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# A large-format lithium-ion battery with heat-dissipation design

Sheng-Fa Yeh, Deng-Tswen Shieh, Chun-Jui Hung, Li-Lun Liu, Shu-Ping Lin, Bing-Ming Lin

*MCL, ITRI / 195, Sec. 4, Chung Hsing Rd., Chutung, Hsinchu, Taiwan*
*skyfar@itri.org.tw , DTShieh@itri.org.tw, joary@itri.org.tw, lionerliu@itri.org.tw, Ping-Apple@itri.org.tw, BMLin@itri.org.tw*

## Abstract

In this study, a 40Ah cell with heat-dissipation design is demonstrated with excellent electrochemical, safety and reliability performances. The cell shows a high specific energy of 126Wh/kg and high specific power of 1147W/kg, it can be continuously discharged by 200 Amps current with an acceptable maximum temperature rising to 50℃. The cell has a special heat-dissipation design inside cell, which enhances heat dissipation from the electrodes to electrical terminals. The function of heat dissipation design in cell is proved by discharging the cell under adiabatic and natural convection environments. It can be more efficient combined with water cooling connections at electrical terminals. Besides, the cell shows excellent safety and reliability performances under overcharge, force discharge, external short-circuit, force discharge, nail penetration, crush, vibration, mechanical shock, temperature cycling and high temperature endurance tests following IEC 62660-2 test methods.

*Keywords: Safety, Reliability, Heat-dissipation, Large-format, Lithium-ion battery, STOBA*

## 1. Introduction

Due to global warming issue, electric vehicles are considered to replace traditional ICe vehicles for reducing $CO_2$ emission. Large-format lithium-ion batteries are attracting many attentions in the application of EVs due to easier system management compared to the small ones. However, large cells have more concerns on the safety and thermal behaviors due to higher capacity and temperature gradient insides. A more uniformed temperature distribution inside the cell will be preferable.

As the capacity and dimension become larger, more heat is generated and difficult to dissipate to outside. Higher temperature built-up in cell causes more safety and cyclability issues.

In order to get uniform temperature distribution in cell, a thinner stacking or jelly roll design is preferable. However, thinner cell needs larger electrodes area to meet capacity requirement and hence sacrifice the stiffness of cell, besides, swelling of lateral becomes another issue. Therefore,, to compromise between capacity requirement and thermal stability is a key issue in cell design. The normal heat transfer route in cell is through electrodes, separators to the casing of cell. Separator behaves a quite low thermal conductivity due to its porous polymer structure and is the bottleneck. In order to compensate the inefficient heat transfer through separator, current collector which has good thermal conductivity must be utilized and enhanced as major heat dissipation agent. A large format lithium-ion battery with heat-dissipation design is demonstrated in this article. Its special design is aiming to transfer cell inside heat from the middle to electrical terminals and removed by water cooling system. In order to ensure the safety and reliability performances of the large cell, unique STOBA (Self Terminated Olygomers with hyper-branched Architecture) technology is adopted in this cell.

## 2. Designs of heat-dissipation cell

Lithium-ion battery is mainly composed by multi-layers of cathode/separator/anode, conducting mechanism and case. During operation, heat is generated inside the cell and transferring from center to case. In order to have better temperature distribution inside cell, the thickness of stackings or layers is the thinner the better; it’s the same philosophy on either metal can or soft-pack cell design. Besides, large area soft-pack cell has more latent damage issue during module assembly process which is difficult to be investigated.

The main heat-transfer route is through electrodes, separator and to case in normal cell. The thermal conductivity of separator is quite low due to their porous polymer structure and it blocks the heat transfer to outside. In spite of the poor heat transfer by separator, the current collectors of electrodes are metal which have high thermal conductivity should be utilized. If the heat dissipation route from current collectors to electrical terminals can be enhanced, the generated heat can be more effectively dissipated out. In this article we demonstrate a 40Ah lithium-ion cell with heat-dissipation design inside by transferring heat from current collector to electrical terminals, which also behaves excellent electrochemical, safety and reliability performances.

