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DUTH CERTH

Novel Lithium-Ion Cell for Operation at Very Low Temperatures

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ABSTRACT

The poster discusses the development under an ESA TRP activity with a target of high specific energy Lithium-ion cells, capable of operating under low temperature conditions, i.e. -40 °C. Such cells may be encountered in future exploration missions, which do not consider the use of Radioisotope Heater Units. During the activity, ≥1 Ah silicon-based high energy density prototype cells, following components characterization and optimization, were designed, developed, manufactured and tested under room and sub-zero temperature conditions down to -40 °C.

The developed and tested prototype cells exhibited energy density of around 208 Wh/Kg at room temperature under C/10 charge and discharge rate. Moreover, the prototype cells could retain and deliver more than 75% of their capacity at room temperature upon cycling at -40 °C (C/15 charge and C/10 discharge rate), demonstrating an energy density of 140 Wh/kg.

INTRODUCTION

Currently, the state-of-the-art space qualified batteries by European manufactures can reach up to 155 Wh/kg (at C/2) at 25 °C, and provide satisfactory performance in cycling only down to 0 °C. Below 0 °C the charging of these Li-ion batteries is the main limitation. The current solution in order to charge the battery is the use of external power and heaters to bring the cell to relatively high temperatures since there is no electrochemical system that can efficiently charge at low temperature. The necessity of heaters utilization and the low, if any, specific energy, obtained at low temperature, limit satellite operations and payload possibilities and increase the system mass while decreasing system efficiency.

STANDARD ELECTRODES

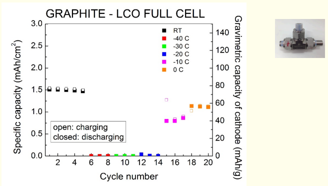

Figure 1. Specific capacity of full cells with standard materials at various temperatures

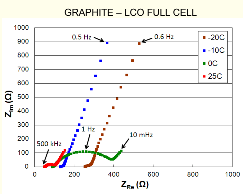

Figure 2. Nyquist plots of charged full cells at various low temperatures

- Standard full cell is unable to operate from -40 °C to -20 °C possibly due to the electrolyte
- Electrochemical Impedance Spectroscopy exhibits high resistance as temperature is lowering. No measurement was possible at T<-20 °C
- Specific capacity of LCO and graphite are not able to produce cells with energy density higher than 220 Wh/Kg

LT ELECTROLYTE DEVELOPMENT

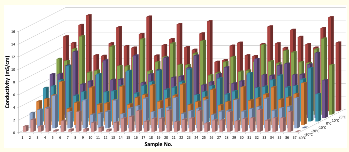

Figure 3. Conductivities of all modified electrolytes at various low temperatures

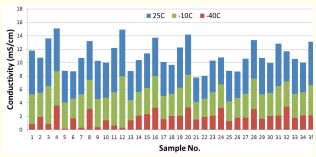

Figure 4. Conductivities of all modified electrolytes at 25 °C, -10 °C and -40 °C.

- Electrolyte mixtures with optimized solvent blends, novel co-solvents and additives
- Conductivity of standard electrolyte (No37), dropped to practically zero value for temperatures below -20°C
- All modified electrolytes showed better performance at Low Temperatures

SILICON ANODE DEVELOPMENT

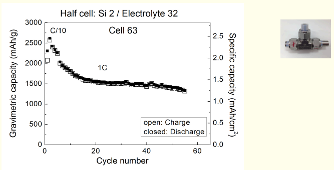

Figure 5. Specific capacity of silicon in half-cell with LT electrolyte at C/10 and 1C rate

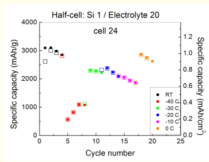

Figure 6. Specific capacity of silicon in half cell at various low temperatures

- Discharge capacity > 2 mAh/cm² @ C/10
- Low irreversible loss (<15%)
- Excellent Coulombic efficiency
- Stable capacity over 50 charging-discharging cycles
- Operational at low temperatures down to -40 °C

FULL CELL DEVELOPMENT

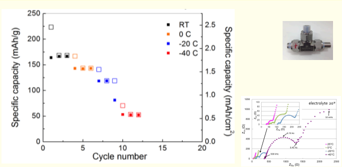

Figure 7. Full cell (Si/cathode/LT electrolyte) specific capacity (C/10 rate) at low temperatures

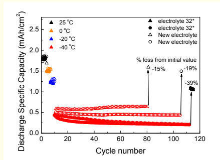

Figure 8. Full cell (Si/cathode/LT electrolyte) cycling at -40 °C

- Full cells with silicon anode and commercial cathode exhibit very good operation even at low temperatures as low as -40 °C
- No lithium plating was observed (reference electrode was used)
- Cycling stability is achievable with further electrolyte development

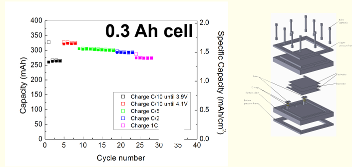

Figure 9. High rate performance of 0.3 Ah full cell (Si/LT electrolyte/cathode)

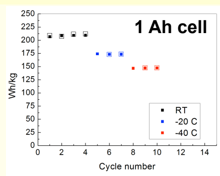

Figure 10. Low temperature performance of 1 Ah full cell (Si/LT electrolyte/cathode)

	Discharge Capacity (mAh/cm2) (C/10 rate)					
Electrochemical System (Swagelok® cells)	RT	0 °C	-10 °C	-20 °C	-30 °C	-40 °C
Si2/Cathode1/Electrolyte 20*	1.39	1.13	0.98	0.70	0.34	0.02
Si2/Cathode1/Electrolyte 32*	1.63	1.18	0.95	0.60	0.18	0.00
Si2/Cathode2/Electrolyte 20*	1.82	1.57		1.31		0.58
Si2/Cathode2/Electrolyte 32*	1.82	1.50		1.22		0.44

- 1 Ah cells with more than 200 Wh/kg of energy density were manufactured
- At -40 °C, more than 150 Wh/kg are obtained

CONCLUSIONS

During this activity, ~1 Ah silicon-based high specific energy prototype cells were designed, developed, manufactured and tested under room and subzero temperature conditions down to -40 °C. The cells exhibit specific energy of around 208 Wh/Kg (cell chemistry is considered) at room temperature under C/10 charge-discharge rate. The prototype cells could deliver more than 75% of their capacity at room temperature when cycled at -40 °C (C/15 charge and C/10 discharge rate), demonstrating a specific energy of 140 Wh/kg.

To our knowledge, these results are the best reported in terms of capacity retention and following charging at -40 °C at high energy cells (>200 Wh/kg).

CONTACT

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