Long Life Molten Salt Battery for NASA Venus Application

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Abstract

A development program is being conducted at Advanced Thermal Batteries (ATB) to create a low discharge rate, long life, molten salt battery for a NASA Venus surface probe. Battery goals are 60 days continuous operation at +25V +0/-6 volts and -25V +6/-0 Volts under severe environments of 465ºC, 92 atm pressure, and corrosive sulfur dioxide in a super critical carbon dioxide atmosphere. Conveniently, molten salt thermal battery electrochemistry starts to operate efficiently at 330°C. However, a major barrier to direct application of existing thermal battery technology is the high self-discharge rate, resulting in lifetimes in only minutes, not days. The best performance to date, which meets the required voltage regulation, has been a lithium silicon (LiSi) alloy anode discharging through all three voltage plateau versus an iron monosulfide (FeS) cathode. In order to perform reproducibly, additional engineering controls within the battery design are required to limit cell–to–cell parasitic discharge mechanisms. Results of these trials have improved the efficiency and manufacturability of the design.

Keywords

Long Lifetime; Thermal Batteries; Venus; Interplanetary Battery; FeS.

Introduction

A development program is being conducted at Advanced Thermal Batteries (ATB) to create a low discharge rate, long life, molten salt battery for a NASA Venus probe. Battery goals are 60 days continuous operation at +25V +0/-6 volts and -25V +6/-0 Volts under severe environments of 465ºC, 92 atm pressure, and corrosive sulfur dioxide in a super critical carbon dioxide atmosphere. Conveniently, molten salt thermal battery electrochemistry starts to operate efficiently at 330°C. However, a major barrier to direct application of existing thermal battery technology is the high self-discharge rate, resulting in lifetimes in only minutes, not days.

Work to date has explored lithium alloy anodes and metal sulfide cathodes in alkali halide molten salt electrolyte. A thick separator employing the use of a non-traditional electrolyte is ATB's strategy to reduce self-discharge while preserving the high temperature performance required for the Venus mission. The best performance to date, which meets the required voltage regulation, has been a lithium silicon (LiSi) alloy anode discharging on the third voltage plateau versus an iron sulfide (FeS) cathode, 1.32V/cell. Operational testing of a 5-cell battery using this electrochemistry has achieved 152 days of continuous discharge to a half-scale load. Also, operational testing of a 17 cell battery was achieved successfully for 117 days before dropping below 19V.

However, it has been determined that in order to perform reproducibly, additional engineering controls within the battery design are required to limit cell–to–cell discharge mechanisms. Destructive physical analysis of the long-life cells has shown that slow migration of lithium-containing material between the cells is the most significant driver for battery failure. Work performed to date has been focused on evaluating new assembly methods to limit interaction between cells using ceramic isolators and containment techniques to limit lithium migration and its effects on the parasitic cell discharge. As these techniques are employed, their functional resistance to dynamic environments will also be considered with the goal of developing a full scale battery capable of handling the dynamic environments of launch, interplanetary space flight, and Venusian atmosphere entry.

The work presented in this paper will be focused on three engineering controls schemes developed to limit the interaction between cells. Previous work on this program at ATB has shown that the most significant driver for accelerated self-discharge in these long life, low load, multicell batteries is migration of electrolyte between cells. Such migration results in an ion-conductive path which bleeds down cell capacity rapidly once formed. Typical migration is increased by materials in contact with the cell stack which may wick the electrolyte between the cells.

To limit such wicking effects, contact to the stack must be limited, an effective barrier must be put in place, or a tortuous path must be created. Minimizing contact with the stack results in an unsupported stack which may be susceptible to both non-operating vibrations and shock which may cause the cells to shift, or slumping during operation which may occur if the battery is tested on its side (the gravity vector lateral to the cell stack).

For this paper, three different designs have been created in order to evaluate each of the proposed controls, each depicted in Figure 1. The bare-cell design was chosen as a baseline and is based on the successful prototypes from the previous work conducted on this project. To pursue the concept of a barrier, the alumina sleeve design was conceptualized to create a tight fit with cell covers to prevent the passage of electrolyte along the length of the battery. Lastly, a stacking ring design was created which is expected to provide both a seal between the cells as well as a tortuous path, resulting in extended operation even in the event that the electrolyte migration begins to occur.

