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Design of High Power Lithium Ion Battery for HEV Application

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An 8Ah prismatic lithium ion cell with high current charge and discharge ability has been developed. Due to the safety and cost issues, the power type Li-ion cell was designed by using $LiMn_2O_4$ and carbon as cathode and anode materials, respectively. Specific power, discharge rate capability and safety performance of the battery is enhanced through the receipt of material system, electrodes design and new conducting mechanism for the cell structure. The internal resistance of the cell is lower than 2mΩ. The performance tests show the specific power of the new developed cell is over 2000W/kg at 80% SOC. For the rate capability characteristic at room temperature (25℃), the cell can be retained 93.6% of its initial capacity when discharge at 15C rate (120A). Safety tests including nail penetration, external short circuit and overcharge are investigated. The results show neither explosion nor fire under all safety test conditions. A 14.4V battery module including 4 cells in series and integrated battery management system (BMS) has been developed. The BMS is capable of monitoring cell condition (voltage, temperature and current), charge/discharge management and safety protection. 10 modules (40 cells) are connected in series to achieve a 144V battery system for HEV. The discharge power of this battery system is higher than 12.5kW at 50%SOC, which meets the requirements of HEV applications.

Keywords: Li-Ion Battery, Hybrid Electric Vehicles, Power Density, Battery Pack

1. INTRODUCTION

Due to oil crisis and environmental issue, Hybrid Electric Vehicle (HEV) became popular during past years. Comparing to traditional Internal Combustion Engine (ICE) vehicles, HEV has many advantages such as low emission, low fuel consuming and better performance. However battery system still plays an important role in HEV application. A high power, high current capability battery system is needed in HEV system. Traditional lead-acid battery cannot meet such requirements.

In the past 15 years, lithium ion battery was growing dramatically, and became widely used for portable electric product. It is known that lithium ion battery has superior energy and power density. Besides, the power and high current capability of lithium ion cell is also making great advancement. Lithium ion battery can be the best solution for HEV application.

Taiwan Government has devoted lots of efforts to improve the air quality in the metropolitan area since early 1970. The efforts include the implementation of the more stringent emission standard each stages, the enhancement of the motor-vehicle technologies, and the education of public environmental awareness. ITRI has also devoted its log-term technical commitment to advance its clean propulsion development to a cost-effective parallel hybrid propulsion system for the light-duty vehicle and a power assisted HEV for the SUV applications.

A previous work has been done for developing propulsion system is a full parallel hybrid electric 18kW power-train and consists of a 375cc lean burn engine and a 6kW motor with an 88.8V, 20Ah Li-ion battery system [1-3]. This is a national research project for HEV development from the support of Bureau of Energy, Ministry of Economic Affair in Taiwan. In the second phase of the project, ITRI has developed a power-assisted hybrid equipped with 100kW of the power and it consists of a 2.2L engine and an 18kW motor/generator with a high power battery system. This power plant has matched into the new-developed 2200kg of the t-car for 25% of fuel-economy improvement than the conventional engine power plant in FTP testing driving cycle [4].

In the new phase project, a commercial high power Ni-MH battery system (288V/8.5Ah) will firstly implant in the HEV system. In addition, a 288V/8Ah energy system consists of a 144V/8Ah high power Li-ion battery system and a high power bi-directional DC/DC converter is development in this project. In this study, an 8Ah prismatic lithium ion cell with high current charge and discharge ability has been developed. The targets of this project is to develop prismatic Li-ion single cells with specific power of 1500W/kg and to develop a 144V Li-ion battery system capable of 12.5kW discharge power at 50% SOC, which meets the

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requirements of mild HEV applications.

2. EXPERIMENTAL

In the positive electrode preparation, $LiMn_2O_4$ was mixed with PVdF (poly-vinylidenedifluoride) binder and carbon black in NMP (N-methyl-2-pyrolidione) solution. The slurry was then coated on aluminum foil to complete the electrode after drying and pressing. The negative electrode was prepared in the same process except using a graphite material as active material and using a copper foil as current collector.

The positive electrode and negative electrode together with a micro-porous PE separator were wound to a prismatic type roll, then assembled into an aluminum can and injected with electrolyte of 1M $LiPF_6$ in a mixture of carbonate solvent. To complete the cell preparation, the can and cap was sealed by laser welding after electrolyte filling. All cells were charged with small current for cell formation before test.

Due to the lower internal resistance, a new designed conducting mechanism was developed to replace the old electrode tab design.

The energy density, specific power, rate capability and cycle life were characterized for the designed cell.

