DEVELOPMENT OF VERY LARGE LITHIUM-ION BATTERIES FOR TELECOMMUNICATION APPLICATIONS

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ABSTRACT

Currently, lead-acid batteries are used as a back-up power source for telecommunication applications. Lead-acid batteries are a very mature technology and have a long history of use in the industry, and as such, its operating and life parameters are fairly well understood. However, in the case of deployment in multi-story buildings, a lighter and smaller battery is required to reduce the floor weight loading, even though the power and energy requirements are not reduced. Lithium-ion batteries have much higher specific energy and energy density that enable a 70% reduction of weight and volume compared with lead-acid batteries. Therefore, a 200Ah and 400Ah class Lithium-Ion battery has been developed which can meet the energy storage and weight and volume requirements of the application. These batteries show approximately 30% of the weight and volume of lead acid batteries and also demonstrate excellent discharge performance even in low temperature environments. Moreover, since the lithium-ion cell voltage is 4V per cell, it reduces the number of cells connected in series to meet the same total system voltage. As for maintenance, the lithium-Ion battery is maintenance free: it is hermetically sealed, it has no memory effect, and it requires no electrolyte level adjustment like flooded lead acid and nickel cadmium batteries. The life performance of this new lithium-ion battery is being evaluated, and to date it shows almost the same performance as previously demonstrated with smaller cells using the same chemistry.

INTRODUCTION

Small-size Li-ion batteries have been already widely commercialized for cellular phones, camcorders and other portable electronics equipments. Middle-size Li-ion batteries have been developed for Electric Vehicles, Unmanned Underwater Vehicles (UUV), Automated Guided Vehicles (AGV), and Railway applications. Since the capacity of these existing middle-size batteries is in the range of 5 to 100Ah, parallel connections, complex circuitry, and sophisticated charging systems are required for larger capacity (>100AH) applications. However, the development of a larger capacity cell has some challenging issues such as; accurate winding of large electrodes, structural design to meet required environmental conditions, and safety. Lithium Manganese Oxide ($LiMn_2O_4$) was selected as a cathode material to build the 200Ah and 400Ah cells because it is more thermally stable than other cathode materials namely Lithium Cobalt Oxide ($LiCoO_2$) or Lithium Nickel Cobalt Oxide ($LiNi_xCo_yM_{(1-x-y)}O_2$). Figure 1 is a graphical comparison of the thermal stability of each of these prospective cathode materials. General properties of these materials are shown in Table 1. In this paper, initial electrical performance, environmental durability and safety test data of the 200Ah and 400Ah cell are reported. Future publication will include the system level design and deployment analysis / strategy.

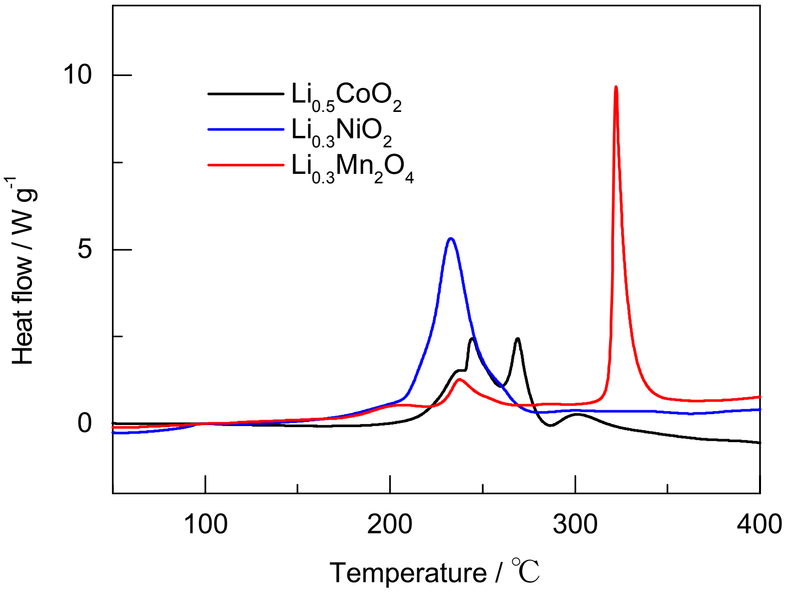

Figure 1. Thermal Stability of lithium ion cathode materials

$LiMn_2O_4$ has the highest temperature before decomposition that means it can withstand temperatures that other materials would decompose at (which generates significant additional heat). Also the relative area under the curve of $LiMn_2O_4$ is less then the others that are a measure of the total heat released in the event of thermal decomposition. So the additional heat generated in the unlikely event of thermal decomposition is less. This makes $LiMn_2O_4$ a good choice for industrial applications.

