

The New High Power Design of 8Ah Li-ion Battery for HEV Application

Mo-Hua Yang*, Bing-Ming Lin*, Sheng-Fa Yeh*, and Jia-Shiuan Tsai*

Researchers at The Industrial Technology Research Institute (ITRI) have developed a new 8Ah prismatic lithium battery cell with high current charge and discharge capability for use in hybrid electric systems applications. When 40 cells are combined in series, the system is capable of producing 144V which can be boosted up to 288V by using a high power DC-DC converter. The design results in (1) lower manufacturing and operating costs, (2) improved safety characteristics, (3) improved heat dissipation, and (4) improved battery management.

Particular emphasis have been given to enhancing both discharge and charge performance of the cell by optimizing material selection and structure to lower the internal resistance of the system, thereby improving both performance and safety characteristics for the single cell. By carefully tuning the design of both electrodes, this second generation cell can provide 300A of continuous discharge current while maintaining the ability to meet the minimum requirement for pulse power characteristics. This provides 625W of discharge power and the ability to accept 500W of regenerative power when the system is operated with the State of Charge (SoC) between 50 and 70%. The cell has also been designed to meet the abusive physical requirements associated with hybrid vehicle applications.

This paper highlights system requirements, describes the research and development process, and provides experimental test results for the 8Ah cell. The battery module design is also described.

Keywords: Lithium Ion Battery, Hybrid Electric Vehicle, High Power

1. INTRODUCTION

Due to the oil crisis and environmental issues, Hybrid Electric Vehicles (HEV's) have become popular during the past few years. Compared to traditional Internal Combustion Engine (ICE) vehicles, HEV's have many advantages such as low emission, low fuel consumption, and better performance. However the battery system still plays an important role in HEV applications. A high power, high current charge/discharge capability battery system is needed for improved performance of HEV's. Traditional lead-acid battery cannot meet these requirements.

Since 1991, the lithium ion battery has gained market share and has become widely used for portable electric products. In addition, the power and high current capability of lithium ion cell have increased dramatically, making lithium ion batteries an attractive alternative to lead-acid batteries for HEV applications.

A new 8Ah prismatic lithium ion battery with high current charge and discharge capability has been developed in our research institute (ITRI). This is a research project of HEV development sponsored by the Bureau of Energy (BOE), Ministry of Economic Affairs (MOEA) in Taiwan. The target is to develop a 288V Li-ion battery system for HEV applications.

In a previous studies [1,2,3], the 1st generation 8Ah cell achieved discharge capability of 15C-rate with 93.7% of capacity retention and specific power of 2062 W/kg at 80% SoC. However, the capability of recharge (or regeneration) was found to be comparably unacceptable for HEV applications. The 2nd generation cell was designed to meet both the discharge and regeneration requirement for HEV applications. The test procedures from the Freedom CAR [4] program were used to evaluate performance of the 2nd generation cell.

2. EXPERIMENTAL

2.1 Cell Design

2.1.1 SYSTEM REQUIREMENTS

The battery system is composed of a 144V battery

*Material and Chemical Research Laboratories, Industrial Technology Research Institute, Room 260-4, Building 77, Number 195, Section 4
Chung Hsing Road, Chutung 310, Hsinchu, Taiwan
Phone: 886-3-5915234
Fax: 886-3-5820039

pack and a two-way DC transformer to boost pack voltage from 144V up to 288V. The system requires 34 kW output and 21 kW input at 50% SoC, which implies that a single cell should be capable of delivering 850W for 10 seconds and absorbing 525W for 10 seconds.

2.1.2 PRISMATIC CELL DESIGN

From system requirements, the cell needs to bear current over 236A for 10 seconds. Therefore, a formed metal device (aluminum for cathode and copper for anode), riveted with electrode current collectors, and press fitted with terminals was designed to have a high conducting cross section area. Two “jelly rolls” in parallel were stacked together to reduce the thickness in order to improve heat dissipation by minimizing the path for heat transfer. The cell dimensions were 112mm x 69mm x 37mm and the weight was approximately 600g.

2.1.3 PREPARATION OF CELLS

In the electrode preparation, active material was mixed with binder and solvent. The slurry was then coated on substrate to complete the electrode. Pure LiMn_2O_4 material and mixed material of $\text{LiMn}_{2/3}\text{O}_4 + \text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$ were used as active materials of the positive electrode. The active material for the negative electrode was hard carbon. The electrodes and micro-porous separator were wound into “jelly rolls”, assembled with conducting devices, and put into an aluminum can with the electrolyte. All cells were charged with a small current for cell formation before test.

