Lithium Sulfur Rechargeable Battery Technology for Computer Application

June 17, 2004

Abstract

This paper provides information about lithium sulfur rechargeable battery development. It provides guidelines for computer manufacturers to assess how this enabling technology will impact their products in the future.

Lithium sulfur rechargeable battery characteristics, state of development and applicability to powering portable electronics will be discussed. It will be shown that this technology is capable of a specific energy of 400WH/kg and an energy density of 425 WH/liter. Evolution of the lithium sulfur technology over time has the potential of achieving a 25% improvement beyond these values. This exceeds the specific energy of the currently used lithium ion rechargeable by a factor of over 2 to 1 and is equivalent to lithium ion's energy density. That is, lithium sulfur will provide the same runtime for a portable computer in less than half the weight or twice the runtime in the same weight while having a comparable volume relative to lithium ion. This level of performance is obtained by virtue of the high energy inherent in the sulfur and lithium active materials and the novel design of the electrodes. Whereas ideally, the active materials in lithium ion yield about 500 WH/kg, the active materials in the lithium sulfur are more capable, yielding 2500 WH/kg. In addition, the ability to use plastic substrates for the sulfur cathode and vacuum deposition of lithium for the lithium anode provides weight savings not realized in other rechargeable technologies.

Prototype lithium sulfur cells, operating at 250 to 300 WH/kg and similar WH/liter values, are demonstrating a rate capability surpassing 3C and a temperature range of minus 60 to plus 60 Celsius. When charged and discharged at –10 to –20 Celsius at the 3C rate, the cell provides about 80% of the capacity and more than 75% of the watt-hours delivered at room temperature. At temperatures above 45 C^{o}, the cell provides more capacity at a higher voltage yielding about a 10% WH improvement relative to the room temperature value. Ragone plot comparison shows that the lithium sulfur cell will deliver higher specific energy than other rechargeable technologies such as LiIon, NiMH and NiCd at any discharge power. Self-discharge is at or below 15% per month.

Safety is improved relative to lithium ion in that, unlike lithium ion, lithium dendrites do not form in the lithium sulfur cell. This is a result of the electrolyte/liquid cathode system employed. Capacity and voltage at end of life are degraded by sulfur electrode fatigue and not by failure of the lithium electrode. Abuse testing at milestone design points in the development of this technology has demonstrated acceptable characteristics. The technology will meet safety standards.

Contents

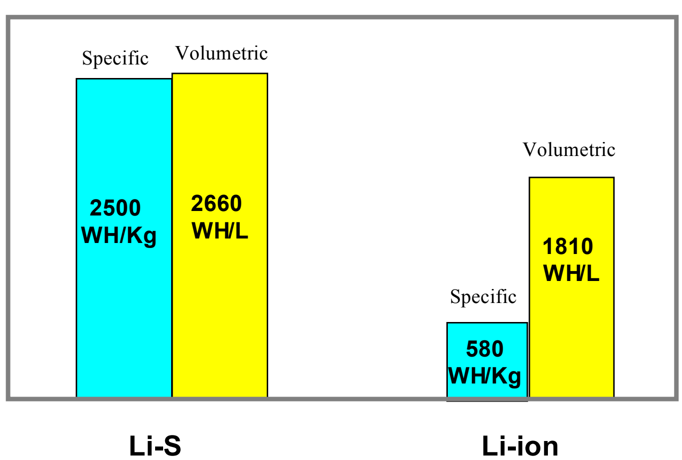
Windows Hardware Engineering Conference

Lithium Sulfur Technology: Background and Status

This paper provides information about lithium sulfur rechargeable battery development aimed at satisfying the power requirement for computer operation. The attributes exhibited by this chemistry are unique in exceeding all existing commercialized rechargeable chemistries in virtually all performance categories. In particular, its high specific energy, expressed as WH/kg, directly addresses the computer manufacturer's need that the battery provide additional runtime for a given weight or the same runtime for less weight. Further, with this battery electrochemistry, the goal of achieving an 8-hour runtime with a battery internal to the computer having a reasonable weight is possible. This will come with no trade-off in volumetric energy density, that is, the battery volume needed to provide a given runtime. This is possible because of the extremely high energy provided by the materials used in the lithium sulfur cell as illustrated in the figure below when compared with the materials used in the lithium ion cell. As shown, the theoretical energy provided by lithium sulfur exceeds that provided by lithium ion by a significant margin both in specific and volumetric energy. And as will be shown in this paper, the advantage in specific energy has already been realized in early

Why Lithium-Sulfur Technology ?