## 3. Electrochemical performances

The appearance of the prismatic cell with aluminum case is shown in Fig.1. Its oval shape has two terminals located on both end surfaces. Two opposite-direction terminals are designed for efficient electrical and thermal conductivity. The dimension of cell is 185mm × 90mm × 37mm. Cathode material is Li(NiMnCo)$O_2$ blended with $LiMn_2O_4$, anode material is carbon and separator is polyolefin (PP/PE/PP). In order to improve the safety performance of cells, a unique technology of STOBA additive is adopted.

Fig. 1 The appearance of 40Ah cell

The cell has nominal capacity of 40Ah and specific energy of 126 Wh/kg with good discharge capability to be used in EV or PHEV application as shown in Fig. 2, it can be continuously discharged at 200 Amps current with more than 93% capacity retention (5C/0.2C) and the maximum temperature is less than 50℃. The cell can be even discharged continuously by 320 Amps (8C) with 87% capacity retention. However, under such heavy load condition the cell temperature will rise to 60℃, which is not recommended in normal operation. Fig. 3 shows the specific power and DCIR performances of the cell. It can deliver 1200W/kg specific power by 18s pulse discharge and 1.7mΩ DCIR by 1.5s pulse discharge at 100% SOC.

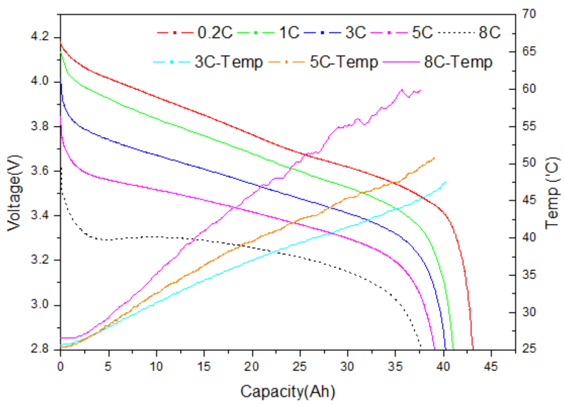



Fig. 2 High rate discharge performance of 40Ah cell (0.2C, 1C, 3C, 5C and 8C discharge rate within 4.2V and 2.8V).

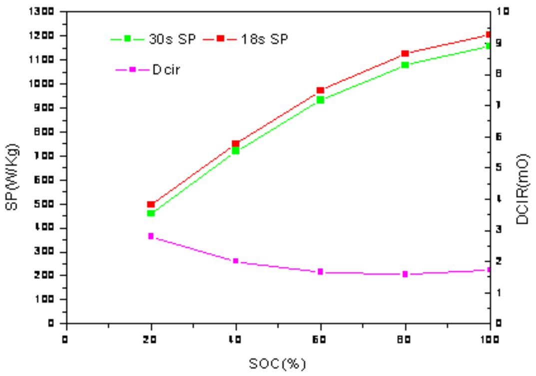
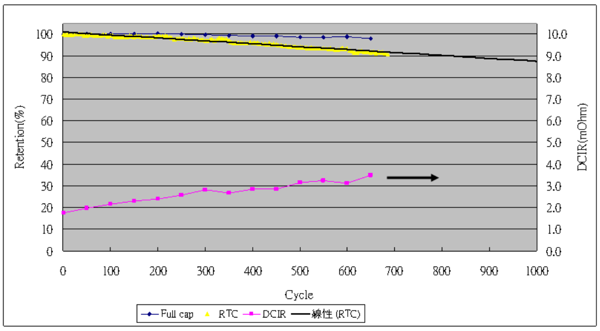
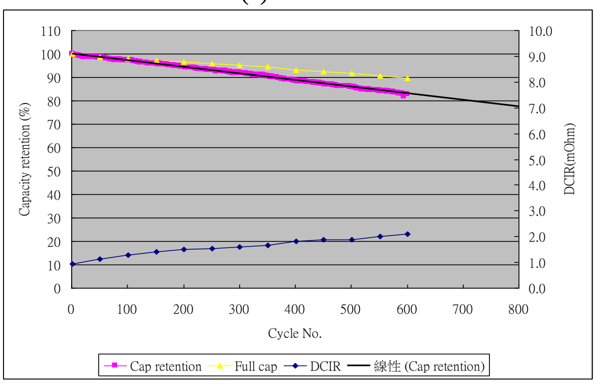



