EVS26

Los Angeles, California, May 6-9, 2012

"10 MINUTE LTO ULTRAFAST CHARGE PUBLIC TRANSIT EV BUS FLEET OPERATIONAL DATA - ANALYSIS OF 240,000 KM, 6 BUS FLEET SHOWS VIABLE SOLUTION"

Thomas Tong, (Microvast, Inc., tongzm@microvast.com)

Chris Groesbeck (Microvast, Inc, chris.groesbeck@microvast.com)

Abstract

Long battery charge times and low battery charge-discharge cycle life are the two major limitations holding back the commercialization of electric vehicles. In order to resolve these problems, a robust battery system was developed by Microvast Inc. The batteries can be charged in less than 10 minutes and rapidly charged and discharged up to 20,000 times, while still maintaining more than 80% of the original capacity. 6 City Buses utilizing the Microvast battery systems have been tested in commercial operation in Chong Qing, China for more than one year. The batteries are still in good condition. The improved $Li_4Ti_5O_{12}$ negative electrode material gives the Microvast battery system its excellent properties.

Keywords: ultrafast charging, LTO technology, electric bus

---

1. L*p*TO Technology

As a negative electrode material, $Li_4Ti_5O_{12}$ (LTO) has been well documented with good stability and high charge-discharge rates. However, the gas generation in the charge-discharge cycles of LTO batteries has been a fatal drawback of the batteries, leading to the degradation of the batteries and limited use of such batteries in the market.

The investigation found that, in most cases, the gas generation in the batteries occurs because of the chemical reactions started on the surface of $Li_4Ti_5O_{12}$ material. In the charge-discharge process, the electrolyte solvent reacts with the $Li_4Ti_5O_{12}$ generating reductive lithium alcoholate, which can be oxidized on the positive electrode in the charged state to form H_2O, CO, CO_2, C_2H_4, and C_3H_6, which lead to much faster battery degradation. In order to resolve the problem, scientists at Microvast developed a new technology to enrich a layer of inert material

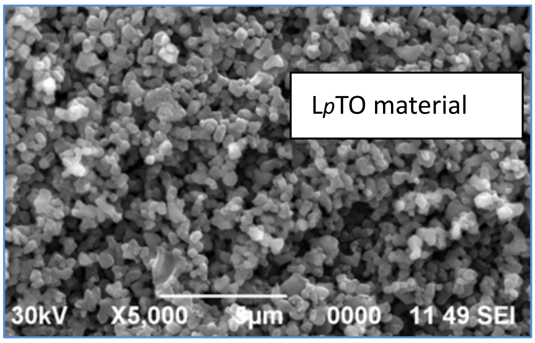

Figure 1. SEM of L*p*TO material

on the surface of $Li_4Ti_5O_{12}$ and retard the reaction between the $Li_4Ti_5O_{12}$ and the electrolyte solution. The newly developed $Li_4Ti_5O_{12}$ material is called L*p*TO material (Fig. 1&2). Batteries using L*p*TO as the negative electrode material have long cycling life.

A battery with L*p*TO negative electrode material and NiCoMnOx positive electrode material has been tested for up to 18 months. The results, shown in Figure 3, reveal that, after 25,000 cycles, the capacity retention is still about 75%.