Theoretical Energy Density Comparison



prototypes. Figure 2 below illustrates the evolution in specific energy that has taken place together with improvement in cycle life. It should be noted that with dramatic increases in specific energy, there is typically a corresponding decrease in cycle life, followed by a period of improvement and so on. Prototype cells in the range of 300 to 350 WH/kg are now undergoing test. Volumetric energy density has been tracking the specific energy very closely to date, but is projected to surpass that value as geometric design factors assume a larger role relative to chemistry factors in any improvements obtained.

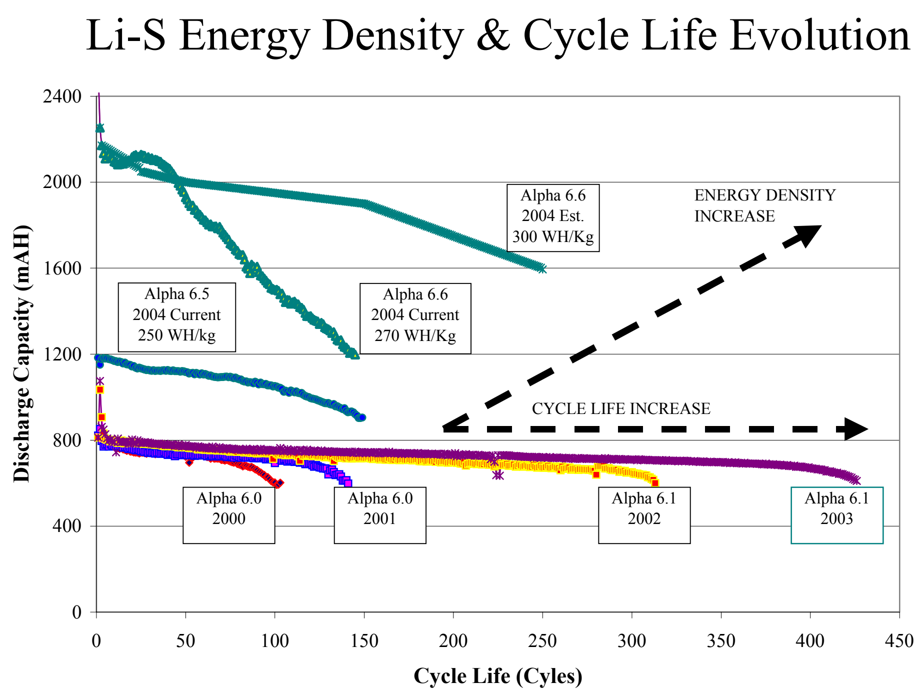
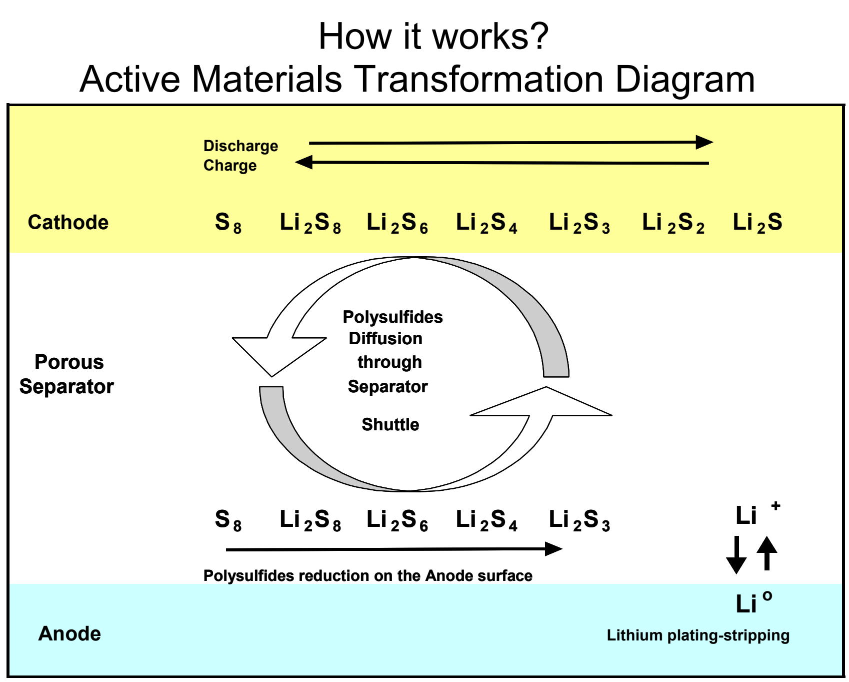
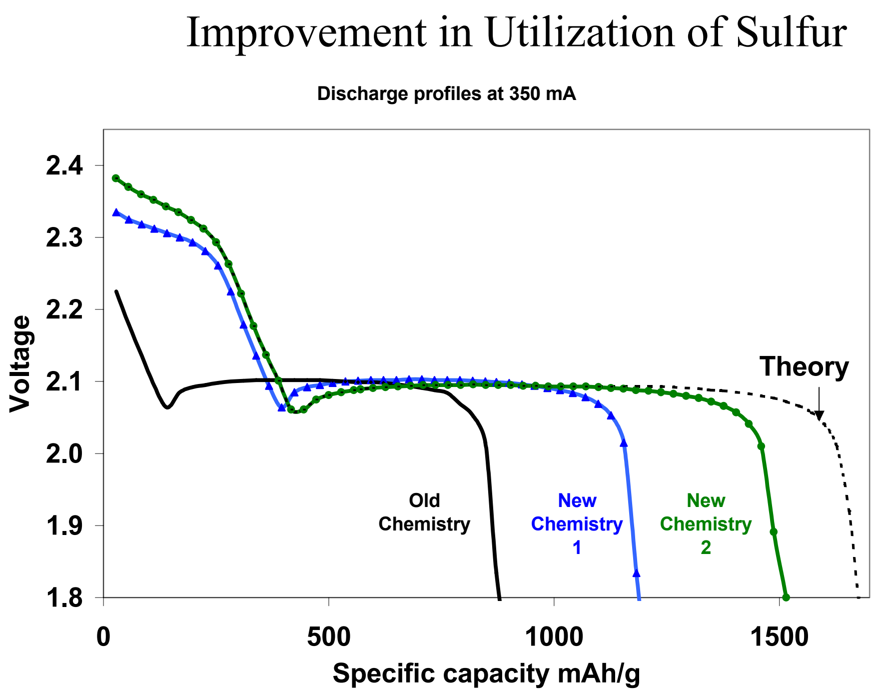