Fig.3 Specific power and DCIR performances of 40Ah cell. (18s/30s discharge for SP; 1.5s for DCIR)

Regarding cyclability, Fig. 4 shows the cycle performance of cell at room temperature and 45℃, respectively. The cells are cycled by 40 Amp current charge and discharge between 4V and 3V. Under room temperature, the cell capacity faded slightly within 600 cycles and is expected to have more than 1000 cycles with more than 80% capacity retention. Under high temperature of 45 ℃, the cell is expected to deliver 700 cycles with 80% capacity retention. Table 1 shows specification of the 40Ah cell.




(a) RTC




(b) HTC (45℃)

Fig. 4 Cycle life tests of 40 Ah cell (40A charge/ discharge between 4~3V) (a) RT, (b) 45℃.

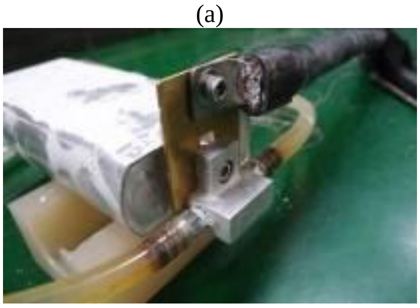
Table 1 Specification of 40Ah cell

| | |
|---|---|
| Dimension H x W x T (mm) | 185 x 90 x 37 |
| Weight (g) | 1275 |
| Capacity (Ah) | > 40 |
| Specific energy (Wh/kg) | 126 |
| Specific power (W/kg)-30s discharge | 1147 |
| Max. continuous discharge current (A) | 200 |

# 4. Heat dissipation effect

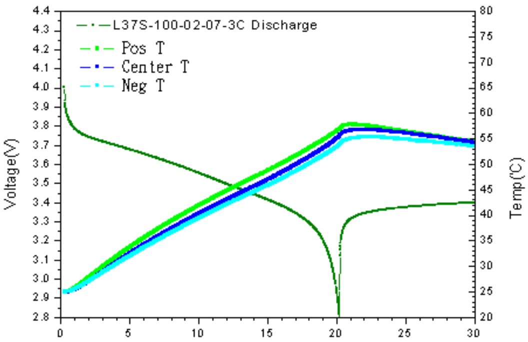
In order to verify the heat dissipation effect, electrical terminals with water cooling connections is compared with those without water cooling connections as shown in Fig. 5. The cell is continuously discharged at 120 Amps (3C) current in adiabatic and natural convection environments respectively. As shown in Fig. 6, the cell temperature rises to 57℃ with normal connections but only 45℃ with water cooling connections in adiabatic environment. It shows the generated heat inside cell can be effectively dissipated outside by the unique conducting mechanism design. Fig. 7 shows the temperature rising of cell discharged at 120 Amps (3C) with the normal and water cooling connections in natural convection environment. The cell temperature rises to 47.4℃ and 43.1℃ under normal and water cooling connections respectively. Generally, heat can be dissipated out by can surface and electrical terminals, the area of can surface is ca. 50 times larger than that of terminals, however, the small area of terminals may play an obvious and important role on heat dissipation with propriate cooling design. In adiabatic environment, the dissipation route is limited and the heat can be dissipated effectively by the assistance of water cooling connections (temperature difference between two cases is 12 ℃). Under natural convection environment, the generated heat can be dissipated by can surface due to its large surface area (ca. 10℃ difference between natural convection and adiabatic environment when without water cooling connections). Even in natural convection environment, the water cooling connections can further reduce the temperature of 3.3℃. It is evident that the heat-dissipation design in this cell is effective.