The energy density was measured and calculated from 1C-rate discharge energy. For the specific power characterization, the cell was discharged to the desired SOC (State of Charge) and discharged with 18secs pulse current of 1.6A, 8A, and 24A. The specific power was than calculated from the voltage drop and discharge current.

For the rate capability, the cell was charged to 4.2V at 1C-rate, rest for 30 minutes, and discharged at different rates. The discharge rates used in this experiment were 1C, 5C, 8C, 12C and 15C.

Cycle life test for 60-80% SOC were carried out by charging and discharging the cell at the 1C rate under ambient temperature. Every 50 cycles, the cell was charged to 4.2V, and full capacity retention of the cell was measured between voltage 4.2V and 2.8V at the ambient temperature.

The safety tests include nail penetration, overcharge and external short circuit. The cell was charged to 100% SOC and rest for 1 hour before test. All safety tests were performed for single cells without any battery manage systems or electronic protection devices. The cell voltage, current (in short and overcharge test) and surface temperature was measured. For the nail penetration test, a 6 mm diameter metal nail was pierced at center of the cell. For the overcharge test, the cell was charge with 8A constant current and 12V voltage upper limit. For external short circuit, a 5 mΩ metal wire was used to connect the positive and negative terminals of the cell.

3. RESULT AND DISCUSSION

Fig. 1 shows the appearance of the cell, the capacity of the cell is 8Ah. Energy densities in weight and volume are 94.5Wh/kg and 190.2Wh/L, respectively.

Fig. 2 shows the discharge characteristics of 8Ah cell at different current rate of 1C, 8C, 12C and 15C. The discharge capacity ratio of 15C/1C rate is 93.67% with final temperature of 54℃. It can be concluded that the 8Ah $LiMn_2O_4$ cell has good performance at high current discharge condition. In a 144V system, 15C-rate (120A) discharge current could achieve ca. 17.3 kW of power output, which meets the target of this project.

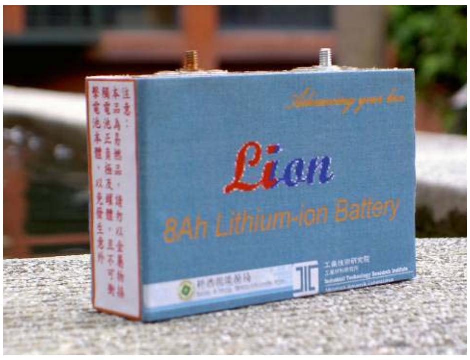

Fig. 1 Appearance of 8Ah Lithium-ion cell

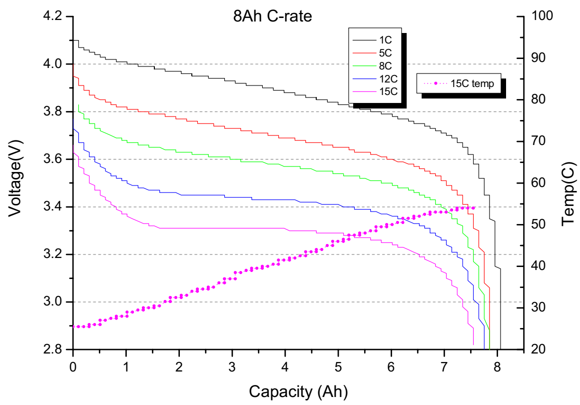

Fig. 2 Different C-rate discharge capability of 8Ah Lithium-ion cell (cell charged with 1C rate at all test condition)

The characteristic of specific power was shown in Fig. 3. It can be found that specific power increase when increasing the cell SOC. The specific power can be reached to 2062W/kg and 1614W/kg at 80% SOC and 20% SOC, respectively. This result meets with the target of 1500W/kg, even at low SOC.

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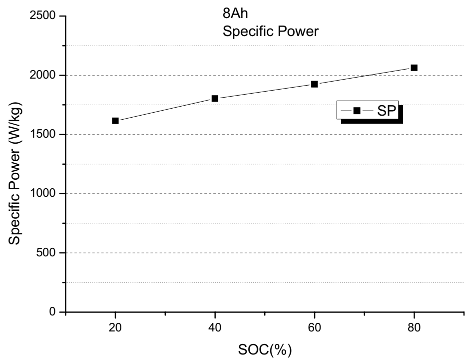

Fig. 3 Specific power characteristic of 8Ah Lithium-ion cell

According to the requirement of the battery system operated in HEV, the 60%-80% SOC cycle life performance of the cell with 1C rate charge/discharge at ambient temperature is test and the result shown in Fig. 4. The result shows the cell capacity retained 85% (compare to the initial capacity) after 4000 cycles. In our development project, the vehicle system has defined the battery system should operate at 60-80% SOC for charge and discharge. After the recently review meeting, the battery operation condition has been change to test at 50-70% SOC [4]. The cycle life of the battery relating to the driving mileage still under evaluation, in this study, the cycle life test results in the single cell level only for the data collection.