Figure 3 illustrates the electrochemical working of the cell. At the negative



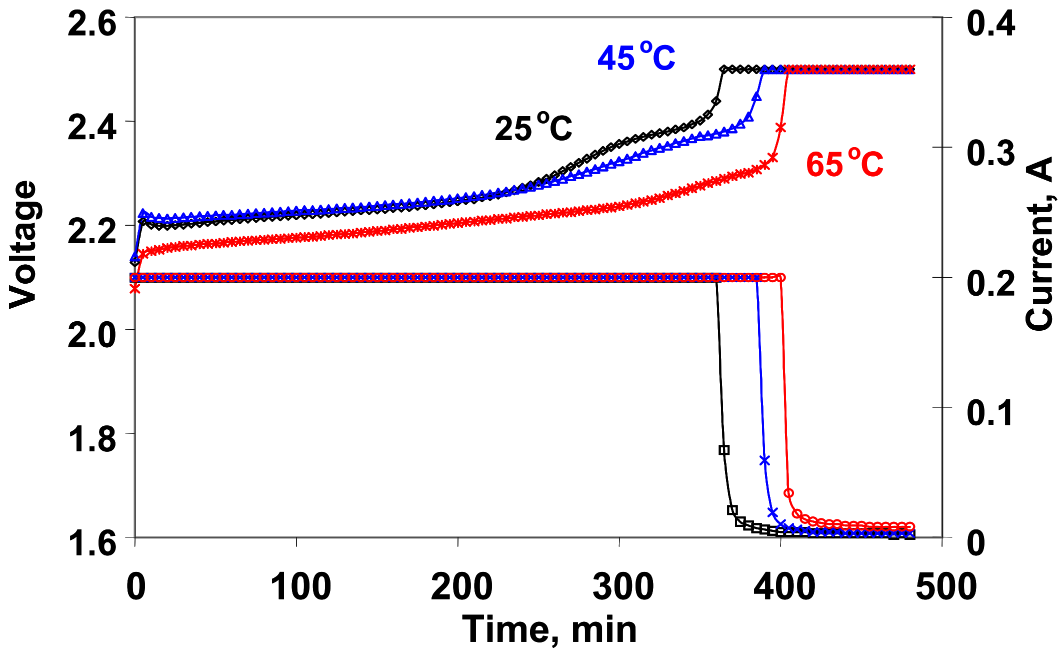
electrode, lithium is dissolved into solution on discharge and plated out on charge. The sulfur chemistry is more complex in that a series of sulfur polymers are formed. Higher polymer states exemplified by Li_2S_8 are present at high states of charge, the charged form of the battery. Lower polymer states, exemplified by Li_2S, are present at low states of charge, the discharged form of the battery. Significant advances in specific energy and energy density have been achieved recently by virtue of understanding the sulfur electrochemistry. Sion has been able to improve the sulfur utilization dramatically from about 46 to over 90 %. The result is that a gram of sulfur that was providing about 800 mAH now provides about 1500 mAH with no accompanying increase in weight or volume of the cell. This improvement is depicted in Figure 4 below.



Ease of charge and charge termination is of paramount importance in devising a battery technology suitable for consumer use. An industry-accepted charging protocol is the use of a constant current charge terminated when reaching a pre-set voltage. This may or may not be followed by a tapering current while maintaining the pre-set voltage. This method is simple, inexpensive to implement and well understood by both battery and device manufacturers.

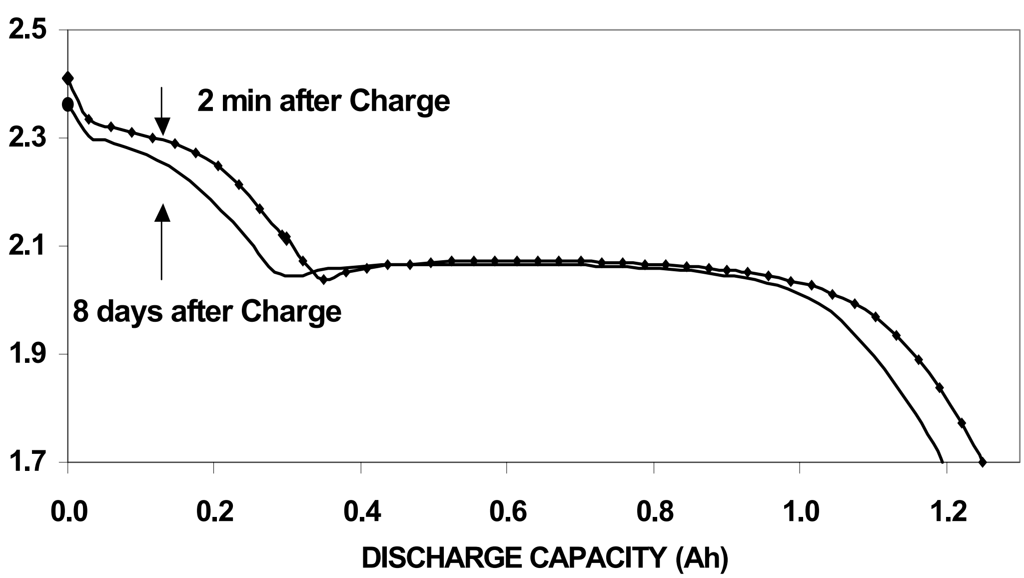
Studies have shown that the lithium sulfur electrochemistry adheres to this accepted standard charge protocol. This is demonstrated in Figure 5 below. As can be seen, the charge voltage increases during the charge until it ultimately exhibits a steep rise. In the test being illustrated, at the pre-set voltage, in this case 2.5 V, the current is tapered to lower values forcing the voltage to remain at 2.5. Further, this repeats itself in the same manner at all temperatures tested: 23, 45, and 65 C^{o}.