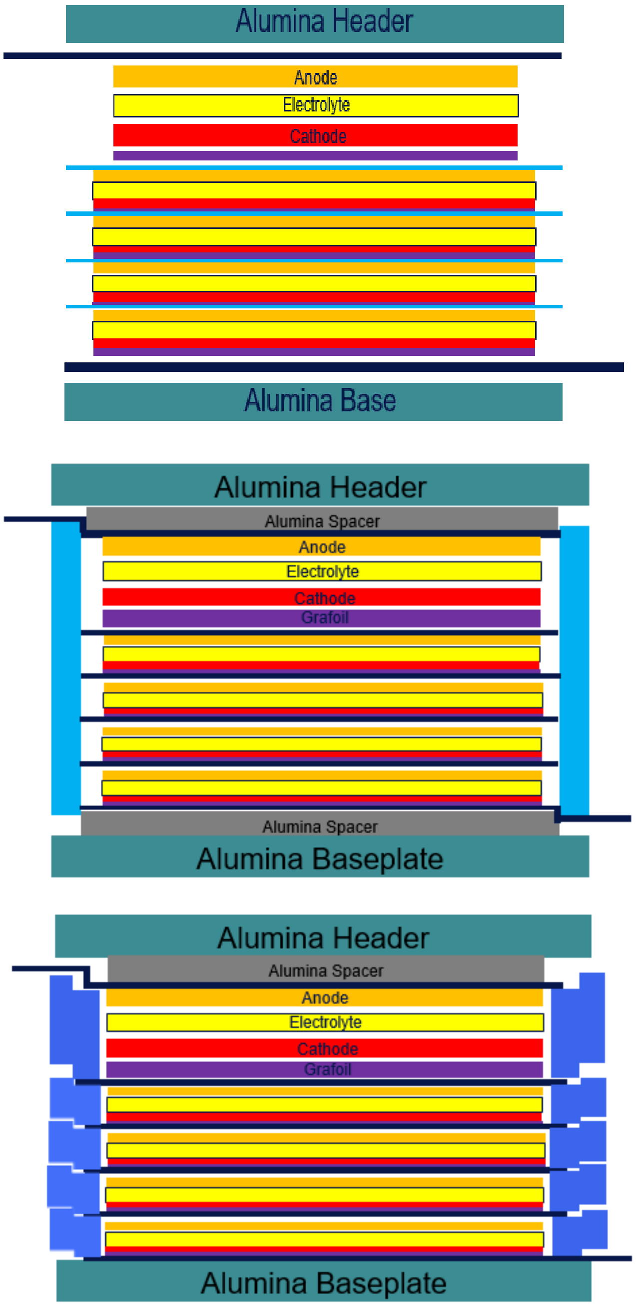

Figure 1. Depiction Of the Three Tested Stack Configurations from top to bottom a) Bare b) Sleeve c) Stacking Ring.

Experimental

Eight 5-cell test units were constructed based on these design concepts utilizing the LiSi/FeS chemistry developed in the previous phase of the work. Serial numbers 1037-1040 were constructed with the bare cell design and overhanging cell covers. SN 1037 and 1038 had larger overhangs from the cells compared to 1039 and 1040. SN 1041 and 1042 were constructed with pure alumina sleeves. SN 1043 and 1044 were constructed using the pure alumina stacking rings.

Units were placed into an oven and connected to independent resistive loads and data acquisition system. Units prepared for testing are shown in Figure 2. Current, voltage and temperature were logged at a rate 1 sample every 10 seconds. A timer circuit and relay switched from “base load” (12 kΩ) to “pulse load” (160 **Ω**) every 8 hours for 2 minutes to mimic mission parameters.

To start testing, the oven was stepped up to 465°C and held constant during the test. In the event that a unit needed to be removed or added to the furnace for testing, data acquisition was halted, the oven was stepped down to room temperature, and the batteries were added or removed. This process did not appear to impact the other units under test significantly aside from drive a freeze/thaw cycle, which can be seen in the data.

Figure 2. Photograph Of the Units, One Set on the Baseplate and One on the Side, Under Test in the Oven.

Results and Discussion

Initial test units for the SN 1037 and 1038 bare-cell design were constructed based on a scale down in capacity and diameter based on the efficiencies determined from previous testing efforts. In the process of scaling down the cell diameters, the cell covers were left at the original diameter. This characteristic was expected to result in a longer path for the migration of electrolyte between cells. The unintended consequence of this extreme overhang resulted in the deflection of the cells upon heating up and the rapid shorting and discharge of the batteries. An X-ray radiograph of the expended battery in Figure 3 shows the cell cover edge having been significantly deflected to the point of making visible contact.

Repeat tests of the bare-cell designs were realized in SN 1039 (tested on base plate) and 1040 (tested on side). SN 1040 continued to run past the 60-day requirement with margin (~85 days). Voltage data for SN 1040 is shown in in Figure 4. The voltage performance of SN 1040 compared to SN 1039 had a discharge rate which was twice as fast, based on LiSi plateau rundowns, despite demonstrating nominal discharge current. Evaluation of SN 1039 post-test demonstrated an insulation resistance failure between the battery terminals and the case. Further investigation of the glass seals of the feedthrough suggested either dielectric breakdown of the glass at the high temperatures the item was exposed to or contamination from inside the battery condensing on the seals resulting in failure. Such findings suggest that design and procurement of robust electrical feedthroughs are a necessary step in a fully realized battery that is compatible with the Venusian environment. Furthermore, the success of SN 1040 while being tested on its side shows that there are no significant slump characteristics of the cell material.

SN 1041 and 1042 were built to the sleeve design concept. In the construction of SN 1041, the alumina cover insulator bottomed out on the sleeve, and the stack itself was not fully under compression. This resulted in extremely high cell impedance and unusual discharge characteristics. SN 1042 was built with an addition component to compress the cells without losing stack force or bottoming out on the sleeve. Regardless, both 1041 and 1042 showed accelerated self-discharge. Destructive physical analysis (shown in Figure 5) of SN 1041 revealed a large degree of contact between the cell material and the alumina sleeve. Several locations appeared to show clear signs of migration between adjacent cells, likely a prime driver for the observed discharge characteristics.