Table 1. General properties of positive materials for lithium ion cell

	$LiNi_xCo_yAl_{(1-x-y)}O_2$	$LiCoO_2$	$LiMn_2O_4$
Actual utilizable capacity at material level	165mAh/g	150mAh/g	100mAh/g
Average discharge voltage	3.6V	3.7V	3.8V
Specific energy at cell level	160Wh/kg	150Wh/kg	95Wh/kg
Thermal stability	Inferior	Good	Excellent
Life at room temperature < 30 ^{O}C	Excellent	Good	Good
Life at high temperature > 30^{O}C	Good	Inferior	Inferior
Future possibility of cost reduction	Limited	No	Promising

The ability of the material to meet the life requirements is another key factor in choosing the proper cathode material. $LiMn_2O_4$ is not as tolerant high temperature float operation as nickel based systems. However the priority for deployment of this technology should be to minimize risk and maximize benefit. For this reason, the LCLB battery systems are designed for unique applications to provide solutions in cases of CO and other controlled environment solutions where floor loading, and volume are key project drivers. This chemistry is not applicable to OSP or other uncontrolled environments.

CELL DESCRIPTION

Fig.2 shows the 200Ah and 400Ah cell appearance. The cell itself has a prismatic external shape but internally it is made with spiral (wound) construction in which the positive and negative electrodes are wound together with micro porous separators. The base design is same as that of the LIM40 (40Ah) cell, which has been developed and commercialized earlier (1) (2). The chemistry (electrode materials, separator, electrolyte) is identical to the LIM40. The 200Ah and 400Ah cell characteristics are shown in Table 2.

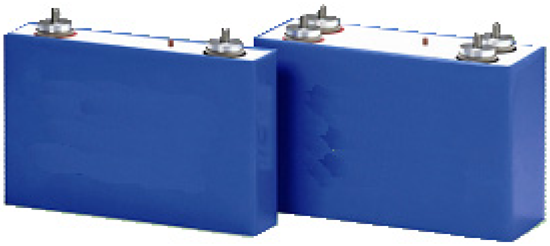

Figure 2. 200Ah and 400Ah Prismatic cells

Table 2. Specifications of 200Ah and 400Ah Lithium-ion cell

Name	LCLB200	LCLB400
Rated capacity	200 Ah	400 Ah
Nominal capacity (at C/2, 25 °C, BOL (Beginning of life))	230 Ah	460 Ah
Shape:	Prismatic	
Dimensions (mm):H	232 mm	
Dimensions (mm):W	312 mm	
Dimensions (mm):T	62 mm	120 mm
Mass	8.4 kg	16 kg
Case material	Stainless steel	
Positive material	Lithium Manganese Oxide ($LiMn_2O_4$)	
Negative material	Carbon graphite	
Separator	Micro-porous plastic film	
Electrolyte	Li salt dissolved in mixture of alkyl carbonate solvents	
Nominal voltage	3.8V (at 1C, 25 °C)	
Nominal specific energy (at C/2, 25 °C, BOL)	90Wh/kg	95 Wh/kg

The nominal cell voltage of 3.8V is equivalent to that of three cells of conventional nickel-cadmium connected in series (Ni-Cd) and nickel-hydrogen (Ni-H_2) cells and to that of two cells of conventional lead-acid (Pb) cells connected in series. The specific energy of 95 Wh/kg is two times higher than that of existing lead-acid cells.

TEST CONTENTS

3-1 Electrical performance

C/5, C/2, 1C, charge at 0,25,50 °C
C/5, C/2, 1C, discharge at -20,0,25,50 °C
Storage life test at 100% SOC(state of charge) and at 25, 45 °C

3-2 Environmental durability

Sine vibration

3-3 Safety

Extreme over-charge, 40A constant current charge with no voltage limit at 25 °C
External short circuit at 0.5 m-ohm

RESULT AND ANALYSIS

4-1 Electrical performance

Discharge performance at various rates
Fig.3 shows the discharge curves at various rates. Discharge capacities were around 460Ah (LCLB400) at C/5 (80A), C/2 (200A), and 1C (400A). Even at high discharge rates, like 1C, the cell showed 100% capacity of the C/5 capacity at 25 °C.