CHARGE PROTOCOL: Constant Current/Voltage w/ Taper

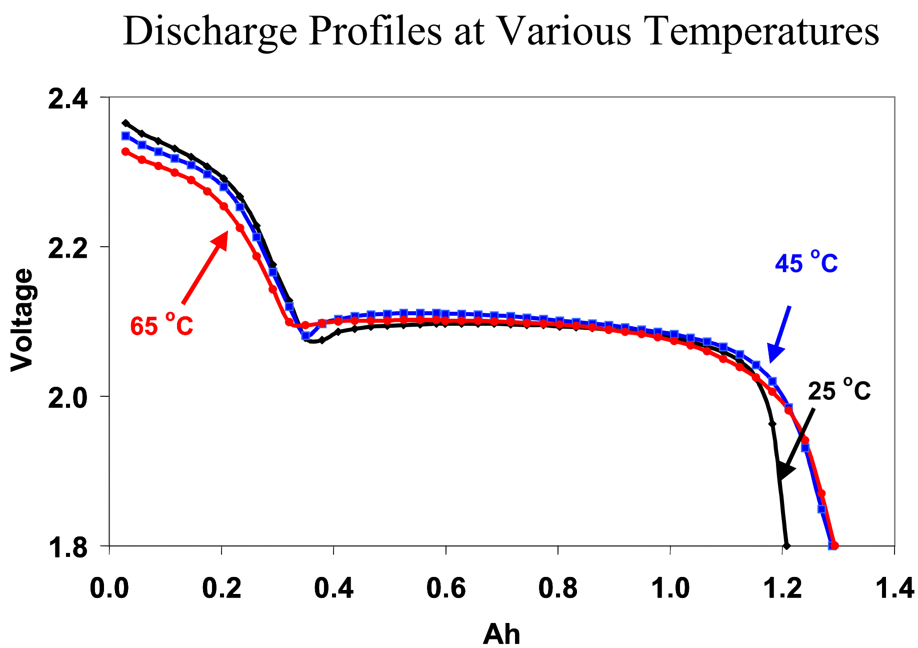


Following charge, typically the user does not immediately use the device, but may go for some extended and variable time prior to using. To measure the self-discharge from the charged cell, tests are conducted to characterize the charge retention over stand time. The figure below illustrates the voltage and ampere-hours delivered by the lithium sulfur cell following a charged stand time of over 8 days. As can be seen, the high voltage plateau is slightly depressed but the low voltage plateau is unaffected. In addition the delivered ampere-hours is about 96 % the value obtained with no stand. This performance is comparable with that of LiIon.

Charge Retention with Stand Time



The discharge of the lithium sulfur cell at various temperatures is given below in Figure 7. An approximate 10% improvement in watt-hours is obtained when discharge is conducted at 65 C° versus 25 C°. This is the result of an increase in delivered ampere-hours plus an increase in the average voltage.



Other characteristics of this technology include high discharge rate capability extending beyond 6 times the rated capacity and the ability to obtain useful energy at temperatures ranging from a low of minus 60 C° to a high of plus 60 C°. The latter comes with the additional benefit of being able to perform the charge as well as the discharge at the test temperature.

