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380 Wh/kg Rechargeable Li/S Batteries Operating at 90% of Sulfur Utilization

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This work was focused on the development of high specific energy Li/S rechargeable cells with sulfur utilization close to the theoretical limit. New sulfur discharge promoter introduction resulted in 90% of total sulfur utilization or specific capacity exceeding 1500 mAh/g. Sulfur utilization breakthrough leads to creation of rechargeable batteries with experimentally proved specific energy of 380 Wh/kg. Experimental cells with weight~13.5 g, capacity ~2.4 Ah and average discharge voltage ~2.14V have been used as a test vehicle to evaluate the impact of electrolyte volume on the rate capability and to gather preliminary data on cycle life. Experimental cells contained 1.5 g of Li foil as anode and 1.5 g of elemental sulfur incorporated into a high porosity (~75%) cathode.

New capacity promoter impact has been studied in the cells with a protected Li anode[1]. Development of Li anode protection from polysulfide attack leads to a shuttle reduction of several orders of magnitude and self-discharge of ~ 4% per month. Fig.1 represents sulfur specific capacity typically observed with and without Li protection and capacity promoter. In the absence of Li protection Li-S cell cannot be recharged completely because of a shuttle and demonstrates reduced high plateau discharge capacity (Curve 1, Fig.1). Slow kinetics at end of discharge typically leads to reduced capacity at low plateau as well (Curve 1, Fig.1) with a total specific capacity ~ 800 mAh/g. Introduction of capacity promoter and Li protection elevated sulfur specific capacity to 1500 mAh/g (Curve 3, Fig.1). Ragone plot analyses show that Li/S cells deliver higher specific energy than LiIon, NiMH and NiCd at any discharge power (Fig.2). Li-S cells incorporating protected Li and capacity promoter deliver 380 Wh/kg at discharge power rate 35W/kg or C/12. Discharge power 35 W/kg corresponds to ~ 1C rate for Ni/Cd and ~C/5 rate for Li-ion systems. At discharge rates exceeding 500 W/kg cells with capacity promoter demonstrated lower rate capability compared with Li protected cells but without catalyst. More detailed study showed that these limitations were not caused by slow electrochemical kinetics itself, but blocking electrode porosity at very high sulfur utilization. Blocking was strongly affected by electrolyte volume/sulfur ratio. The lower the electrolyte volume the higher was the capacity drop at high discharge rate. Discharge curves generated at various electrolyte/sulfur ratios and discharge rates 130 and 2600 mA per gram of sulfur illustrate this phenomenon (Fig.3).

Preliminary cycle life evaluation showed that first generation of 380 Wh/kg cells can demonstrate ~70 cycles compared with 250-300 cycles already demonstrated for 250 Wh/kg Sion Power cells incorporating protected Li (Fig.4).

References

1. Y. V. Mikhaylik, J. R. Akridge, *204th Meeting of The Electrochemical Society, Orlando ,Florida, October 12-16, 2003.* Abs.430.

2. S. Cheon et el, *J. Electrochem. Soc.*, A800-A805, **150**, (2003)

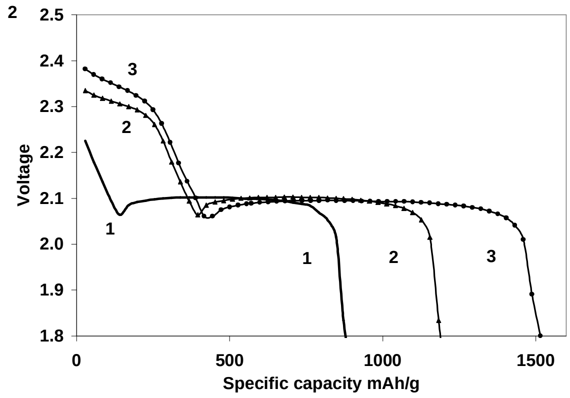

Fig.1. 10th cycle discharge profiles at C/3 rate:
1- typically published [2] for unprotected Li;
2- Sion Power protected Li;
3 - Sion Power protected Li + capacity promoter.

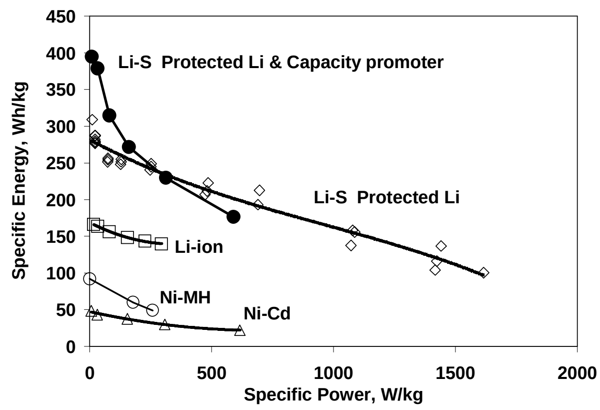

Fig.2. Ragone plots for various electrochemical systems.

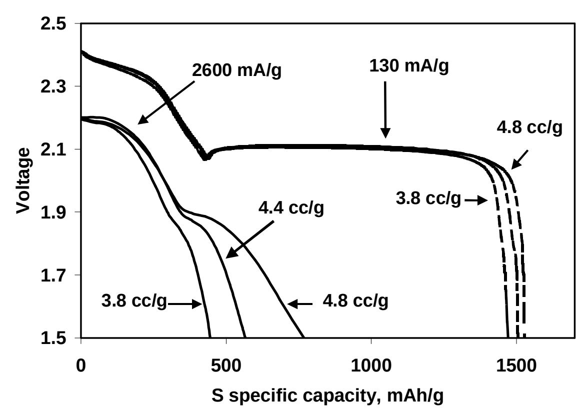

Fig.3. Discharge profiles at various electrolyte volume/sulfur ratios.

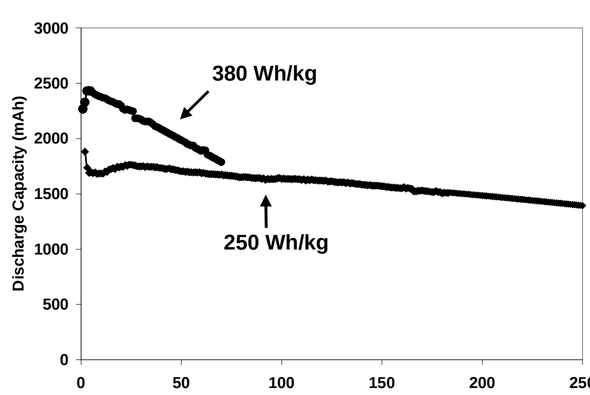

Fig.4. Discharge capacity vs Cycle for 250 and 380 Wh/kg cells.