Advance Anode Chemistry for High Energy Li-ion Cell

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Abstract: *The incorporation of silicon base anode chemistries has been expected to be a viable and most feasible approach to achieve demanding higher energy requirements due to the high specific capacity of silicon anode material. Several technical challenges still impede the high degree of utilization of silicon material in products. Poor cycling and initial capacity loss are typical drawbacks of silicon material, mostly resulting from mechanical swelling and electrochemical instability of silicon material during continuous cycling.*
Research and development efforts at EaglePicher have focused on implementing silicon-based anodes and high-specific cathodes for high-energy lithium-ion cells. The technical efforts were focused on selecting appropriate binder materials and the optimal composition of the anode for the high degree of silicon content in the anode, more than 20%, and the development of optimal electrode processing conditions to overcome its inherent drawbacks. A selection of binder and binder content optimization proved critical to reducing silicon anode material's structural instability for better cycling performance. Also, it was found that the incorporation of pre-lithiated silicon material improves overall performance.

Keywords: Li-ion battery; high energy density; silicon carbon anode; high power capability;

Introduction

In the past few years, EaglePicher Technologies (hereinafter: EPT) has developed a lithium-ion cell that has a high energy density of 300Wh/kg. As part of the technical effort to develop high-energy lithium-ion (Li-ion) cells, EPT intends to develop a chemistry and cell design for high-energy lithium-ion cells to be used in the existing Li-ion cell production line, established through the award of the Title III Lithium Ion Battery Production for Military Applications (LIMA) project in 2013 and completed in 2017. Several applications can be supported by EPT's Li-ion cell production line, which is an automated production line for high-volume production.

Technical efforts for high-energy-density lithium-ion (Li-ion) cell development are to incorporate a high-specific capacity cathode with silicon-carbon composite anode for a wide spectrum of applications [1] and [2]. The incorporation of silicon-carbon composite anode chemistry requires the reliable design of cells and electrode chemistry to be suitable for reliable performance as well as high power capability [3].

Scope of Development

The technical objectives of high-energy Li-ion cell development are to achieve more than 300Wh.kg-1 of high energy density and power capability. Considering silicon carbon anode chemistry was selected to achieve high energy density, cycling performance, and cell life are key technical aspects to confirm. The major technical tasks are: 1) identifying the core design to meet the needs, 2) determining the optimal anode composition, with a particular focus on binder selection, 3) optimizing electrode processing, and 4) determining the appropriate electrolyte composition for silicon anodes to maximize their stability and power. Two different sizes of cells are developed to support overall technical demands. Table 1 summarizes the detailed information on the two cells.

Table 1. Summary of cells developed at EPT

Cell Model No.	SLC-202	SLC-203
Capacity nominal	2.3 Ah	13Ah
Specific Energy density	240 Wh/kg	300Wh/kg
Tested Max continuous C-Rates	Up to 8C	Up to 8C
Max Pulse rate	12C-rate	8 C-rate
Operation temperature	-30◦C~50◦C	-30◦C~50◦C
Cell Dimension, W x H x T (mm)	50 x 57 x 7	115 x101 x 7
Packaging Material	Polymer Coated Aluminum	Polymer Coated Aluminum
Target Applications	UAV, Portable Power, etc.	UAV, eVTOL Portable Power, etc.

Cell and chemistry development

Objectives of cell and chemistry development were to meet the following goals 1) high energy density with high power capability, 2) flexibility to customize cell performance for optimal power and energy relationship 3) compatibility to incorporate next-generation chemistry higher specific capacity cathode and high content of silicon material in anode 4) enhancing safety.

SLC-202 cells (2.3Ah pouch cell)

SLC-202 is designed to provide high power capability with relatively high energy density which can be operated in a wider temperature range of -30°C to 50°C as shown in Table 2. A picture of SLC-202 cell is shown in Figure 1.