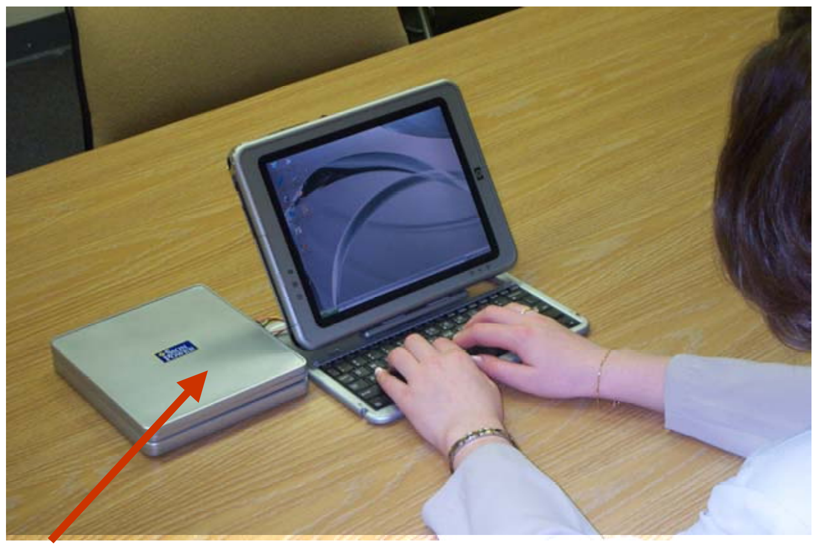
These attractive features come together in designs currently exhibiting 300 to 350 WH/kg and similar WH/liter values. Cycle life for these high specific energy and energy density designs is still low approaching 100 cycles but as shown above in Figure 2, historically this is typical. That is, as the energy within the cell is dramatically increased, cycle life becomes less until refinement of the design drives that characteristic back to acceptable values.

Application Testing

To study the operation of the lithium sulfur battery with a pen tablet, a HP TC1000 pen tablet was acquired for test. Design of a lithium sulfur smart battery was initiated during the summer of 2003 utilizing prototype cells having a specific energy of 250 WH/kg. The electronics, comprised of discreet components, provided controlling, monitoring and safety circuits. Fuel gauging was not part of the scope and will be incorporated in a following project. The plastics were machined parts. Although functionally sophisticated, the battery design, by virtue of the components used to construct it, is not optimized for either weight or volume nor was it possible to insert the battery into the cavity in the pen tablet since the form factor was different. The resultant battery consists of 20 cells arranged in 4 parallel strings of 5 cells inclusive of safety and controlling electronics. The battery provides 50 WH characterized by a voltage of 10.5 volts and capacity of 4.8 AH. The LiIon battery supplied as original equipment with the computer delivers about 40 WH and is characterized by a rated voltage of 11.1 volts and a capacity of 3.6 AH. It consists of 6 cells arranged in 2 parallel strings of 3 cells.

The prototype battery being used in conjunction with the computer is shown below.

WinHEC: HP Pen Tablet & Prototype Li-S Battery



10.5 V, 50 WH Battery utilizing 250 WH/kg prototype cells, discreet electronic components & machined plastics!

The particulars on the prototype lithium sulfur battery together with those of the target commercial product are given in Table 1. A 100 WH battery is projected for production using cells having a specific energy of 350 WH/kg.

Lithium Sulfur Battery Specification

Item	Prototype (1)	Production (2)
Voltage (V)	10.5	10.5
Capacity (AH)	4.8	8.8
WH/ battery	50	100
Cells (#)	20	20
Cell WH/kg	250	350
Cell WH/liter	265	400
Battery WH/kg		265 (3)
Battery WH/liter		320 (4)
Note 1: Prototype developed for WinHEC		
Note 2: Initial production battery for pen tablet applications		
Note 3: Projected based on current battery designs w/ cell contribution at 75 %		
Note 4: Projected based on current battery designs w/ cell contribution at 80%		

Summary

Lithium sulfur technology is demonstrating specific energy and energy density values that are far superior to any rechargeable battery technology in commercial production or on the research horizon. Charge retention with storage and charge termination protocols are consistent with the LiIon technology. Characteristics such as range of temperature use, rate capability and providing higher or at least the same capacity delivery as the temperature increases from 23 C^{o} to 60 C^{o} are far superior to those of LiIon and thus can be device and application enabling.

Areas for additional advancement are: increasing specific energy and energy density; increasing cycle life; continuous improvement in safety of cells and battery packs; and finally, exploiting lithium sulfur's unique chemistry for battery fuel gauging.