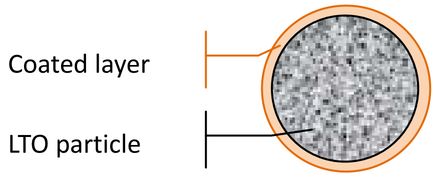

Figure 2. Coating structure of LpTO material

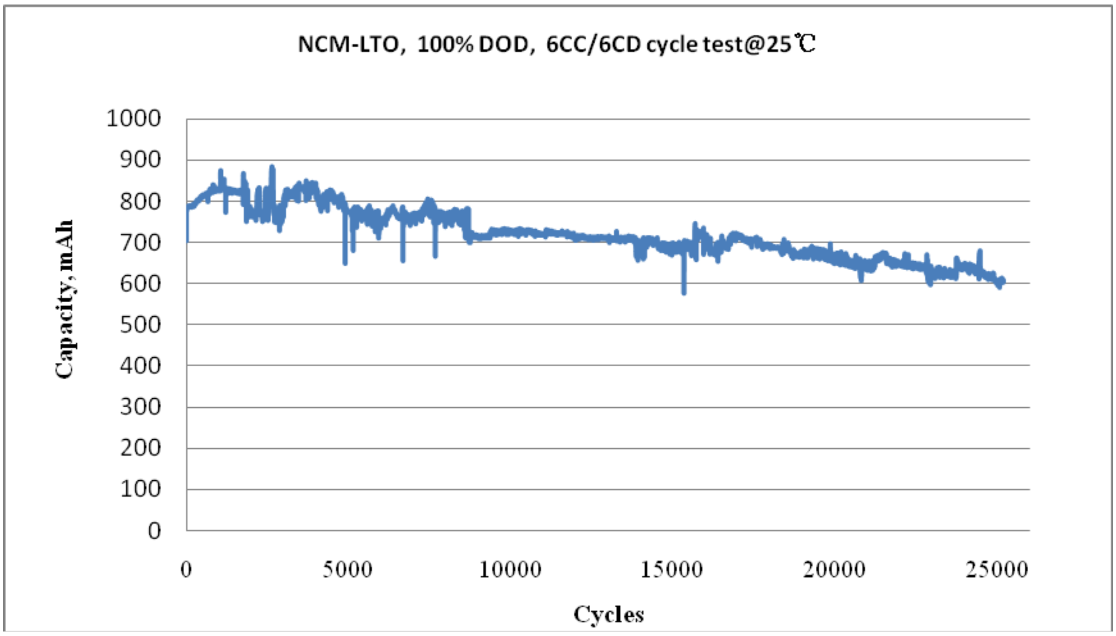

Figure 3. NCM-L*p*TO battery cycle test

2. Application of L*p*TO

Li-ion batteries are beginning to appear in both the electric vehicle and smart grid energy storage markets. Although they are now entering markets, they still face high lifetime total-cost-of-ownership challenges, blocking true mass market development. The L*p*TO battery, with its long cycle life, brings an alternative solution, which is much more cost effective.

Combining the ultrafast charging solutions now available with the long cycle life L*p*TO technology can transform the electric vehicle industry. Two particularly attractive applications are the Shuttle Bus and the City Bus, which are typically operated on high use and fixed loop routes every day. With L*p*TO battery technology, the bus or shuttle can be ultrafast charged every loop, taking less than 10 minutes per charge. Because the battery is charged in each loop, a very small battery pack can be used, meeting a single loop energy requirement as opposed to a whole day energy requirement that would require a much larger battery pack.

The advantage can be found in the following example: Compare a 30 unit small bus fleet equipped with LTO battery technology with that of one equipped with LFP battery technology. .

We find that a small bus equipped with an LTO battery that can be ultrafast charged, has the following advantages: 1) a smaller pack is less expensive, 2) a smaller pack weighs less reducing strain on the bus chassis and freeing up space, 3) reduced weight increases vehicle efficiency, and 4) reduced charging infrastructure investment is required due to higher charging port efficiency.

Table 1. LFP / LTO Battery Comparison for Bus or Shuttle Use

	LFP battery	LTO battery
Miles per loop	15	
Cycles per day	10	
Miles per day	150	
Energy consumption, kWh/mile	1.2*	1.2
Energy needed for one loop, kWh	18	18
Energy needed for one day, kWh	180	180
Charging time of battery	5 hours, at night	10 minutes, every loop
Cycles per year	365	3650
SOC intervals for operation	20%-100%	20%-100%
Capacity loss at EOL	20%	20%
Battery capacity installed, kWh/bus	281.25	28.13
Weigh of battery pack	3 tons	0.8 tons
Charging ports,	30	4
Power of each charging ports, kW	60	200
Overall power of charging station, kW	1800	800

**Assume same energy consumption for bus with different weight*

3. City Bus Operation Data

Microvast Inc., through its majority owned joint venture company, HT eBus Power Systems Co. Ltd., fielded six, L*p*TO battery electric city buses in Chongqing, China in March, 2011. These six buses continue to run on their route in Chongqing and data is collected daily on each of the six buses. The buses operated on Line 609 in Chongqing, carry fare paying passengers each day.

