High-Power Density Thermal Batteries for Space and Defense Applications

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Abstract

The ASB Group's LAN anode has been utilized for thermal batteries used in space and defense applications requiring high power density. The battery design provides a higher cell voltage, lower impedance and single flat voltage plateau compared to conventional lithium alloy anodes. Results are demonstrated in differing applications with consideration for practical application.

Keywords
Molten Salt Battery; Thermal Battery Power Density; LAN Anode

Introduction

Due to their maturity, reliability, and high-power densities, thermal batteries used in "one shot" systems are well known within the defense industry. They require no charging, no heating, no logistic constraints for transportation/storage, and no dedicated ground installation. Thermal batteries provide the highest power densities of any reserve battery technology and are unaffected by environmental conditions such as pressure, temperature, humidity, etc. They can be used in sets of several batteries connected in parallel or series thus providing modularity. Thermal batteries can be activated before the launch and safely sit during the no-load "idle time" in the minutes leading up to the high-power discharge. With such a proven record, thermal batteries are a great solution to support growing needs within the space and defense industry.

The use of LAN anodes for thermal batteries has been demonstrated in prior applications within the defense industry. LAN consists of a pure lithium anode, mechanically immobilized to allow practical implementation without the need to alloy the lithium with another material. Due to the inherent performance characteristics of LAN anodes, it has been used in applications requiring high power output within a relatively small battery volume.

Design Considerations

Current Density: Thermal batteries typically operate at steady state current densities of 1A/cm2, with short duration high current pulses of 10A/cm2 for durations in the hundreds of milliseconds. Practical implementation for satisfying high current requirements requires an increased battery volume, with a goal of increasing voltage and cell surface area. The primary means of addressing this is through increasing the cell diameter and thus the battery diameter, as well as increasing the battery length to accommodate parallel cell stacks or increased voltage. This can be challenging due to size and weight constraints experienced in aerospace applications as well as maximum allowed voltages for the system electronics. Use of the LAN anode provides an alternative to these constraints.

Voltage Profile: The LAN anode has the operating voltage of pure lithium. The voltage under discharge offers a relatively flat voltage plateau compared to the lithium alloys used broadly in thermal batteries. The single voltage plateau allows a higher operating voltage and thus higher power output during the entire battery discharge. Unlike lithium silicone alloy anodes, the consumption of all lithium during the discharge without subsequent lower voltage plateaus results in a safer battery design without excess and unusable electrochemical capacity. This becomes increasingly important when high current is being sourced which generates additional heat within the battery cells. In addition to high power output, the single voltage plateau provides a greater ability to remain within the required operating voltage during high current draw and the subsequent reduction in voltage due to cell impedance. Figure 1 provides comparison of lithium silicone, lithium aluminum, and LAN anodes for a cell of the same total capacity.

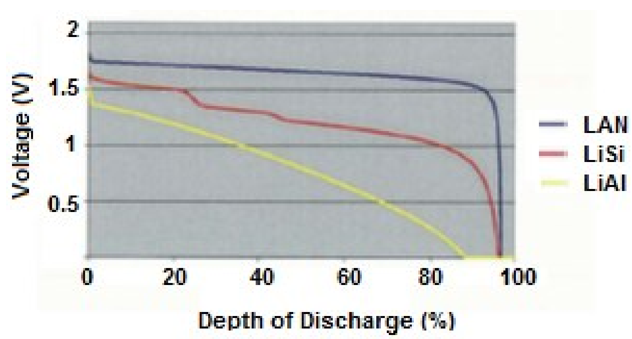

Figure 1. Cell Voltage Comparison

Cell Impedance: The internal resistance of a LAN anode is very low, in fact lower than in alloy anodes. Additionally, it is almost constant during discharge, since there is always liquid lithium which can react at the surface of the electrolyte separator layer. This is necessary during high current draws when the voltage is still required to be within the required operating voltage limits.