(a)

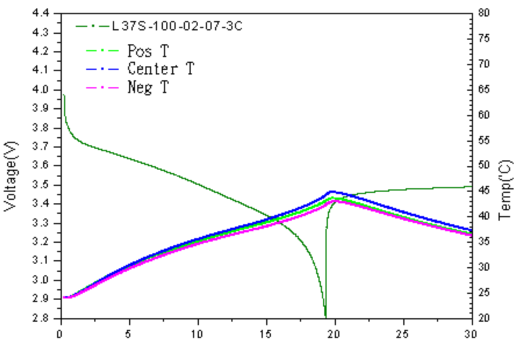


(b)

Fig. 5 The appearances of (a) normal and (b) water cooling connections

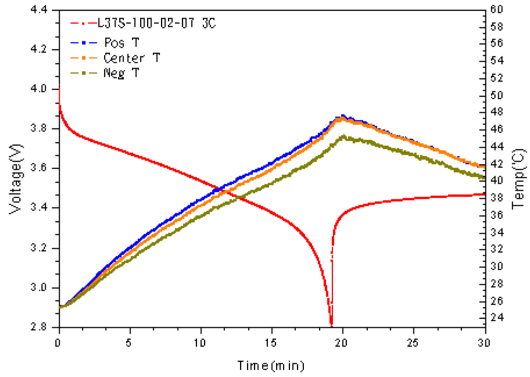



(a)

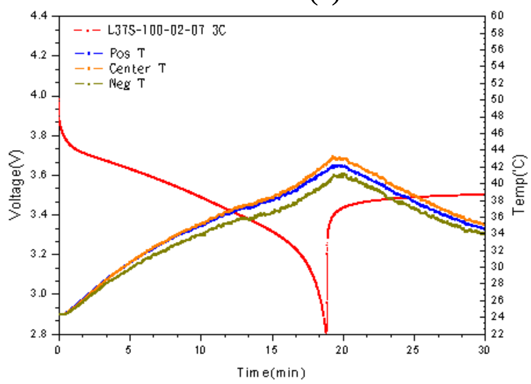



(b)

Fig. 6 The temperature response when discharged at 120A (3C) in adiabatic environment having (a) normal or (b) water cooling connections




(a)




(b)

Fig. 7 The temperature response when discharged at 120A (3C) in natural convection environment having (a) normal or (b) water cooling connections

# 5. Safety and reliability performances

For large format lithium ion battery, safety and reliability performances are the most important index. In order to get good safety characteristics, a novel additive STOBA technology is adopted. STOBA is a nano-grade high-molecular material which is added to a lithium battery to form a protection layer on the surface of the active material. When a lithium battery experiences overheating or puncturing, STOBA instantly suppresses thermal runaway and prevent battery from explosion caused by internal short-circuit. Regarding the reliability characteristics, the cell is also verified by test bench to see if the electrical and mechanical connections are reliable or not.

The safety and reliability tests are following IEC 62660-2 and UNT38.3 standard. Fig. 8 shows the 40Ah cell is overcharged by 1C current till 8.4V. The result shows the cell is free from explosion or fire with only slight venting and leakage and a maximum temperature rising around 119℃ on the surface.