2.2 Cell Characterization

After formation, basic characteristics including ACIR, DCIR, capacity, energy density and specific power were characterized. For DCIR and specific power characterization, the cell was charged to the desired SoC and then discharged with 18 second current pulses at rates of 1C, 3C, and 5C.

For high rate discharge testing, the cell was charged to 100% SoC and rested for 1 hour, then discharged with 300A continuous current until the cell voltage reached 2.8V. During high rate continuous discharge, the temperature rise of the cells was also measured.

For rapid charge testing, the cell was discharged to 0% SoC and rested for 1 hour, then charged with 40A constant current until the cell voltage reached 4.2V. The charged capacity were measured and compared.

For HPPC (hybrid pulse power characterization)

testing, the Freedom CAR Low Current HPPC test of 5C-rate profile [4] was used. The cell was discharged to the desired Depth of Discharge (DoD), rested for 1 hour, and then the HPPC profile was conducted beginning as follows: (1)10 seconds of pulse discharge at 5C-rate, (2) rested for 40 seconds, (3)10 seconds pulse regeneration at 3.75C-rate. The full test was made up of single repetitions of the profile, separated by 10% DoD, from 10% DoD to 90% DoD. After full HPPC testing, the discharge and regeneration power capabilities were defined and plotted from the voltage and resistance characteristics.

For cycle life testing, fully cycles were conducted between 0 and 100% SoC (2.8V-4.2V) at 1C-rate charging and 3C rate discharging at the elevated temperature of 55°C. The DCIR of the cells were measured every 50 cycles.

For hybrid (pulse) cycle life testing, the Freedom CAR baseline of minimum Power-Assist (25Wh) cycle life test profile [4] was used. The test profile is: (1)20 seconds discharge at 3kW, (2)2 seconds discharge at 15kW, (3)66 seconds charge at 1.15kW, (4) 2 seconds charge at 12kW. In this study, the SoC of the cell was controlled at 50% and proper battery size factor (BSF) was selected. The full discharge capacity and HPPC test were performed every 5,000 or 10,000 cycles.

For abuse overcharge testing, The cell was charged to 100% SOC before the overcharge test. Then, the cell was charged with 1C-rate (8A) constant current and 5V voltage upper limit.

3. RESULTS AND DISCUSSION

3.1 Basic Characteristic of the Cells



Figure 1: Appearance of lithium ion cell

	Pure cathode cell (LiMn_2O_4)	Mixed cathode cell ($\text{LiMn}_2\text{O}_4 + \text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$)
Dimension	L 112mm x H 69mm x W 37mm	
Weight (g)	597	598
ACIR (mOhm)	1.05	1.36
DCIR @ 80% SOC (mOhm)	1.88	2.06
Capacity (Ah)	7.29	8.24
Specific Energy (Wh/kg)	48	56
Specific Power @ 80% SOC (W/kg)	2187	2044

Table 1: Basic characteristics of the cells

Figure 1 shows the appearance of the cell. Table 1 shows the basic characteristics of two cells with different cathode materials. The appearance and conducting mechanisms were identical. The differences were the active materials and design of the electrode plates.

In the pure cathode cell, a very low internal resistance and high power performance cell was achieved. However, the capacity was lower than the target of 8Ah. In order to increase the capacity and energy density, a mixed cathode was adopted. With the same dimensions, weight and cell structural design, the capacity and energy density were improved by 13% and 17%, respectively. The internal resistance of the mixed cathode cell was slightly higher than pure cathode cell, and resulted in lower specific power.

3.2 High Rate Discharge Test

In the previous study, the 1st generation cell could achieve a 15C (120A) continuous discharge rate. In this study, a much higher discharge current of 300A

was tested. Figure 2 shows 300A continuous discharge characteristics of pure cathode and mixed cathode cells. The pure cathode cell achieved 80% capacity retention at 300A discharge test with a temperature increase of 42°C. It is well known that the LiMn_2O_4 active material could achieve high discharge and power capability. With optimized mixing ratio, recipe and electrode design, the mixed cathode cell delivered 78.8% capacity retention with a temperature increase of only 23.5°C.