The buses were put into service on March 18, 2011; the data contained in this paper reflects the data collected from one bus (bus number 62051) over the 12 month period from March

18, 2011 to March 31, 2012. During this period, bus number 62051 traveled 40,000km (24,000 miles) or approximately 100 km/day (65 miles/day).

The same circular route is run by each of the buses each day. The route is approximately 20 km (14 miles) long with an average 5 or 6 trips taken each day. Fast charging between routes takes place at a central location; fast charging times average about 10 minutes at charge power levels of approximately 400 kW.

The L*p*TO battery used (Fig. 4) in the buses is an air cooled, 560V, 110Ah (60kWh) battery pack utilizing 11Ah pouch cells (Fig. 5) connected in a 10 parallel, 254 series configuration.

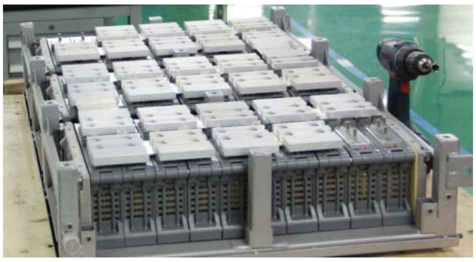

Figure 4. Microvast L*p*TO Battery Pack

Over the approximately 380 days run, the 62051 bus was charged approximately 1930 times. Over this time, battery capacity has decreased only slightly and we estimate a pack life of at least 15,000 cycles allowing for a 70% end of life capacity retention.

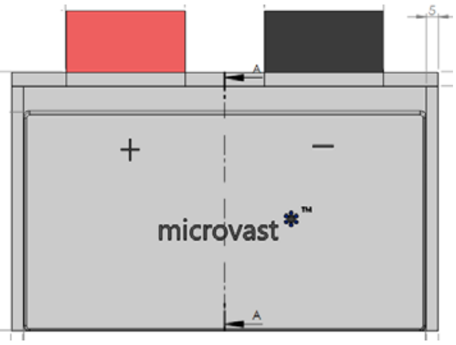

Figure 5. Microvast L*p*TO 11Ah Cell

The following information reflects data captured from bus 62051 during its operation between March 18, 2011 and March 31, 2012.

1) Current during Operation (Fig. 6)

While driving, the current from the battery pack was recorded. Negative data indicates energy regeneration during braking or downhill driving. A maximum 380A or about 3.5 C discharge was observed.

2) Number of Charges (Fig. 7)

The number of charges was about 2,000 with the average energy added per charge of 20 - 40kWh. The average duration of each charge was less than 10 minutes, with the minimum charge duration being approximately 3 minutes, and the maximum charge duration being approximately 14 minutes. Charge power was, on average, approximately 400kW.