SN 1043 and 1044 were built with the stacking ring configuration. SN 1043 shows similar discharge characteristic to SN 1040 (bare cell). The stacking ring was significantly simpler to build and more forgiving of misalignment of the cell components. There is expectation also that the more confined cells of the stacking rings will be more resilient against non-operating dynamic environments.

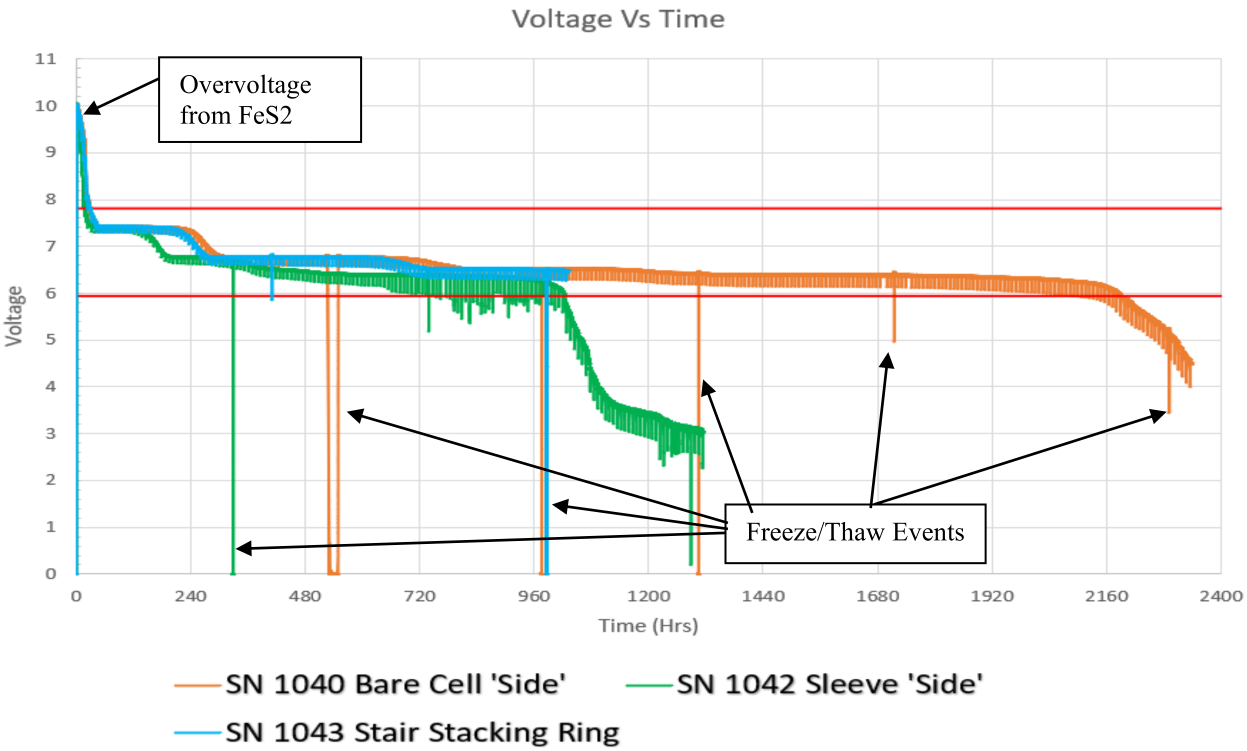

Figure 4. Voltage Data Showing Full Discharge of SN 1040 Bare Cell, and Two Additional Voltage from Additional Designs, with Voltage Regulation Limits and Target Lifetime.

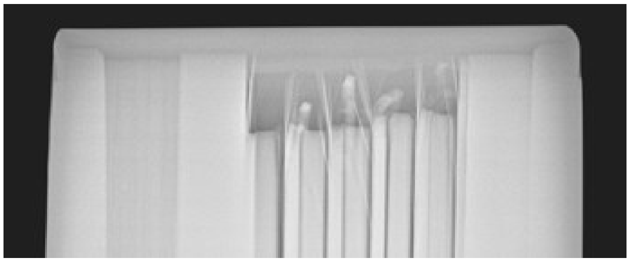

Figure 3. X-ray Radiograph of the SN 1037 Post-Discharged Showing the Deflected Cell Covers.

Figure 5. DPA Photo of the Sleeve Contamination.

Conclusion

Based on the results, ATB will be proceeding with 17-cell full scale prototypes based on the stacking ring design. This design style has led to robust performance with relatively little manufacturing complexity. These full-scale prototypes will also be subjected to relevant non-operational dynamics to ensure robust performance. If confirmed as successful, ATB will begin advancing the rest of the required subcomponents need. Future work on this project will begin the process of designing the pressure vessel and electrical feedthroughs required for the harsh Venusian environment.