High-Energy Lithium-Sulfur Batteries

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Overview and Scope of Project

This project investigates solid-state Li-S chemistry as high energy batteries for electric grid applications. In this design, solid electrolytes will replace conventional liquid electrolytes and separators. Lithium ion-conducting sulfur compounds will be cycled at the solid state as the cathode. The anode will be pure metallic lithium. The use of a solid electrolyte is a key innovation of solid-state Li-S batteries as opposed to conventional Li-S batteries in which liquid electrolytes cause intrinsically short cycle-life, low energy density, and safety concerns. The goal of the project is to achieve long-lived stable cycling of high-energy solid-state Li-S batteries through the discovery of new functional materials and the innovation of electrode and battery structures.

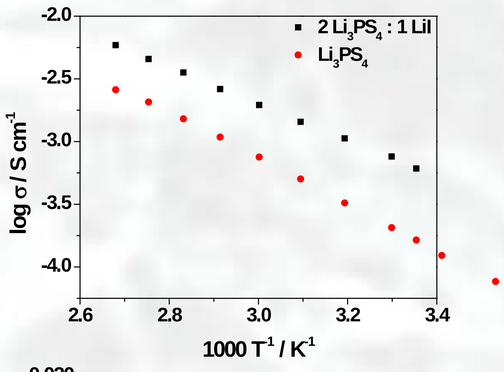
Why Li-S batteries

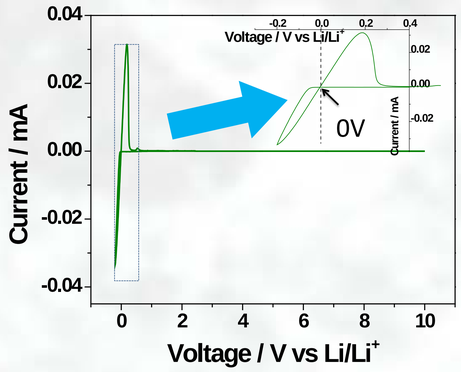
Li-S Batteries Research Is Motivated by Their High Energy and Low Cost

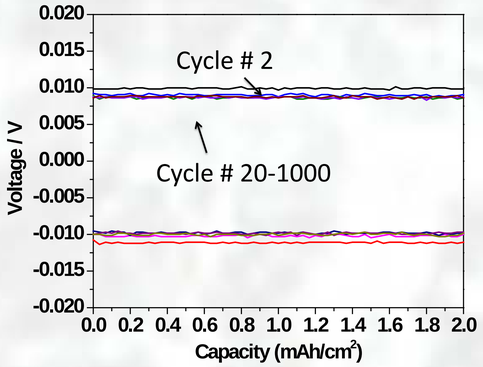
High energy density
- Theoretic: 2550 Wh/kg, 2862 Wh/l

Low cost
- Sulfur is free
- Cell cost is low: $100/kWh

Development of high performance solid electrolyte has a high ionic conductivity and excellent compatibility with metallic lithium anode

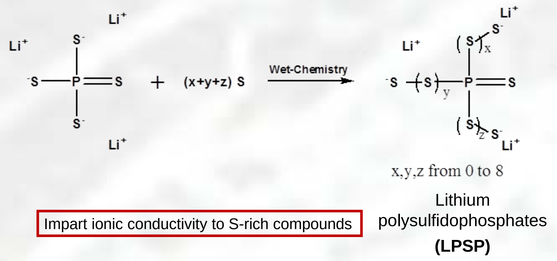






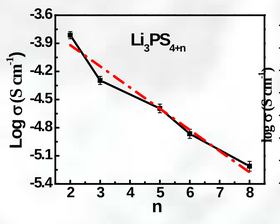
- 2 LPS·LiI has the best electrochemical stability among reported Li-ion conductors
- DC conductivity = AC conductivity → Low charge transfer resistance
- DC polarization is linear up to a current density of 1.26 mA cm^{-2}
- 10V electrochemical window