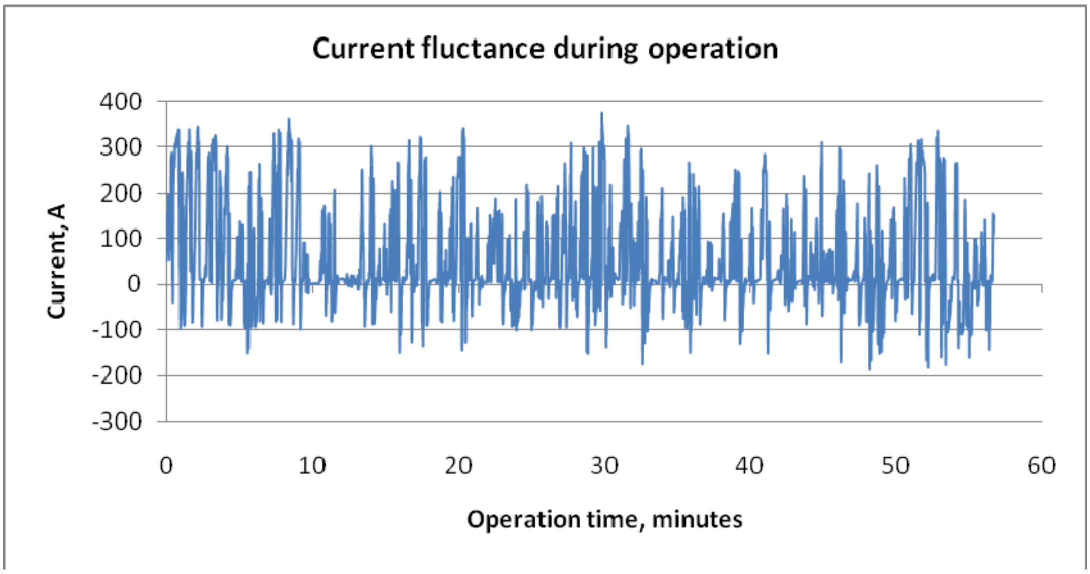

Figure 6. Discharging/regeneration current of battery pack during operation

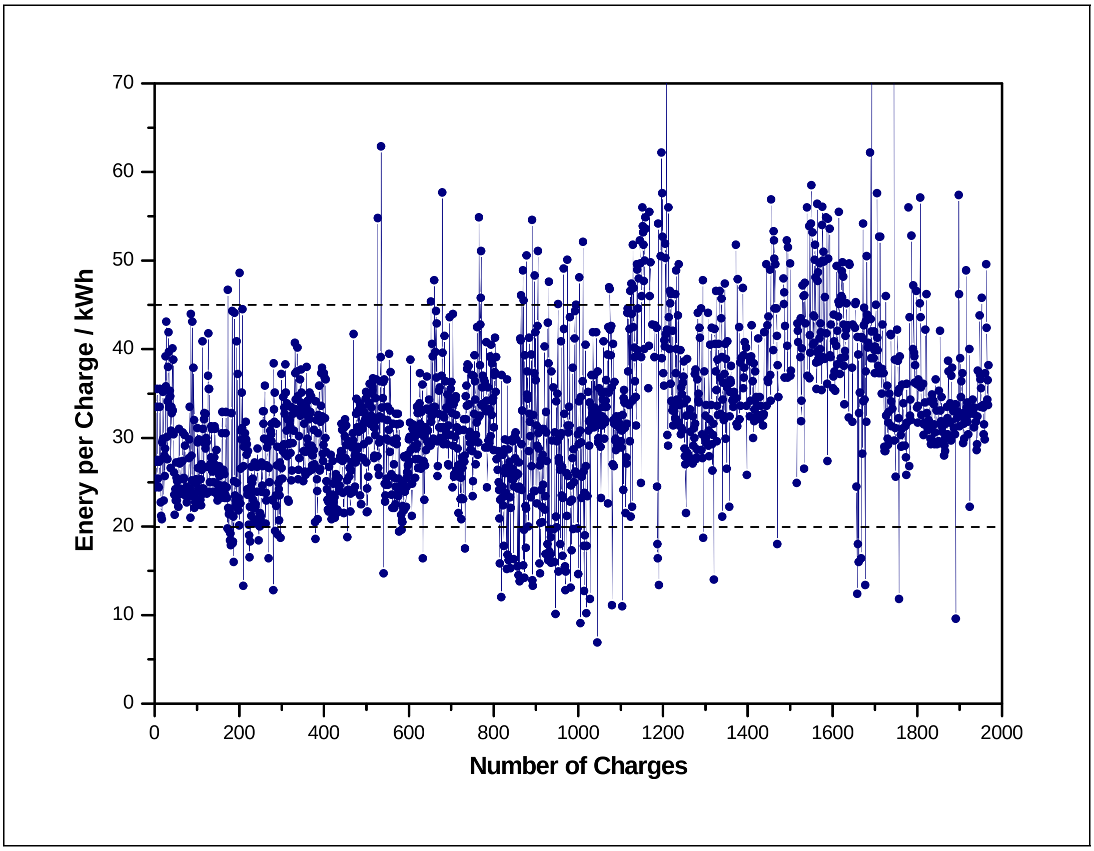

Figure 7. Number of Charges

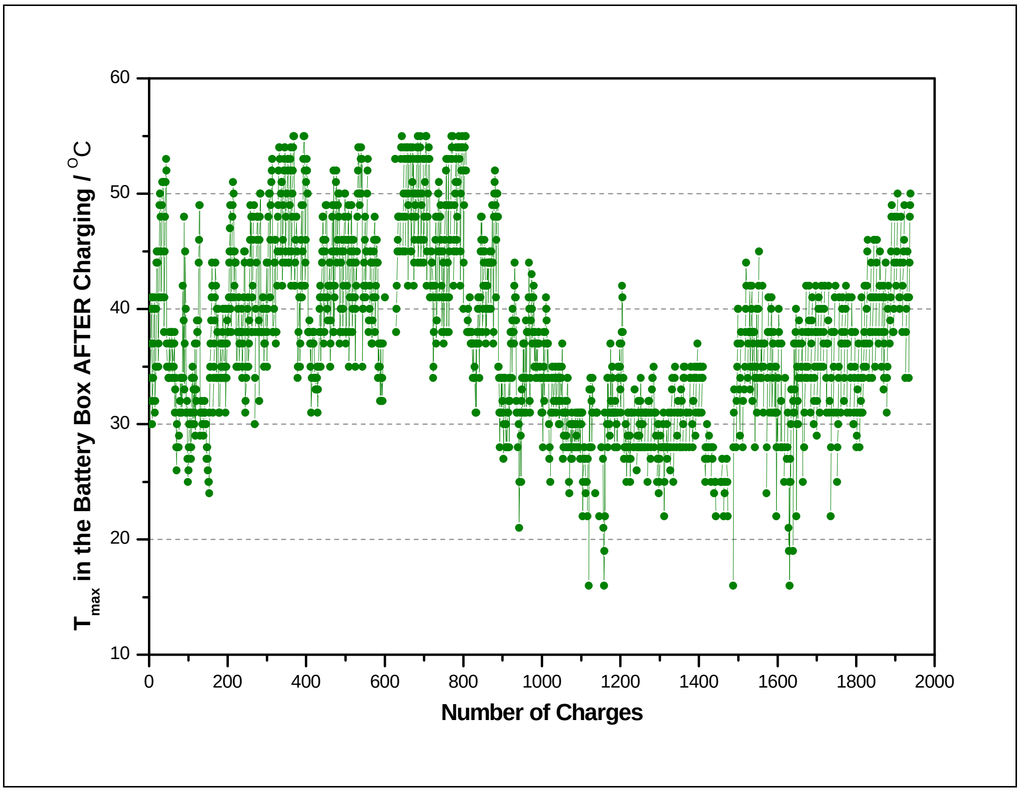

Figure 8. Temperature in battery pack during months operation

3) Battery Temperature

Battery temperatures were recorded (Fig. 8) at the cell surface during operation and charging. Air cooling was used for the battery pack; at no time was the recorded maximum temperature (Tmax) above 55^{O}C. Charging station ambient temperature ranged from a low of about 5^{O}C to a high of more that 42^{O}C. It should be noted that during the months of June, July, and August, 2011, the City of Chongqing experienced hot weather with daily high temperatures often reaching 42^{O}C. During the months of September and October, the temperature dropped significantly.

4. Analysis of Battery Modules

In April, 2012, modules were removed from the buses and analyzed for capacity retention, increased impedance, and constant current capacity. These test results are shown below in Figure 9, 10, and 11.

1) Capacity Retention

In order to evaluate capacity retention, 5 cells were removed from the module and evaluated. The nominal 1 C capacity of the 5 cells was tested at 1 C and compared with original delivery capacity data:

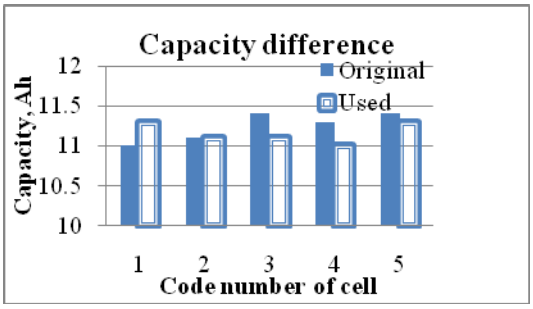

Figure 9. Capacity retention of used cells

Averaging these 5 cells, we observed about a 0.7% capacity loss, with a maximum capacity loss of 2.7%.