Discharge performance at various rates
Fig.4 shows the discharge curves at various temperatures. Discharge capacities were around 460Ah (LCLB400)、at 20 °C, 0 °C, 25 °C, and 50 °C. Even while discharging at -20 °C, the cell showed 99% of the C/5 capacity at 25 °C.

Charge performance at various rates
Fig.5 shows the charge curves at various rates. Charge capacities were around 460Ah (LCLB400) at C/5, C/2, and 1C. Even when charging at 1C, the cell showed 100% capacity of C/5 charging capacity at 25 °C.

Charge performance at various temperatures
Fig.6 shows the charge curves at various temperatures. Charge capacities were around 460Ah (LCLB400) at 0 °C, 25 °C, and 50 °C. Even if 0 °C Charging, the cell showed 99% capacity of C/5 discharging capacity at 25 °C.

The LCLB200 result is very similar to that of LCLB400, the rate capability is directly proportional to capacity. Fig.7 shows discharge curve of the 200Ah cell.

Storage life data at high temperature condition
Fig.8 and 9 show the storage life test data of LIM40, LCLB200, and LCLB400. They show almost identical life performance. In the case of 25 °C, the capacity retention is 90% after 2 years. However it becomes 70% at 45 °C.

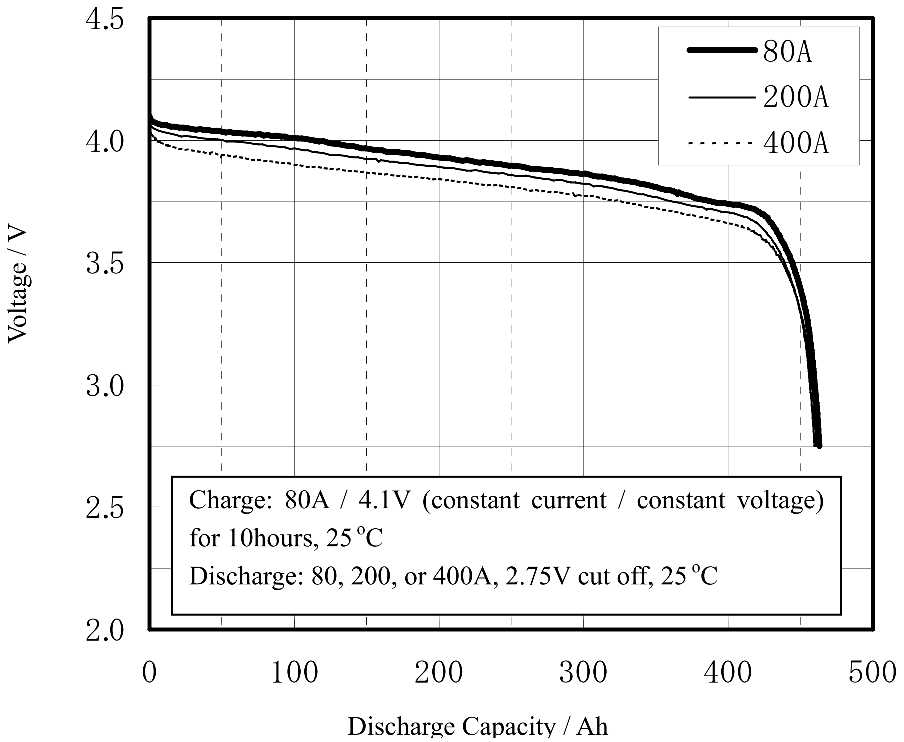

Figure 3. Discharge characteristics of LCLB400 at Various Currents

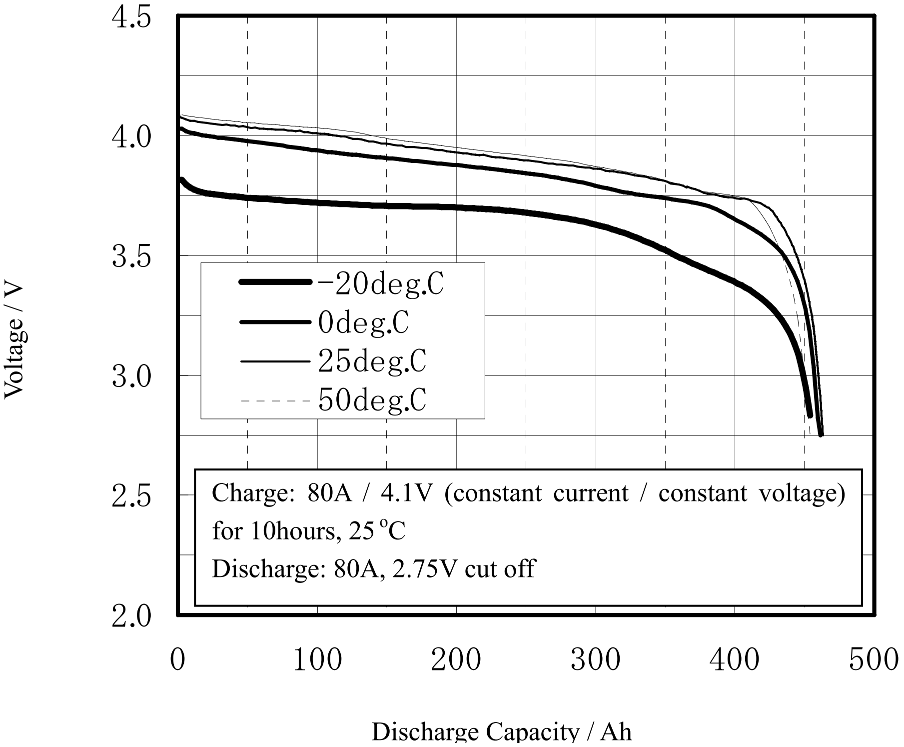

Figure 4. Discharge characteristics of LCLB400 at various temperatures

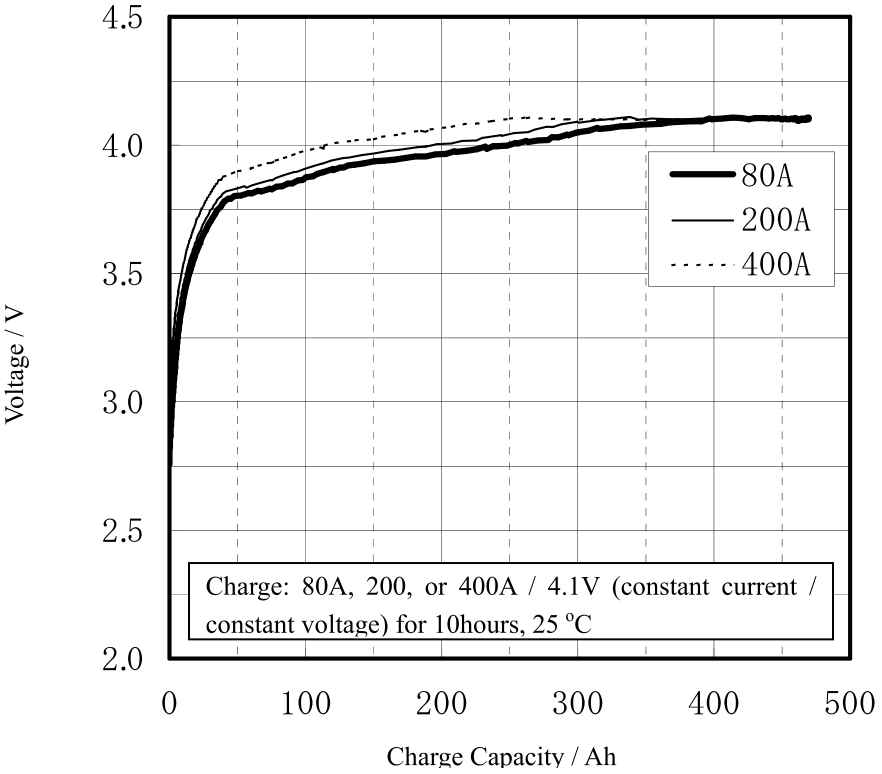

Figure 5. Charge characteristics of LCLB400 at various currents

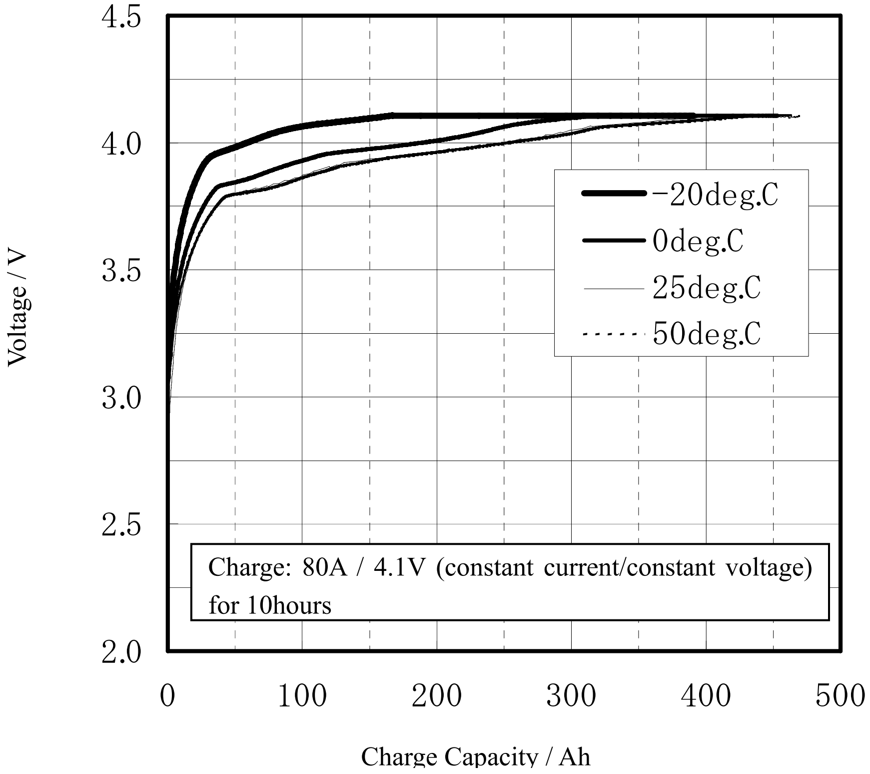

Figure 6. Charge characteristics of LCLB400 at various temperatures

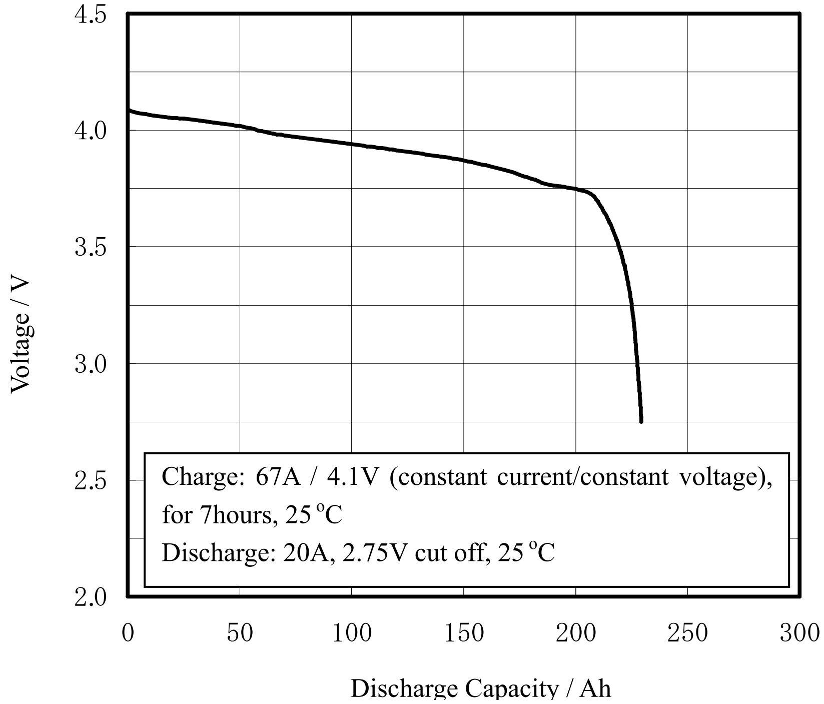

Figure 7. Discharge characteristics of LCLB200

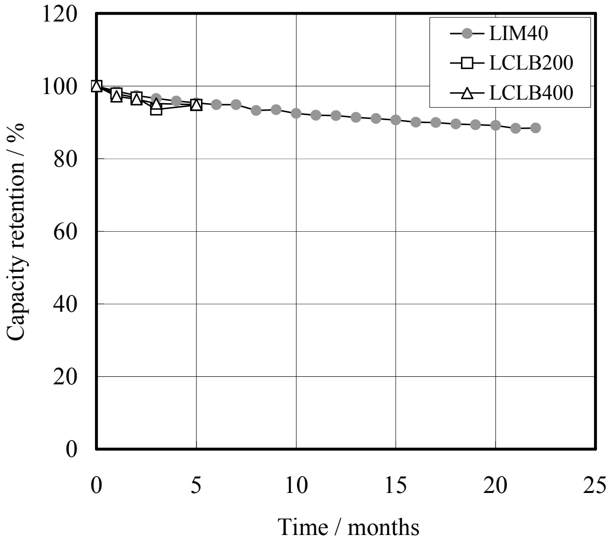

Fig.8 Storage life test data at 100% SOC and at 25 °C

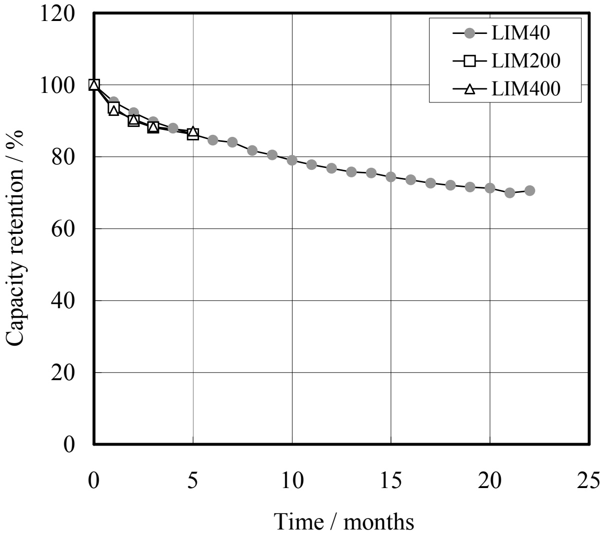

Fig.9 Storage life test data at 100% SOC and at 45 °C

4-2 Environmental durability

Sine vibration test
The cell was subjected to sine vibration test consecutively in the axial and radial directions. The test conditions are shown in Table 3. During vibration test, the cell voltage was monitored. The cell voltage during the test was stable, no abnormality was observed after the vibration test.

Table 3. Sine vibration levels

	Frequency (Hz)	Levels (m/s^2)	Time (sec)
Axial Direction	10	9.8	10