3.3 Rapid Charge Test

In HEV applications, a rapid charge capability for the battery system is required. Figure 3 shows 40A continuous charge characteristics. The pure cathode cell and mixed cathode cell can be charged up to 68.6% and 70.5% of rated capacity, respectively, under 40A rapid constant current charge to 4.2V.

3.4 HPPC Test

The HPPC test is intended to determine dynamic

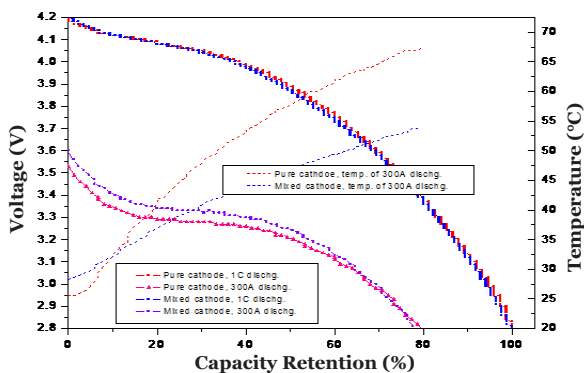


Figure 2: Characteristics of 300A continuous discharge

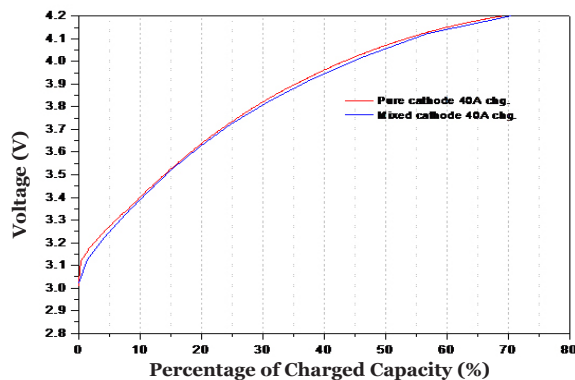


Figure 3: Characteristics of 40A continuous charge

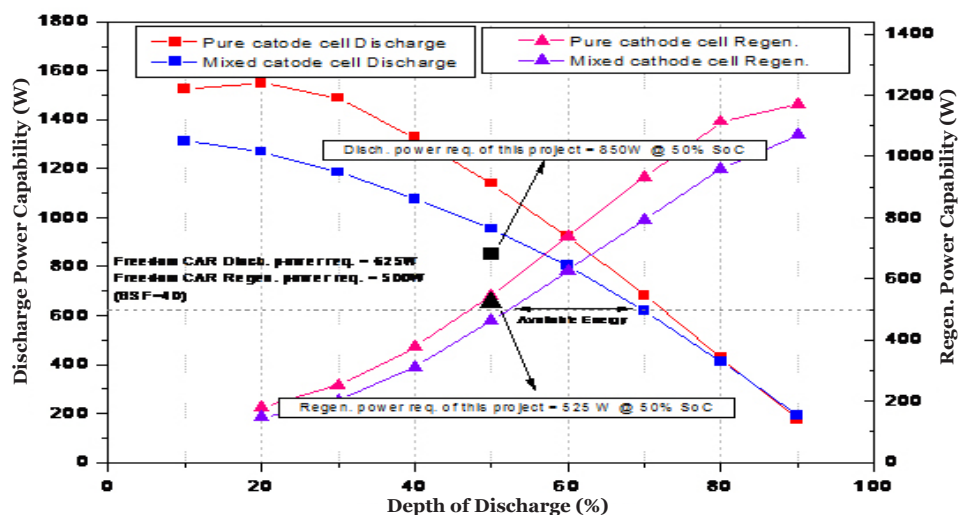


Figure 4: Result of HPPC test

power capability over the device's useable charge and voltage range using a test profile that incorporates both discharge and regeneration pulses at various depth of discharge levels [4]. The minimum power-assist of pulse discharge power (10 sec) and peak regenerative pulse power (10 sec) defined in the Freedom CAR Energy System Goals are 25kW and 20kW, respectively. HPPC test results will indicate whether or no the battery system can meet this Freedom CAR goal.

Figure 4 shows HPPC test results of pure and mixed cathode cells. The battery system requirement of this study (34 kW/21kW at 50% SoC, 10 seconds) could break down to 850W/525W for a single cell. The pure cathode cell had 1141W and 546W for discharge and regeneration power capability, respectively, and

therefore meets the system requirements of this project. The mixed cathode cell had 955W and 463W for discharge and regeneration capability. Regeneration capability of the mixed cathode cell was lower than the system requirement.