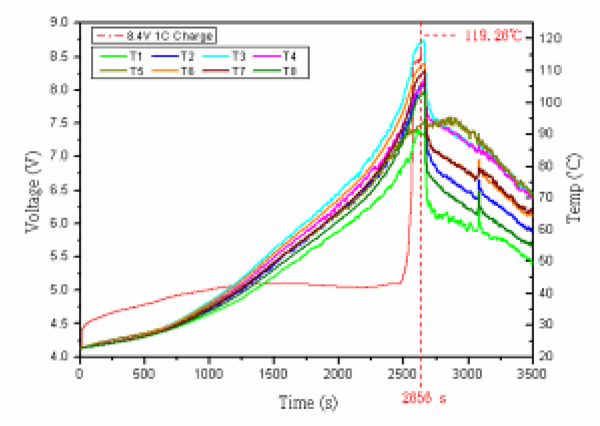



Fig. 8 Overcharge test for
40Ah cell @ 100% SOC, 1C/8.4V

Fig. 9 shows force discharge test for the 40Ah cell. The fully discharged cell is further drew by 40Amp current for 90min. Maximum temperature rising is less than 70℃, the cell doesn't get fire or explosion. Fig. 10 shows the cell under external short-circuit test, the cell doesn't get fire or explosion, maximum temperature of cell is around 110℃ and short current is around 900 Amps for 150 seconds.

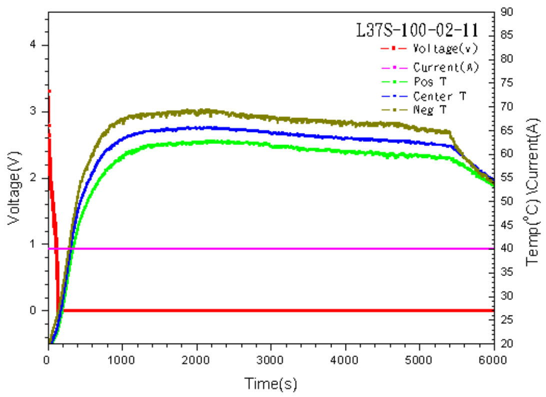



Fig. 9 Force discharge test for 40Ah cell @ 0% SOC

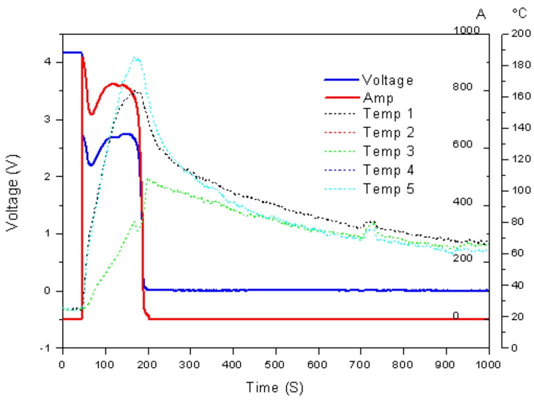
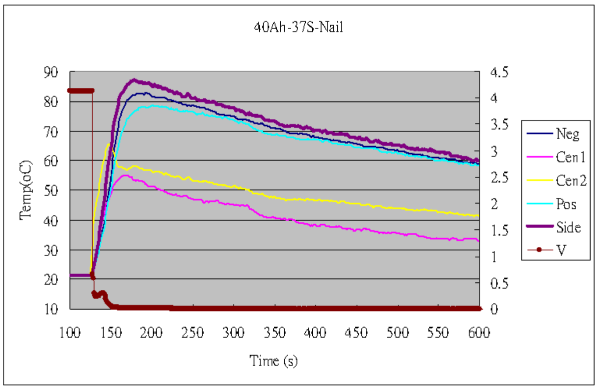



Fig. 10 External short-circuit test for 40Ah cell @ 100% SOC. (T1, T5 electrical terminals, T2~T4: cell)

Fig. 11 shows the results of nail penetration by 5mm OD nail and 110mm/s speed. The full charged cell get no explosion and the maximum temperature is less than 90 ℃ . Regarding mechanical reliability, the 40Ah cell behaves also save under crush, mechanical shock and vibration tests following IEC 62660-2 and UNT 38.3 test methods, as shown in Fig. 12~14. During crush test, the semi-sphere steel head presses the cell at 0.1mm/s slow speed until the deformation reaches 15% depth or loading reaches 1000 times of cell weight or cell voltage drops over 1/3 OCV. The cell behaves save without any voltage drop, temperature rising, fire or explosion until the test is stopped by reaching loading limit. As to the vibration and mechanical shock tests, the cell behaves also very stable showing no voltage drop or physical change after tests.