Radial Direction	10	9.8	10

4-3 Safety

Lithium ion battery systems store power in a very energy dense structure, and have to be managed to prevent the release of that energy in an uncontrolled manner. The 200Ah and 400Ah battery systems designed for the telecom market include a sophisticated and reliable battery management unit integrated into the battery module. This paper is about the cell level testing to date, information about the battery system is available upon request. Cell level safety testing is required to show what happens to the cells in the extremely unlikely even of the management system failure. The following tests were performed for this reason.

4-3-1 Extreme overcharge

Lithium ion cells generally to not tolerate overcharge very well. For this reason, the various lithium secondary battery systems deployed today use electronic control circuitry to manage and prevent this phenomenon from occurring. Depending on the thermal stability of the cell (which is primarily based on the cathode material), the level of energy released during a destructive overcharge occurrence varies proportionally. The cathode material selected for the LIM series and these LCLB200 and LCLB400 is $LiMn_2O_4$. This material is one of the most thermally stable and has a safer overcharge reaction than most the other systems.

The extreme overcharge test is required to show the effect of the failure of the battery management system. This test was performed on a LCLB200 (1cell). The cell was charged with 40A constant current (C/5 rate) with no voltage limit starting from fully charged condition (100%SOC). The cell voltage smoothly increased and reached 4.3V after 25 minutes. Then, the voltage rapidly increased to 5.0V. This transition in voltage change is considered to be related a change in mechanism from that of the lithium ion desorption at the cathode to decomposition of electrolyte solvents. During this period no cell bulging or swelling was observed. After that the cell voltage gradually increased and reached 5.2V at 2 hour 18 minutes from the test start. Then, the voltage slowly decreased to 5.0V with a slight cell bulge. After 2 hour 48 minutes the safety vent was opened and white smoke was emitted. The voltage quickly decreased to 0V. At the conclusion of the test, the cell case was bulged, but no explosion or no fire was observed.