Temperature Considerations: By design, the lithium in the LAN anode is molten when in the operating state, but mechanically constrained to prevent it from leaving the confinement of the cell. Because the lithium is always and intentionally molten, it does not have the same risk of thermal runaway as lithium alloy anodes where the alloy can be broken down releasing lithium to escape from the cell. During high current discharge, the cell temperature will increase due to resistive heating. In small batteries with short operating times this increase in temperature may not be significant due to heat dissipation, however it becomes increasingly important in larger batteries with longer operating times. In these applications the heat is retained within the cells due to the inherent thermal mass, as well as the thermal insulation used to retain heat for longer operating life. The LAN anode's ability to tolerate increased temperatures without significant degradation in performance nor risk for thermal runaway makes it ideal for such uses

Conductors: Transmission of the high current from the battery requires special consideration. Battery size must be sufficient to fit the required number of internal leads between the cell stack and glass to metal sealed terminals in the header. Similarly, the header must have sufficient space for terminals and connections that may be larger than a typical battery. External connections that are welded or mechanically clamped are preferred as opposed to soldered to mitigate risk of the solder melting due to current induced temperature rise.

Battery Application A

A battery was developed and tested for an emergency power application requiring a very high current draw sustained for between 4 to 5 seconds. The maximum allowed voltage was 60V. The battery design consisted of a single cell stack of 28 cells in series. The overall battery size was 3.60 inches in diameter by 4.15 inches in length utilizing a stainless steel container. The LAN anode was paired with all lithium ternary electrolyte and iron disulfide cathode.

Figure 2. Thermal Battery A Configuration

Batteries were tested at operational temperatures of -40°C and 71°C. The battery is activated into an open circuit condition for up to 10 seconds followed by up to 16kW in the hot battery and 12kW in the cold battery for 4-5 seconds. Following the high current application, a bleed down current was applied until the capacity was depleted at approximately 300 seconds. In both cases the batteries supported the required load and continue to perform nominally after the high current. The load applied results in a constant current draw of up to 9.5A/cm^2 and a power density of more than 23 W/cm^3. Due to the activation mechanism used for the battery tested at -40°C, the battery was activated just before data recording started, not capturing the initial voltage rise.