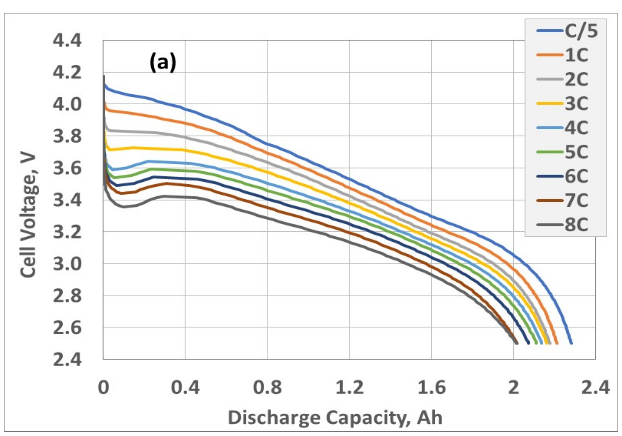
Table 2 Specification of SLC 202 cell

Part Number	SLC-202
Nominal Capacity @ C/5	2.3Ah
Nominal Energy @ C/5	8.2Wh
Specific Energy @ C/5	240 Wh.kg-1
Max. Pulse Current	>10 C-rate, 23A
Dimensions	50.0 x 56.0 x 7 mm
Operation Temperature	-20°C to 50°C
Nominal Voltage	3.55V
Cycle life	> 500 cycles
Anode	SiO-Carbon composite
Cathode	High Ni content NMC
Separator	Shutdown separator

Figure 1. Picture of SLC-202 cell (2.3Ah)

Performance of SLC-202 Cell

To ensure that the developed SLC-202 cell performs as designed, its performance was evaluated by testing its rate and power capabilities using constant current discharge and constant power discharge techniques, across various levels of current and power. SLC-202 cells delivered 2.0 Ah at 8C-rate constant current discharge, 88% of their nominal capacity obtained at C/5 discharge, as shown in Figure 2(a).



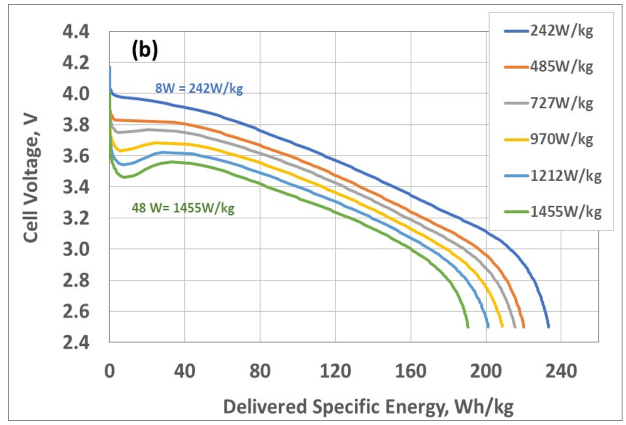


Figure 2. Rate and Power capability of SLC-202 cells, a) tested at various constant discharge currents and b) tested with various constant power rates; in the voltage range of 2.5V-4.2V and at 20°C

Figure 2(b) demonstrates the consistent power discharge test performed on SLC-202. The results indicate that the cell can deliver 233Wh/kg at a constant power discharge of 242W/kg, and still maintain an energy density of 190 Wh/kg at a constant power discharge of 1455 W/kg.

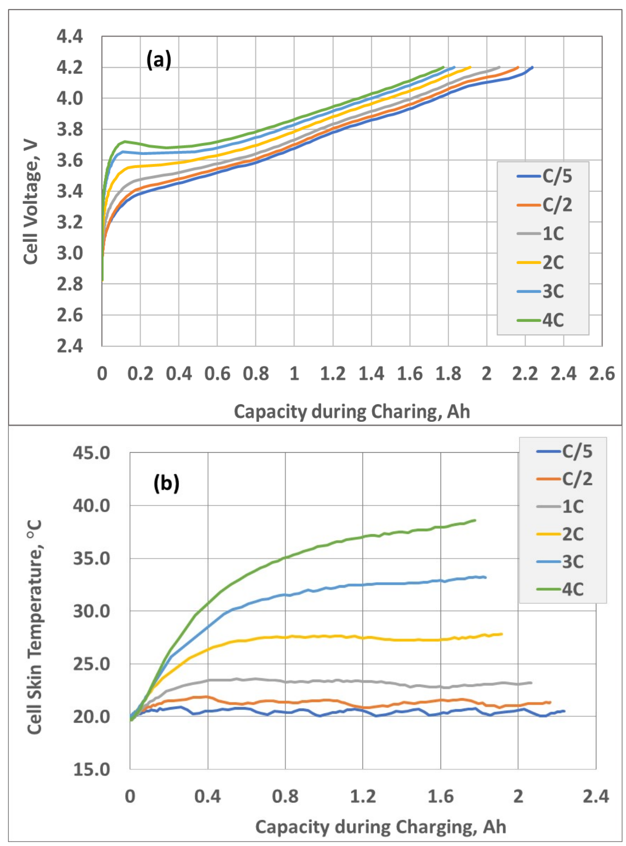


Figure 3. Fast charging capability of SLC-202 cell (a) charge capacity at various charging currents without trickle charge, b) cell temperature response at each charging current