Lithium-ion conducting cathode materials are key to solid-state batteries

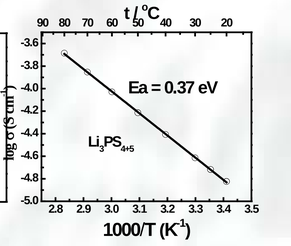


Impart ionic conductivity to S-rich compounds

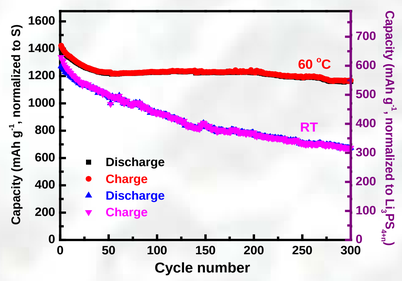
Lithium polysulfidophosphates **(LPSP)**

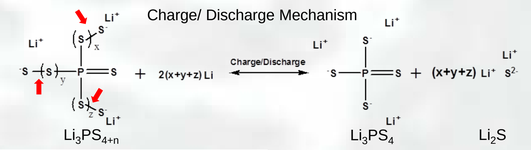


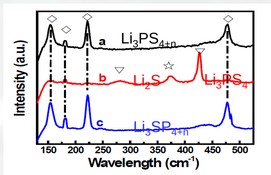
Room temperature conductivity as a function of S-S bonds in LPSP



Room temperature ionic conductivity of Li_3PS_{4+5} is 10^7 times higher than that of Li_2S!



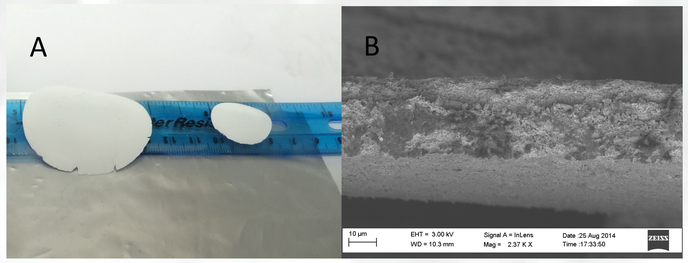




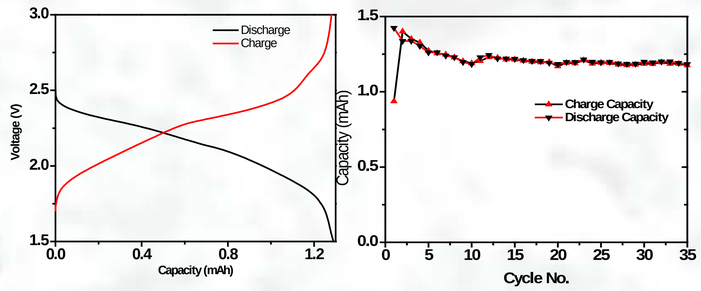
a, before cycling
b, after first discharge cycle
c, after first charge cycle

S-S bonds are key to the electrochemical function.

Key development for high-energy and high power solid-state batteries



Thin solid electrolyte membranes are crucial for high energy density and excellent cell performance. A slurry coating method has been developed to create free-standing membranes of 2" diameter and 20 µm thickness.



TiS_2 has been identified as a mixed conductor to carry out three functions: (1) inorganic binder, (2) electronic and ionic conductor, and (3) contributor to total capacity.

Stable cycling of LPSP with TiS_2 at the solid state

Conclusions

- Newly developed composite electrolyte of LiI-LPS is promising
  - High ionic conductivity >10^{-4} Scm^{-1} at room temperature
  - Wide electrochemical window up to 10V
  - Extremely stable with lithium metal anode
- Li^+-conducting sulfur cathode enables all-solid Li-S batteries
  - Ionic conductivity is key to battery cycling
  - TiS_2 functions as the binder, electronic and ionic conductor, and capacity contributor
- Slurry coating method provide thin solid electrolyte membrane
  - Cell resistance has been reduced because of a thin membrane
  - Energy density can be improved

FY15 plan for grid applications

- Explore the additive effect with metal sulfides as the electronic and ionic conductor for the optimization of cathode compositions.
- Construct large cells to demonstrate the high energy density of solid-state Li-S batteries.
- Optimize the membrane synthesis procedure for large pouch cells.
- Enhance the cell rate performance by using high conduction solid electrolytes.

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