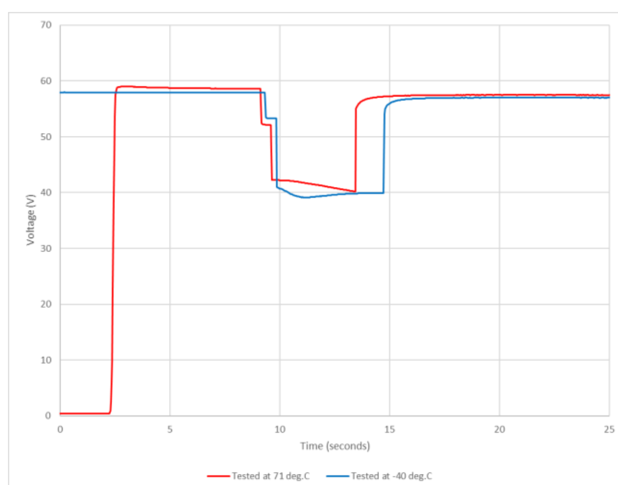

Figure 3. Thermal Battery A High Power Discharge

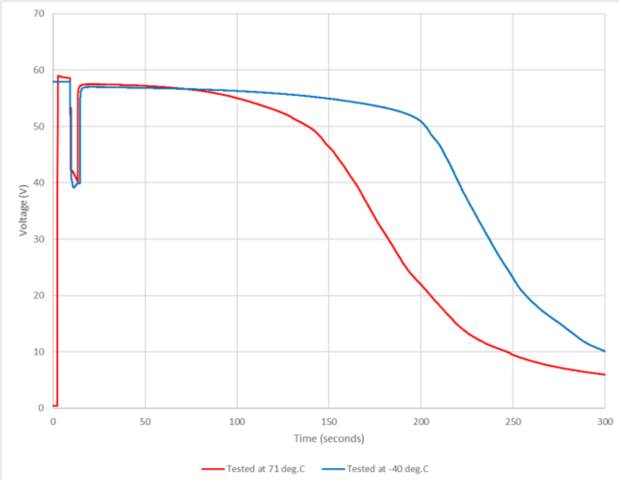

Figure .4 Thermal Battery A Complete Discharge

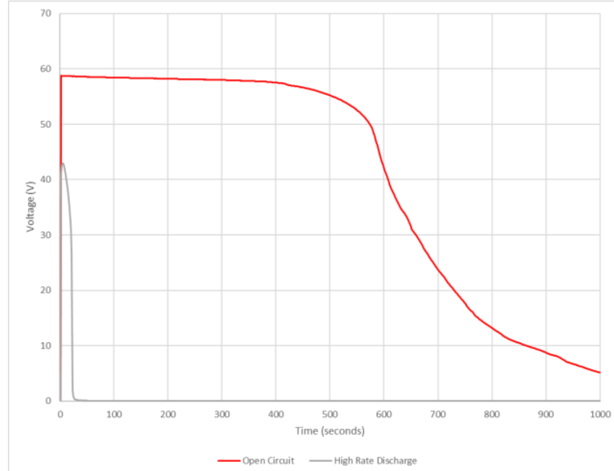

Figure 6. Thermal Battery A Abuse Testing – 1,000 Seconds

In addition to testing under normal system conditions, abuse tests were performed. One battery was preconditioned to 71°C and discharged using a high rate condition simulating the device continually drawing the peak power expected, with the load applied immediately upon battery activation. A second battery was tested after preconditioning to 71°C and activating into an open circuit condition. Both batteries remained intact with no abnormal conditions experienced. Upon completion of the tests, post-fire disassembly confirmed that the battery cells remained in nominal condition with no indication of degradation or thermal runaway.

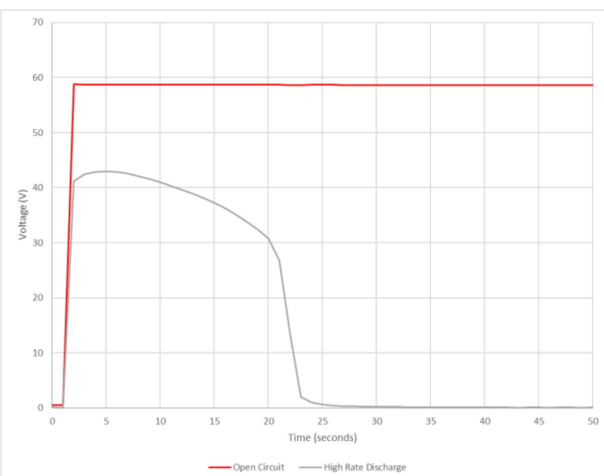

Figure 5. Thermal Battery A Abuse Testing – 50 Seconds

Battery Application B

A battery was developed and tested for an application that required a long operating life consisting mostly of a no load condition, but included high current pulses applied periodically through the discharge. The maximum allowed voltage was 200V. The battery design consisted of a single cell stack of 95 cells in series. The overall battery size was 3.00 inches in diameter by 8.7 inches in length utilizing a stainless steel container. The LAN anode was paired with a binary ternary electrolyte and iron disulfide cathode.

Figure 6. Thermal Battery B Configuration

Batteries were tested at room temperature. The battery is activated into an open circuit condition, with pulses of up to 16kW applied for 0.50 seconds each. The battery is able to support the high pulse load for over to 1000 seconds without significant change in voltage under pulses. Due to the use of the LAN anode, the battery remained stable during the discharge with no signs of thermal runaway or degradation of the cell stack. The load applied results in a pulsed current draw of up to 3.5A/cm^2 and a power density of more than 15 W/cm^3.

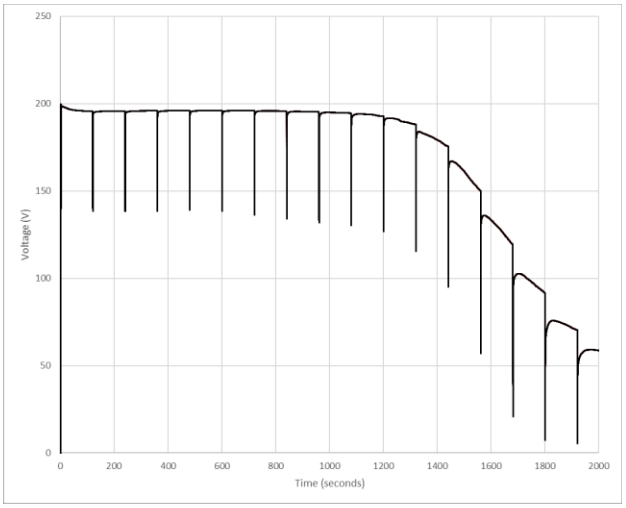

Figure 7. Thermal Battery B Discharge

Potential Applications

Development and testing work has demonstrated the use of thermal batteries using the LAN anode in applications requiring high current draw and power density across a range of conditions including constant and pulse loading Long operating time including low or no current draw is also tolerable. The unique set of performance characteristics allows for use in systems where high power is required in conjunction with the typical benefits of a thermal battery. Potential applications include emergency power, directed energy, charging capacitor banks, and decoy power.