Figure 3(a) displays the charge capacity at varying charging rates without constant voltage charge. At C/5 charging rate, the capacity reached 2.23Ah, which is 97% of the cell's nominal capacity, but it declines as the charging rate increases. Even at 4C-rate charging, a capacity of 1.77Ah was still achieved, representing 77% of SLC-202 cell nominal capacity.

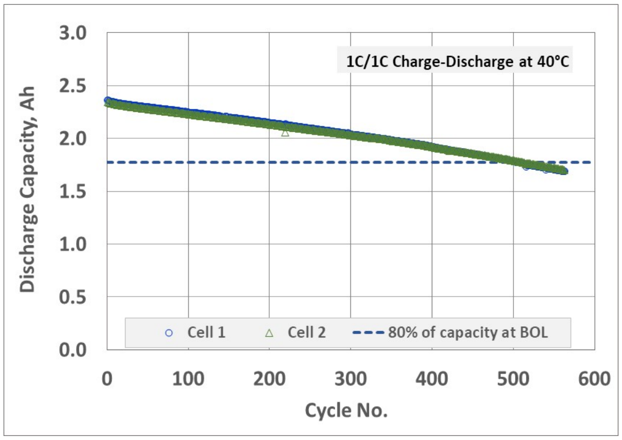


Figure 4. Cycling Performance of three SLC-202 cell 40 °C and 1C-rate charge/1C-rate discharge in the voltage range of 2.5V-4.2V

Figure 4 shows the cycling performance of two of SLC-202 cells. The test was performed by cycling them at 1C-rate charge and followed by 1C-rate discharge until their discharge capacity reached 80% of the capacity at the beginning of life (BOL). The cells were able to maintain a discharge capacity above 80% of the BOL capacity for 500 cycles, as shown in Figure 4.

SLC-203 cell (13Ah) for high-power application

The technical goal for SLC-203 cell development is to achieve an energy density of 300Wh/kg and to provide high power capability for a wide spectrum of applications. Table 4 shows a preliminary specification of the current SLC-203 under development.

Table 4 Specification of SLC-203 Cell

Part Number	SLC-203
Nominal Capacity @ C/5	13 Ah
Nominal Energy @ C/5	45 Wh
Specific Energy @ C/10	300 Wh.kg-1
Max. Pulse Current	8C (104A)
Dimensions	115 x 101 x 7.0 mm
Operation Temperature	-20°C to 50°C
Nominal Voltage	3.55V
Cycle life	> 500 cycles
Anode	SiO-Carbon composite
Cathode	High Ni content NMC
Separator	Shutdown separator

Figure 5. Picture of 13Ah SLC203 cell

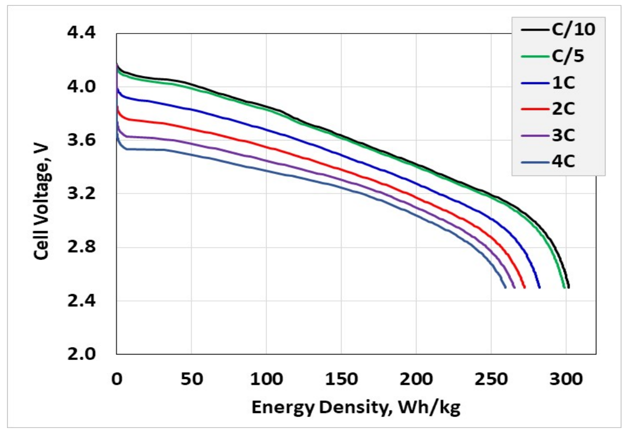


Figure 6. Discharge curves of SLC 203 cells tested at different C-rate to estimate specific energy density; 1C current is 13A, the voltage range of 2.5V-4.2V at room temperature

Figure 6 shows several discharge curves performed at different levels of discharge current to estimate the specific energy density of the developed SLC-203 cells. SLC-203 cells delivered 300Wh/kg (13Ah) at C/10 and 299 Wh/kg at C/5-rate. SLC-203 cell still delivered more than 250Wh/kg at 4C-rate discharge in the same voltage range. The test results of SLC203 were summarized in Table 5.

