High Performance Li-S Batteries Using Bio-Inspired Materials  
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Introduction

- **Background**
  - Lithium-sulfur (Li-S) batteries are considered as beyond Li-ion technologies to the future energy system in the applications of electrical vehicles.
  - Sulfur, an abundant element on Earth, can accept two electrons per atom above 2.1 V vs. Li/Li⁺, which promise the Li-S battery a high theoretical energy density of 2500 Wh kg⁻¹.
  - **Major issues that impede Li-S application:**
    1. Low capacity due to the insulating nature of both sulfur and its discharge products;
    2. Poor cycling life caused by shuttle effect of soluble long-chain lithium polysulfides that produced during the cycling.
- **Solution:**
  1. Encapsulating sulfur within the conductive porous carbon;
  2. Doping heteroatoms to chemically absorb polysulfide.
  - **Natural silk cocoon** is an environmentally friendly and nitrogen-rich carbon precursor.

Objective

- Synthesize a novel hierarchically porous nitrogen-doped carbon material from silk cocoon biopolymer.
- Fabricate the silk-derived nitrogen-doped carbon/S (NC/S) composite as cathode material for Li-S batteries.

Experiment

- **Synthesis of silk-derived nitrogen-doped carbon (NC)**
  - Regenerate Silk Precursor → Carbonize at 750°C/800°C → Heat at 140°C → Regenerate Carbon

Fabrication of NC/S composite

Coin cell test with low and high sulfur loading

Results

Figure 1. SEM images of NC carbonized at 750 °C (a), 800 °C (b) and 900 °C (c).

Figure 2. (a) N₂ adsorption–desorption isotherm; (b) Pore size distribution; (c) XRD patterns of sulfur, NC800 and NC800/S composite; XPS spectra of (d) C1s, (e) N1s, and (f) S 2p.

Figure 3. SEM image with corresponding energy dispersive spectroscopy (EDS) maps of the NC800/S composite.

Electrochemical Performance

Figure 4. (a) Cycling performance of NC750/S, NC800/S and NC900/S at 0.5C; (b) Rate performance of NC750/S, NC800/S and NC900/S at various current densities from 0.1C to 2C; (c) Discharge/charge profiles of NC800/S; (d) Long-term cycling performance of NC800/S electrode with higher sulfur ratio at 0.2C.

- NC800/S exhibit the highest specific capacity and best rate performance.
- The specific capacity of the battery could remain 528 mAh g⁻¹ at 0.2 C after 500 cycles.

Conclusion

- A novel biomass porous nitrogen-doped carbon has been developed through a carbonization procedure by using natural silk as precursor.
- The pore structure and nitrogen content of the NC change with the carbonization temperature.
- NC800 possess the most mesopores, and it is rich in nitrogen element in carbon frame, which can confine and absorb the polysulfide. In hance, the NC800/S composite exhibit the best electrochemical performance.
- With a higher ratio of sulfur and carbon, the NC800/S composite cathode can still display a stable cycling ability over 500 cycles.

Future Work

- Investigation of the interaction mechanism between nitrogen and polysulfides.
- Construction of physical barrier outside S/C composite to further mitigate shuttle effect during the initial cycles.

Reference