2) Impedance

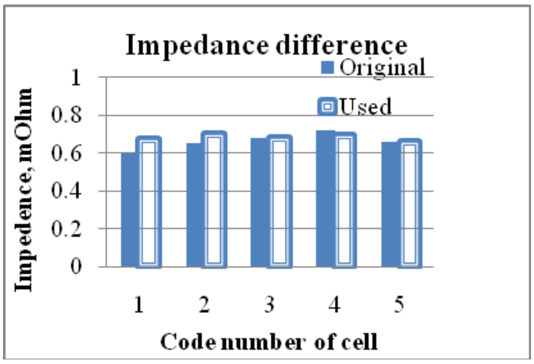

Figure 10. Impedance increase of used cells

In order to test for impedance gain, initial impedance data was compared with that of the 5 removed cells. The impedance rose from 0.662 mOhm initially to 0.676 mOhm. An increase of about 2% was observed.

3) Constant Current Capacity

When testing for constant current capacity loss, the ratio of initial capacity of 5C constant current charging was compared with that of the removed cells. Nominal constant current capacity decreased from 90.2% to 88.6%.

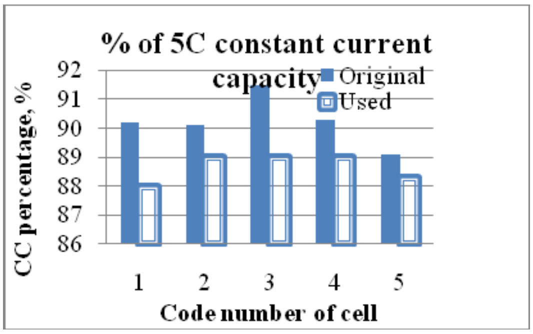

Figure 11. Impedance increase of used cells

Based on the results of the tested cells and modules, the data shows very good results after 2,000 ultrafast charging cycles.

Conclusion

Beginning with research and development on L*p*TO anode material, Microvast has introduced a battery that appears to offer long cycle life even during ultrafast charge events. Tests of buses utilizing the L*p*TO chemistry and ultrafast charge appear to validate the long cycle life of the Microvast cells. Further analyses on removed battery modules supports the bus test data.

References

[1] T. Ohzuku，A. Ueda，N. Yamamoto, J. Electrochemistry Soc. 1995，142(12), 1431.

[2] K. Nakahara, R. Nakajima, T. Matsushima [J]，J. Power Sources 2003, 117, 131.

[3] P. P. Prosini，R. Mancini，L. Petrucci，et al. J. Solid State Ionics 2001，144(1-2), 185.

[4] A. D. Robertson，L. Trevino，H. Tukamoto et al. J. Power Sources1999，81-82, 252.

[5] K. Nakahara，R. Nakajima，T. Matsushima，et al. J. Power Sources 2003，117(1-2), 131.

[6] I. Belharouak, K. Amine, Electrochemistry Communications 2003, 5, 435.

[7] P. Kubiak, A. Garcia, M. Womes, et al. J. Power Sources 2003, 119-121, 626.

[8] SUN Y K, JUNG D J, LEE Y S, et al. J Power Sources, 2004, 125: 242-245.

[9] Beatrice G，Serge L，et al，Room temperature molten salts lithium battery electrolyte，Electrochimica Acta，2004，49（26）：4583-4588；

[10] Diaw M，Changes A，et al，Mixed ionic liquid as electrolyte for lithium batteries，J Power Sources，2005，146（1-2）：682-684；

[11] http://www.eet-china.com/ART_8800474245_628868_NT_f88f6d0e.HTM

[12] Phys. Chem. Chem. Phys., 13, 15127-15133, 2011

Authors

Dr. Thomas Tong studied chemistry at Tsinghua University and has more than 10 years of research and development experience and five years working with lithium ion materials. He is considered an expert in the industry, has made several contributions and regularly gives public presentations about the advantages and benefits electric energy storage.

Mr. Christopher James Groesbeck studied Finance at the University of Colorado, receiving his Masters of Business Administration in 2003. Mr. Groesbeck has worked with battery companies and electric vehicle drive-train companies since 2001 after returning from studies and work abroad, primarily in China.