With Battery Size Factor (BSF) =40, Freedom Car's requirement for the system (25kW/20kW) to 625W/500W for a single cell. The pure cathode cell had to attain a working region between 47% and 72% DoD in order to meet the pulse power capability requirement. Due to higher internal resistance, the working region was narrowed to 52%-70% DoD in the mixed cathode cell, but was still found to be capable of meeting the minimum power-assist requirements established as goals for the Freedom CAR.

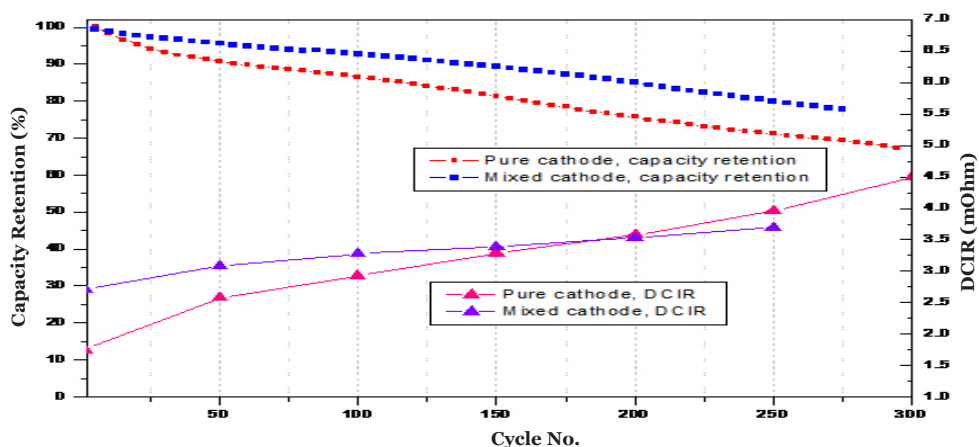


Figure 5: Result of 1C-3C full cycle test at elevated temperature of 55 °C

	Pure cathode cell	Mixed cathode cell
Capacity retention after 5,000 cycles (%)	97.1	N/A
Capacity retention after 10,000 cycles (%)	95.9	98.7
Capacity retention after 20,000 cycles (%)	N/A	97.8
Capacity retention after 30,000 cycles (%)	N/A	97.2

Table 2: Result of hybrid cycle life test

3.5 Cycle Life Test

A high stress cycle life testing method was used in this study. As expected, lithium ion cells deteriorate rapidly when fully discharged at rate of 3C at 55°C. Figure 5 shows the result of cycle life testing. Capacity retention of the pure cathode cell decayed to 80% after 160 cycles. The mixed cathode cell showed better cycle performance as 250 cycles before capacity retention decayed to 80%. DCIR of the pure cathode cell also showed higher increasing rate than the mixed cathode cell.

Table 2 shows the result of hybrid (pulse) cycle life testing. Capacity retention of the pure cathode cell decayed to 95.9% after 10,000 cycles, while the mixed cathode cell remained 98.7%. After 30,000 cycles, capacity retention of the mixed cathode cell still remained at 97.2%. Further cycle life characteristic of

mixed cell is under investigation.

3.6 Abuse Test

For $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$ cathode material system, the safety characteristic would be an issue compared to the LiMn_2O_4 system. Overcharge testing of the mixed cathode cell was performed to identify safety characteristics. Internal short and rapid temperature increases were observed during overcharge testing. The maximum temperature was 132°C. The cell did not catch fire or explode. Further safety characterization of the mixed cell is under investigation.

4. CONCLUSIONS

In this study, new prismatic HEV lithium ion cells were developed. By combining (1) new conducting mechanism, (2) optimized recipe of electrode composition and (3) new design of electrode plate, a new LiMn_2O_4 lithium ion cell was developed with 300A continuous discharge and 40A rapid charge capabilities. The pure cathode cell also met the system requirement of this project (discharge capability 34kW/ regenerative capability 21kW) and Freedom CAR minimum power-assist goals (discharge capability 25kW/ regenerative capability 20kW) with BSF=40.

