20%. The reason for improvement of recovery capacity in the lower SOC region is considered to be

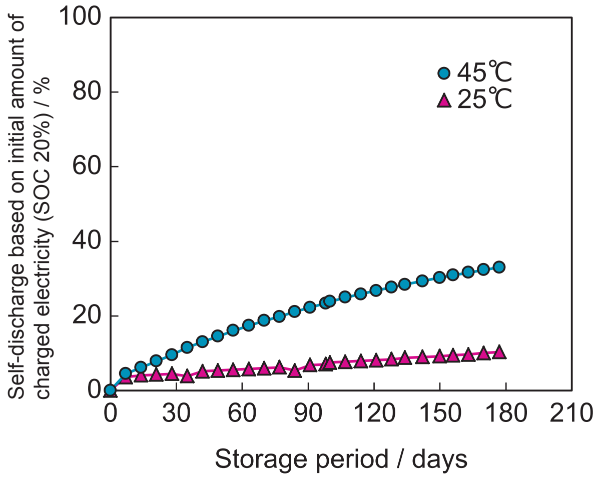

Fig. 10 Self-discharge of LIM25H during a period of 180 days at 25℃ and 45℃. The stage of charge for storage was 20%. Cell was charged with 1 CA to SOC 20%.

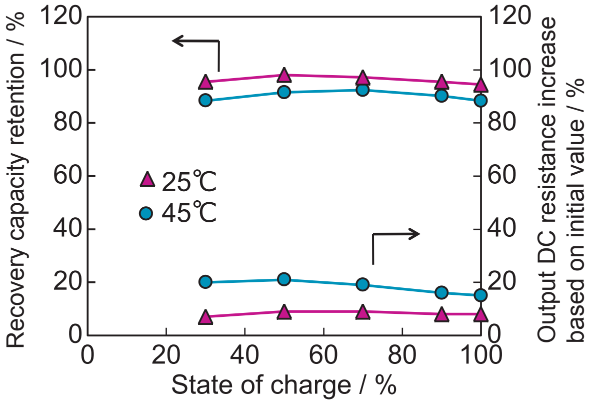

Fig.11　Recovery capacity retention and increase of output DC resistance as a function of SOC of LIM25H after storage for 180 days at 25℃ or 45℃. Supplementary charge was performed every 30 days at 25℃.

an effect of the optimizing the electrolyte and anode design. These results provide high confidence that LIM25H can be utilized in a variety of application, operated effectively, and tolerate a range of conditions.

5　Safety performance

The LIM25H has satisfied all items of testing according to the United Nations Recommendations[7] and the JIS C8715-2[8] standard.

6　Conclusion

GS Yuasa has successfully designed and manufactured a high power Li-ion cell, "LIM25H", and battery module, "LIM25H-8", for use in industrial hybrid systems. The volumetric energy density of the LIM25H has been increased by approximately 9% and DC resistance at low temperature has been improved compared to the LIM30H. Furthermore, the maximum discharge capacity for LIM25H is 70% even at a very high discharge rate (600 A, 24 CA). These results demonstrate the LIM25H' s ability to provide high power performance with improved energy density. The discharge capacity retention after 5000 cycles at average rates that is typical of demanding industrial regenerative energy storage systems is an impressive 90% of beginning of life capacity. Clearly, the LIM25H has performance characteristics suitable for high power energy storage systems; enabling these systems to operate more efficiently, reduce fuel consumption, and diminish the CO_2 emissions of hybrid power systems.

GS Yuasa has begun the mass production of the LIM25H cells and modules from March, 2015 in a state-of-the-art facility in Kyoto, Japan. GS Yuasa continues to perform research and development of lithium-ion technology to meet the current and future demands of the industrial markets.

References

1. M. Ogasa, *Rolling stock & Technology*, **89**, 13 (2004).
2. J. Ishii, *GS Yuasa Technical Report*, **3**(2), 1 (2006).
3. Y. Seyama, K. Okazaki, N. Higashi, and T. Sakuno, *GS Yuasa Technical Report*, **2**(2), 25 (2005).
4. Y. Seyama, T. Nakamoto, K. Nishiyama, and T. Sonoda, *GS Yuasa Technical Report*, **4**(2), 24 (2007).
5. Y. Kogetsu, M. Kohno, T. Hatanaka, T. Saito, and J. Yamaura, *200th Meeting of Electrochemical Society*, 181 (2001).
6. N. Tanaka, Y. Kogetsu, T. Saito, T. Hatanaka, and J. Yamaura, *42th Battery Symposium, Japan,* Abs. No. 3A06 (2001).
7. *United Nations UN Recommendation on the Transport of Dangerous Goods*/ T1-T8.
8. JIS(Japanese Industrial Standard) C 8715-2: 2012. Secondary lithium cells and batteries for use in industrial applications-Part 2, Tests and requirements of safety.