High Energy Rechargeable Li-S Cells for EV Application. Status, Challenges and Solutions

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Outline

- Why lithium-sulfur technology?
  - Specific energy.
  - Rate capability.
  - Low temperature performance.
- Status of lithium-sulfur technology.
- Addressing the challenges.
- New approach pursued by Sion in collaboration with BASF for EV applications.
- Conclusions.
Why Lithium Sulfur Technology?

- Lithium ions are stripped from the anode during discharge and form Li-polysulfides in the cathode.
  - Li$_2$S in the cathode is the result of complete discharge.
- On recharge the lithium ions are plated back onto the anode as the Li$_2$S$_x$ moves toward S$_8$
- High order Li-polysulfides (Li$_2$S$_3$ to Li$_2$S$_8$) are soluble in the electrolyte and migrate to the anode scrubbing off any dendrite growth.

Theoretical Energy: ~2800 Wh/l and 2500 Wh/kg
Why Lithium Sulfur Technology?
Specific Energy

Typical experimental discharge and charge profiles with strong shuttle.

Charge and discharge profiles with shuttle inhibitor.

With NO₃⁻ additives Sion Power controls shuttle and achieves 100% of high plateau sulfur utilization, 99.5% charge efficiency and 350 – 450 Wh/kg
Why Lithium Sulfur Technology?

Rate Capability

Specific Energy, Wh/kg

Specific Power, W/kg

Sion Power Li-S
Li-ion 18650
Li-ion High Power
Ni-MH
Ni-Cd

Why Lithium Sulfur Technology?
Why Lithium Sulfur Technology?
Low Temperature Performance
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Batteries with optimized solvent and salt concentrations delivered:
1)~160 Wh/kg at -60°C at 1C,
2)~130 Wh/kg at -70°C at 1C,
3) The battery can be recharged at -60°C.

Charge and Discharge Profiles at -60°C

Voltage vs. Discharge Capacity, Ah

Charge 50 mA to 2.95 V
Discharge 2500 mA to 1.0 V
Status of Lithium Sulfur Technology

Limiting Mechanisms: 1) Rough lithium surface during cycling 2) Li/electrolyte depletion.
Addressing the Challenges
Keys to the EV Market for Lithium-Sulfur

• Challenges - cycle life and high temperature stability:
  – Dynamics of lithium surface roughness and cycling.
  – Solvent depletion chemistry.
The Dynamics of Lithium Surface Roughness
Monte-Carlo Simulation

- Initially, surface roughness increases in direct proportion to Li depth of discharge (DoD).
- Maximal surface roughness can be observed at ~50-70% of Li DoD.
- The typical scenario is cycling at low Li DoD.
- The best scenario is cycling Li anodes at 100% DoD – but only with a current collector.
The Dynamics of Lithium Surface Roughness
Experimental Observations

Cycling at 100% DOD of lithium prevents surface roughness but lithium/electrolyte depletion still occurs.
The Chemistry of Solvent Depletion
Experimental Observations

Solvent and metallic Li mass vs. Cycle Number (2.5 Ah Li-S battery).

- 1,2-Dimethoxyethane (DME) is mainly responsible for depletion.
- Mass of metallic Li in the cell did not change dramatically.
- However, visually Li looks completely depleted at 60-80 cycles due to roughening and disintegration of Lithium foil.
- The slopes suggests that Lithium and DME may react in a molar ratio of 1:1 to 1:2. Several Lithium alcohohlates can form by reaction with DME.
The Chemistry of Solvent Depletion
Products and Effects

Identified depletion products and their impact on battery performance.

- **DME**
  - Li/Li$_2$S$_x$
  - O\(\text{OLi}\)
  - MeOLi
  - MeS$_2$Li
  - CH$_4$
  - Traces

  **DME**
  - High amount, highly soluble and highly detrimental for S cathode performance.
  - Moderate amount, low solubility, neutral.
  - Small amount, soluble, consumes S.
  - Traces.

- **DOL**
  - Li/Li$_2$S$_x$
  - O\(\text{OLi}\)
  - \(\text{R} (\text{O}) \text{OLi}\)
  - \(\text{H}_2\)

  **DOL**
  - Highly soluble and highly detrimental for S cathode performance.
  - Increases anode polarization
  - Traces

New Approaches Pursued by Sion in Collaboration with BASF for EV Application

• Reduction of lithium roughness.
  – Proprietary anode design.

• Development of innovative materials
  – Structurally stable cathodes.

• Materials developed by Sion/BASF
  – Physical protection of lithium with multi-functional membrane assemblies.
Lithium Roughness Development
Proprietary Anode Design

Proprietary design allowed for increased charging rate without increase in surface roughness.

Charge Current Changed from:
an 8-hour charge
to a 2.5-hour charge

Experimental batteries cycling behavior
Lithium Roughness Development
Proprietary Anode Design

Experimental batteries cycling behavior

Li anode after 450 cycles. Initial and final Li thickness ~24 µm.

Li Figure of Merit (FoM) exceeds 100 at Li DoD ~26-30%.
FoM = DoD x Number of Cycles.
Cathode structure improvement resulted in sulfur utilization increase from 1.2 Ah/g to 1.45 Ah/g.

This development paves the way to increasing specific energy from the current 350 Wh/kg to the 550 Wh/kg needed to achieve a 500 km EV range.
Thermal Ramp Test of Fully charged Li-S batteries after 20 cycles at 5 °C/min.

With Sion-BASF protective layer on anode, there is no thermal runaway.
Conclusions

Reduction of lithium surface roughness with new anode design, and better cathode structure, resulted in:

• Recharge time reduced to less than 3 hours.
• Substantial cycle life increase if lithium surface roughness suppressed.
• Sulfur utilization increased to 87%, or 1.45 Ah/g, paving the way to 550 Wh/kg Li-S battery.

Innovative anode design, and Sion Power-BASF protective membranes, increased thermal stability of Li-S cells – eliminating thermal runaway. Batteries passed the melting point of the Li without violent events.
Takeaway

Sion Power Corporation, in collaboration with BASF, is very optimistic that the future of all electric EV applications will be dominated by Sion Power’s lithium-sulfur technology.