Table 5 Summary of the energy density of SLC-203 cell discharged at different C-rate

Discharge rate and current, A	Discharge current, A (Continuous)	Specific energy density, Wh/kg
C/10 rate	1.3A	302 Wh/kg
C/5 rate	2.6A	299 Wh/kg
1C rate	13A	282 Wh/kg
2C rate	26A	273 Wh/kg
3C rate	39A	265 Wh/kg
4C rate	52A	259 Wh/kg

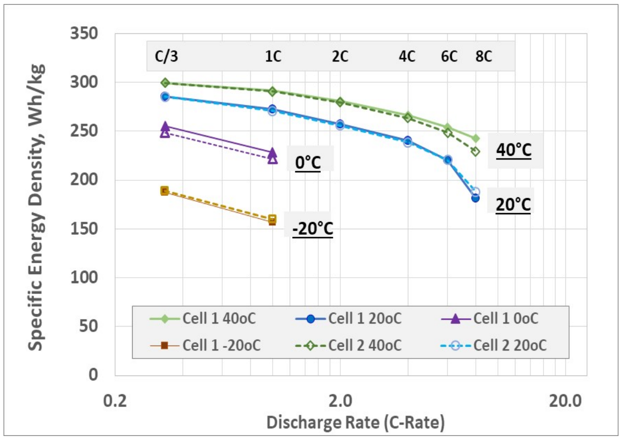


Figure 7 Performance of SLC-203 cell tested at various temperatures and various current levels. In the voltage range of 2.5V-4.2V

In Figure 7, specific energy densities of SLC-203 are displayed for various temperatures and current levels (C-rates). The cell achieved a specific energy density of 300Wh/kg at C/3-rate and 40°C. Even at C/3-rate to 8C-rate at 40°C, SLC-203 cells still maintained a high specific energy density.

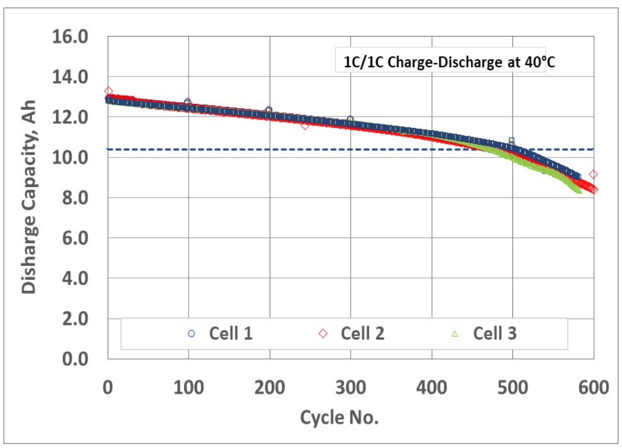


Figure 8. Cycling Performance of three SLC-202 cell 40 °C and 1C-rate charge/1C-rate discharge in the voltage range of 2.5V-4.2V

The cycling performance of several SLC-203 cells cycled at 40°C is displayed in Figure 8. These cells were designed to have an initial discharge capacity (or BOL energy) of around 13Ah. A cycling test was conducted until the discharge cell capacity reached 80% of the BOL capacity. Figure 8 shows that the tested cells maintained a discharge capacity above 80% of the BOL capacity for 500 cycles.

Summary

EPT has been developing next-generation lithium-ion chemistry and the cells by utilizing high specific cathode material and silicon-carbon-based anode material.

The Li-ion cells that have been developed at EPT are currently available in two sizes: 2.3Ah for SLC-202 cells and 13Ah for SLC-203 cells. Both cells have a high energy density and can discharge at up to 8C rate continuously. The SLC-202 cell can also discharge at a constant power of 1450W/kg.

SLC-202 and SLC-203 show good cycling performance at a temperature of 40°C. These cells were designed with an initial discharge capacity of 2.3Ah and 13Ah. A cycling test was conducted until the discharge cell capacity reached 80% of the initial capacity. It was observed that the cells maintained a discharge capacity above 80% of the initial capacity for 500 cycles.

Acknowledgment

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References

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