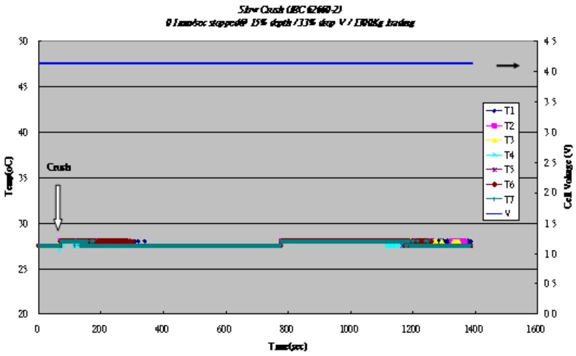
(a)




(b)

Fig. 11 (a) Picture and (b) T-V responses during nail penetration test. (5mm OD nail, 110 mm/s speed, cell at 100% SOC).

(a)




(b)

Fig. 12 (a) Pictures and (b) T-V responses of 40Ah cell @ 100% SOC during crush test.
(0.1 mm/s speed to crush cell till 1/3 OCV drop or 15% deformation or 1000 times cell weight load)

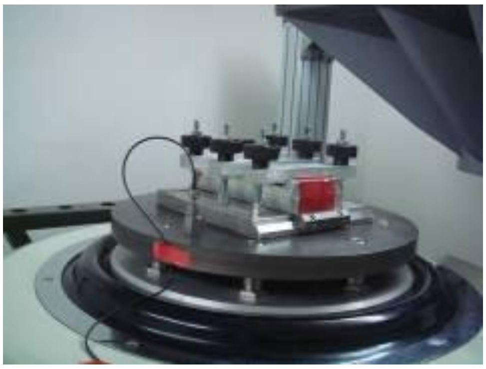


Fig. 13 Vibration test (UN38.3)

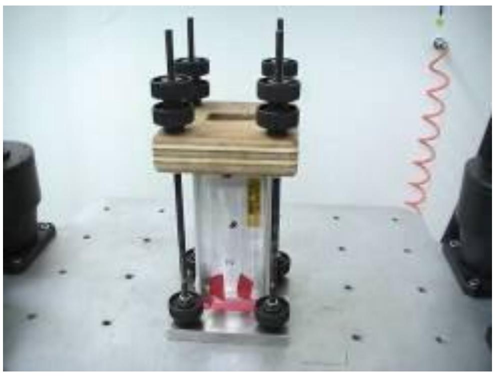


Fig. 14 Mechanical shock test (UN38.3)

As to the thermal stability including high temperature endurance and temperature cycling tests, a fully charged cell is thermal cycled between 65 ℃ and -20 ℃ for 30 cycles (temperature cycling, IEC 62660-2), the cell doesn't show any obvious physical change after test. Fig. 15 shows the result of temperature endurance test also following IEC 62660-2 test method. There is no voltage drop and any physical change observed on cell when heated up to 130℃ and stayed for 30 minutes.

The safety and reliability test results are listed in Table 2, which shows the 40Ah cell behaves excellent safety and reliability performances.

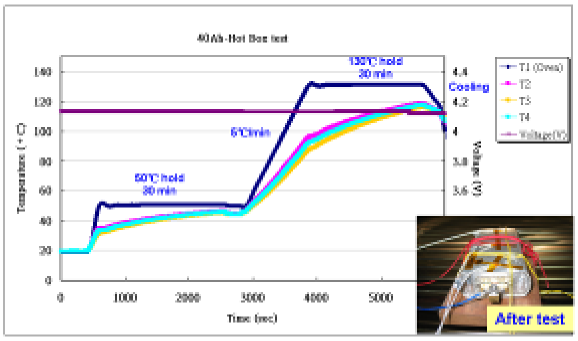



Fig. 15 Hot box test of 40Ah cell @ 100% SOC (5℃/min to 130℃ and stay for 30 min)