As we know that the cycle life of $LiMn_2O_4$ cathode is strongly affected by operating temperature due its instability structure at high temperature. In this study, it has also found that when the cell charge and discharge both with 1C rate at 55℃ and at 60-80% SOC condition, the capacity is faded to 80% retention after 500 cycles. The result shows that the $LiMn_2O_4$ cathode material need to improve its high temperature performance.

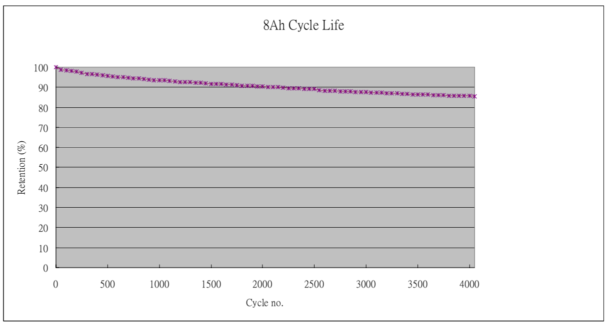

Fig. 4 Cycle life characteristic of 8Ah Lithium-ion cell (charge and discharge at 60%-80% SOC)

Safety tests including nail penetration, external short circuit and overcharge was performed to verify the safety characteristics of the 8Ah cell. Test condition and results of safety test are summarized in Table 1.

In nail penetration and overcharge tests, the safety vent was opened after test. All the safety test results show neither fire nor explosion.

Table 1 Safety test method and result of 8Ah lithium-ion cell

Test Item	Test Method	Test Result
Nail penetration	To penetrate a stainless steel nail with diameter of 6mm through center of cell. The speed was ca. 50mm/sec.	Vent. No explosion No fire Max. temp 115℃
External short circuit	To short circuit between positive and negative terminals through an external circuit. The resistance of the ciruit is 5 m Ohm.	No explosion No fire Max. temp 120℃
Overcharge	To charge the cell with 1C-rate (8A) constant current and 12V voltage upper limit.	Vent. No explosion No fire Max. temp 120℃

A 14.4V battery module including 4 cells connected in series and integrated battery management system (BMS) has been developed. Fig. 5 shows the appearance of the 14.4V battery module. The BMS is capable of monitoring cell condition (voltage, temperature and current), charge/discharge management and safety protection. The detail of the BMS technology development has been reported [5].

Fig. 5 Appearance of 14.4V Lithium-ion battery module

10 modules (40 cells) are connected in series to achieve a 144V battery energy system for HEV. Fig. 6 shows the appearance of the 144V energy system. The discharge power of this battery system is higher than 12.5kW at 50%SOC, which meets the requirements of HEV applications.

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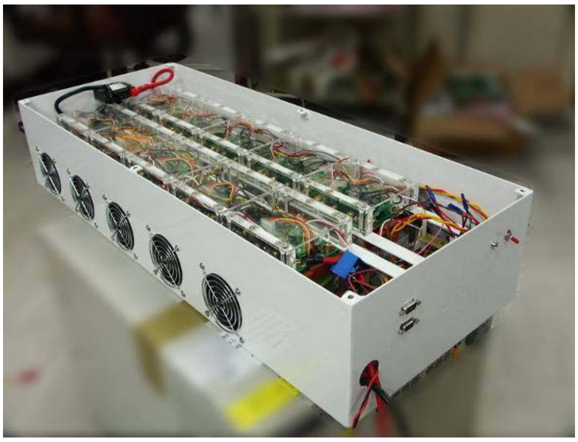

Fig. 6 Appearance of 144V Lithium-ion battery energy system

4. CONCLUSION

In this study, an 8Ah $LiMn_2O_4$ battery was developed by material and cell design. The results of 8Ah $LiMn_2O_4$ battery test shown the specific power can be over 2062W/kg at 80% SOC, the cycle life can be over 4000 times (85% capacity retention at 60-80%SOC). The safety test shows neither fire nor explosion. The further work will continue to improve the battery module and system performance by developing an advance battery management system for HEV application, and plan to commercialize the 8Ah $LiMn_2O_4$ cell for HEV application.

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BIOGRAPHIES

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