In order to enhance the capacity, energy density, and cycle life, a mixed cathode material of LiMn_2O_4 with $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$ was used. Using the same container and conducting mechanism, capacity and energy density of the cell was increased by 13% and 17%, respectively. Due to the optimized mixing recipe and design of the electrode plate, high current discharge and rapid charge capabilities of the mixed cathode cell was found to be comparable to the pure cathode cell. Cycle life was also enhanced. However, due to the higher internal resistance of the mixed cathode cell, the pulse power and HPPC capability were compromised, resulting in a slightly inadequate regeneration power capability. Further study and improvement of the mixed cathode cell is under development.

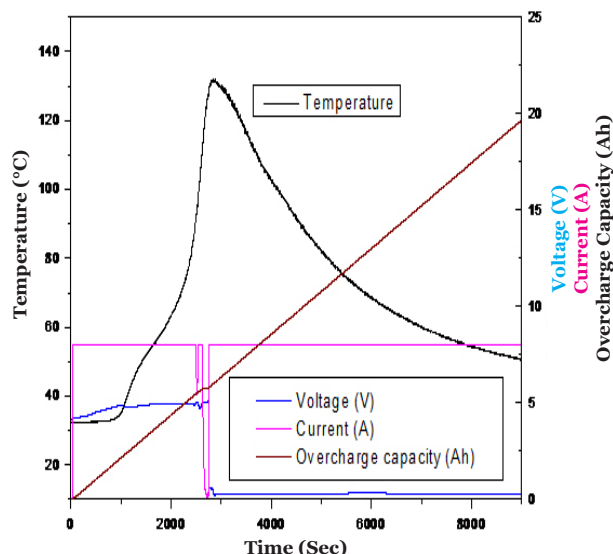


Figure 6: Overcharge test result of mixed cathode cell

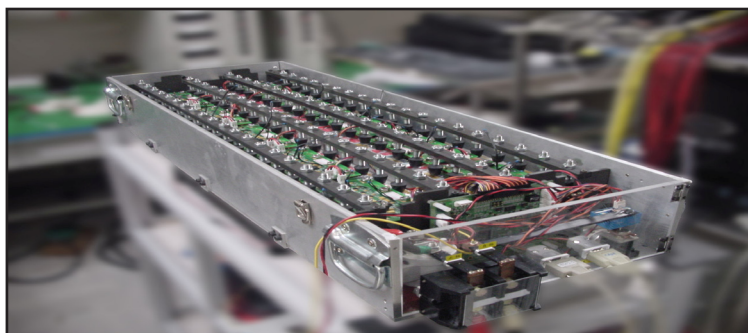


Figure 7: Appearance of 144V battery energy system for HEV

Forty cells were connected in series to achieve a 144V battery energy system for HEV applications. Figure 7 shows the appearance of the 144V energy system. The battery system was installed on a prototype HEV and vehicle tests were conducted. During the preliminary vehicle test, engine cranking and pure electric driving for short range were successfully achieved. Further loading test will be held by the end of this year.

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AUTHORS



Mo-Hua Yang, Ph.D., Senior Researcher, Industrial Technology Research Institute, Material and Chemical Research Laboratories, mhyang@itri.org.tw. Dr. M.H. Yang received his Ph.D. degree from the Catholic University of Louvain in Belgium. He has worked at Industrial Technology

Research Institute (ITRI) on Li-ion battery project since 1997. He is now the project manager of Li-ion development project in MCL, ITRI.



Bing-Ming Lin, Research Supervisor, Industrial Technology Research Institute, phone: 886-3-5914148, fax: 886-3-5820039, BMLin@itri.org.tw. B.M. Lin received his Bachelor's degree from Chung Yuan University in mechanical engineering. He has worked at Industrial Technology

Research Institute for more than twenty years and is now the manager of EV Battery Development Project Department of MCL, ITRI.



Sheng-Fa Yeh, Researcher, Industrial Technology Research Institute, phone: 886-3-5913116, fax: 886-3-5820039, skyfar@itri.org.tw. S.F. Yeh received his M.S. degree from Tamkang University, Taiwan. He has worked at Industrial Technology Research Institute since 2000.

He has expertise in rheology, Li-ion battery design/manufacture, and battery active material system.



Jia-Shiuan Tsai, Associated Researcher, Industrial Technology Research Institute, phone: 886-3-5918216, fax: 886-3-5820039, jiashiuan_tsai@itri.org.tw. J.S. Tsai received his M.S. degree from National Tsing-Hua University, Taiwan. He

has worked at Industrial Technology Research Institute since 2002. He has expertise in electrical chemistry, Li-ion battery design/manufacture, and safety property of batteries.