Table 2 Safety and reliability tests of 40 Ah cell

| Test | Condition | Result |
|---|---|---|
| Overcharge | 1C/8.4V (IEC 62660-2) | PASS |
| Force discharge | 1C/90 min (IEC 62660-2) | PASS |
| External short | < 5 mOhm (IEC 62660-2) | PASS |
| Nail penetration | 3~8 mm OD, 40 ~200 mm/s (SAE & QCT 743) | PASS |
| Crush | 0.1 mm/s, 15% deformation, 1300kg (IEC 62660-2) | PASS |
| Mech. shock | (UN 38.3) | PASS |
| Vibration | (UN 38.3) | PASS |
| Temperature cycling | -20℃~65℃ (IEC 62660-2) | PASS |
| High temperature endurance | 130℃/30min (IEC 62660-2) | PASS |

# 6. Conclusion

A 40Ah cell with heat-dissipation design behaved excellent electrochemical, safety and reliability performances is introduced in this article. The cell behaves a high specific energy of 126Wh/kg and high specific power of 1147W/kg, it can also be continuously discharged by 200 Amps current with an acceptable maximum temperature of 50℃. The cell has a special heat-dissipation design inside cell through current collector to electrical terminals. The effectiveness of the heat dissipation design is proved by discharging the cell with 120 Amps current at adiabatic and natural convection environments. The heat transfer is even better when combined with water-cooling connections at electrical terminals. Besides, the cell shows excellent safety and reliability performances under overcharge, force discharge, external short-circuit, nail penetration, crush, vibration, mechanical shock, temperature cycling and high temperature endurance tests. This 40Ah cell is now under pre-production study and will be a good candidate for EV and PHEV applications.

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## Author

**Mr. Sheng-Fa Yeh**
MCL/ITRI, *195, Sec. 4, Chung Hsing Rd., Chutung, Hsinchu, Taiwan*
Researcher, 12 years experiences in large cell design and fabrication
Tel: 886-3-591-13116
Fax: 886-3-5820039
Email: skyfar@itri.org.tw

**Dr. Deng-Tswen Shieh**
MCL/ITRI, *195, Sec. 4, Chung Hsing Rd., Chutung, Hsinchu, Taiwan*
Researcher, 10 years experiences in LIB
Tel: 886-3-591-3129
Fax: 886-3-5820039
Email: dtshieh@itri.org.tw

**Mr. Chun-Jui Hung**
MCL/ITRI, *195, Sec. 4, Chung Hsing Rd., Chutung, Hsinchu, Taiwan*
Associate Researcher, 7 years experiences in large cell design and fabrication
Tel: 886-3-591-2751
Fax: 886-3-5820039
Email: joary@itri.org.tw

**Mr. Li-Lun Liu**
MCL/ITRI, *195, Sec. 4, Chung Hsing Rd., Chutung, Hsinchu, Taiwan*
Assistant Researcher, 6 years experiences in cell testing and fabrication
Tel: 886-3-591-6911
Fax: 886-3-5820039
Email: lionerliu@itri.org.tw

**Miss Shu-Ping Lin**
MCL/ITRI, *195, Sec. 4, Chung Hsing Rd., Chutung, Hsinchu, Taiwan*
Assistant Researcher, 3 yr experiences in LIB
Tel: 886-3-591-6903
Fax: 886-3-5820039
Email: Ping-Apple@itri.org.tw

**Mr. Bing-Ming Lin**
MCL/ITRI, *195, Sec. 4, Chung Hsing Rd., Chutung, Hsinchu, Taiwan*
Manager, 20 years experiences in LEV system
Tel: 886-3-591-4148
Fax: 886-3-5820039
Email: bmlin@itri.org.tw

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