Table 4 Extreme overcharge test summary

Monitoring item	Results
Maximum voltage	5.2V (after 2 hour 18 minutes)
Vent open	After 2 hour 48 min
Cell temperature of just before vent open	60 °C
Charged electricity from start	110Ah from start (total 340Ah)

4-3-2 External short

This test was performed on a LCLB200 (1cell). A fully charged cell was connected to external circuit with a relay and current shunt. The total external circuit resistance was 0.5 m-ohm. When the circuit was closed, the cell voltage quickly dropped to 2.40V and the short circuit current increased to 4400A after 0.2 second. After 23 seconds, the cell voltage dropped to 0.02 V and the short circuit current dropped to 50A. After 26 seconds both current and voltage dropped to 0. The maximum cell body surface temperature increased to 20°C from the starting temperature of 10°C. The maximum terminal temperature was 55°C, which is an increase of 45°C. The design of the cell includes a non-resettable fuse function at the internal current collector. This fuse function is a slow-acting fusible link that opens in the event of an extended high current >200C for the LCLB200. After 26 seconds the fuse opened completely and this is the reason the current and voltage became 0.

Table 5. External short circuit test summary

Event	Time (second)
Maximum short circuit current (4400A)	0.2
Short circuit current and cell voltage drop (to 50A, 0.02 V)	23
Short circuit current and cell voltage drop (to 0A, 0.00 V)	26

4-4 Comparisons of Lithium Ion and VRLA Chemistries

A key benefit of lithium-ion batteries is the reduced weight and volume when compared to existing legacy VRLA batteries. A lithium ion battery is approximately 1/3 of the weight and volume of existing lead-acid batteries. For example a comparison of a1000Ah-48V VRLA system for telecommunication application:

Battery	System	Discharge capacity at 0.1C	Discharge capacity at 0.2C	Cell mass	Total cell weight	Total cell volume
Lead Acid	24cell-series	1000Ah	800Ah	58kg	58kg×24cells=1392kg	0.94m3
Lithium-ion	13cell-series x 2paralle	800Ah	800Ah	16kg	16kg×26cells=416kg	0.30m3

Because there is a strong relationship between temperature and life, the main application of this technology today is in large, multi-story building installations in an environmentally controlled area. Currently most Li-ion batteries are not suitable for outside plant installations or other high temperature environments. The system made from the LCLB200 and LCLB400 is a solution to cases where it is desirable to install a very large battery on an upper floor in a CO or other controlled environment. Since the mass is reduced by 1/3 as compared to VRLA batteries, a large capacity system can be installed without requiring special structural modifications to the building. Another unique feature of lithium-ion battery is the rate-independence of capacity. Within the typical telecom usage discharge rates, Li-ion batteries do not have the same Peukert relationship between discharge rate and capacity. From the table above, the capacity of the lithium-ion battery is the same at C/10 and at C/5. This allows the installation of a smaller capacity battery to handle higher discharge rates than can be used today with existing VRLA and technologies.

CONCLUSIONS

200Ah and 400Ah cell has developed and evaluated. The cell utilizes Lithium Manganese Oxide ($LiMn_2O_4$) positive material that shows excellent thermal stability. The nominal voltage of 3.8V is equivalent to that of three serial cells of conventional nickel-cadmium (Ni-Cd) and nickel-hydrogen ($Ni-H_2$) cells and to that of two serial cells of conventional lead-acid (Pb) cells. The specific energy of 95 Wh/kg is two times higher than that of existing lead-acid cells. The battery is 1/3 smaller than that of existing lead-acid battery in the case of 1000Ah-48volt system for telecommunication application.

The 200Ah (LCLB200) cell showed 230Ah capacity and the 400Ah cell (LCLB400) showed 460Ah capacity at the beginning of life. Extreme overcharge testing, which has no voltage limitation showed no explosion or no fire. External short circuit test showed no explosion or no fire.

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