Porous Silicon Templated Nanoporous Carbon for Tunable Li-S Battery Electrodes

Dennis C. Ejorh[1], Rachel E. Carter [2], Keith E. Share [3], Anna E. Douglas [3], Adam P. Cohn [2], Dr. Cary L. Pint [2]

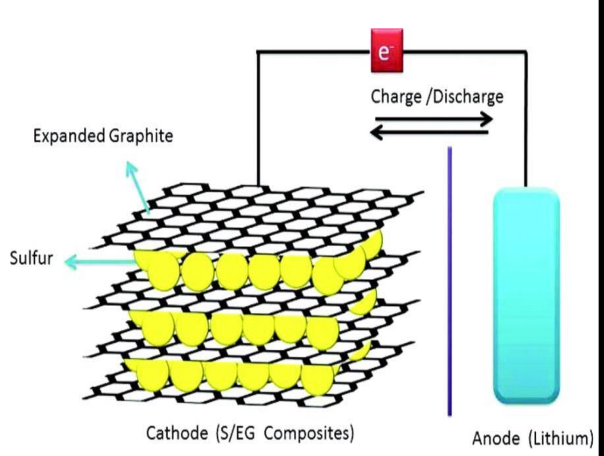
Department of Electrical Engineering[1] *, Tennessee Technological University, 1 William L. Jones Dr., Cookeville, TN 38505*

Department of Mechanical Engineering[2] *and Department of Interdisciplinary Materials Science*[3]*, Vanderbilt University, Nashville, TN 37235*

Introduction

- Lithium-ion batteries have proven to be the universal standard for commercial battery technology. However, materials that comprise conventional lithium-ion battery electrodes are expensive and environmentally scarce (e.g. lithium, cobalt, etc.).
- Lithium- Sulfur batteries are currently viewed as the likeliest replacement for conventional lithium-ion electrodes, boasting high theoretical capacity about 6 times higher than conventional lithium-ion

Li-S Battery in Action



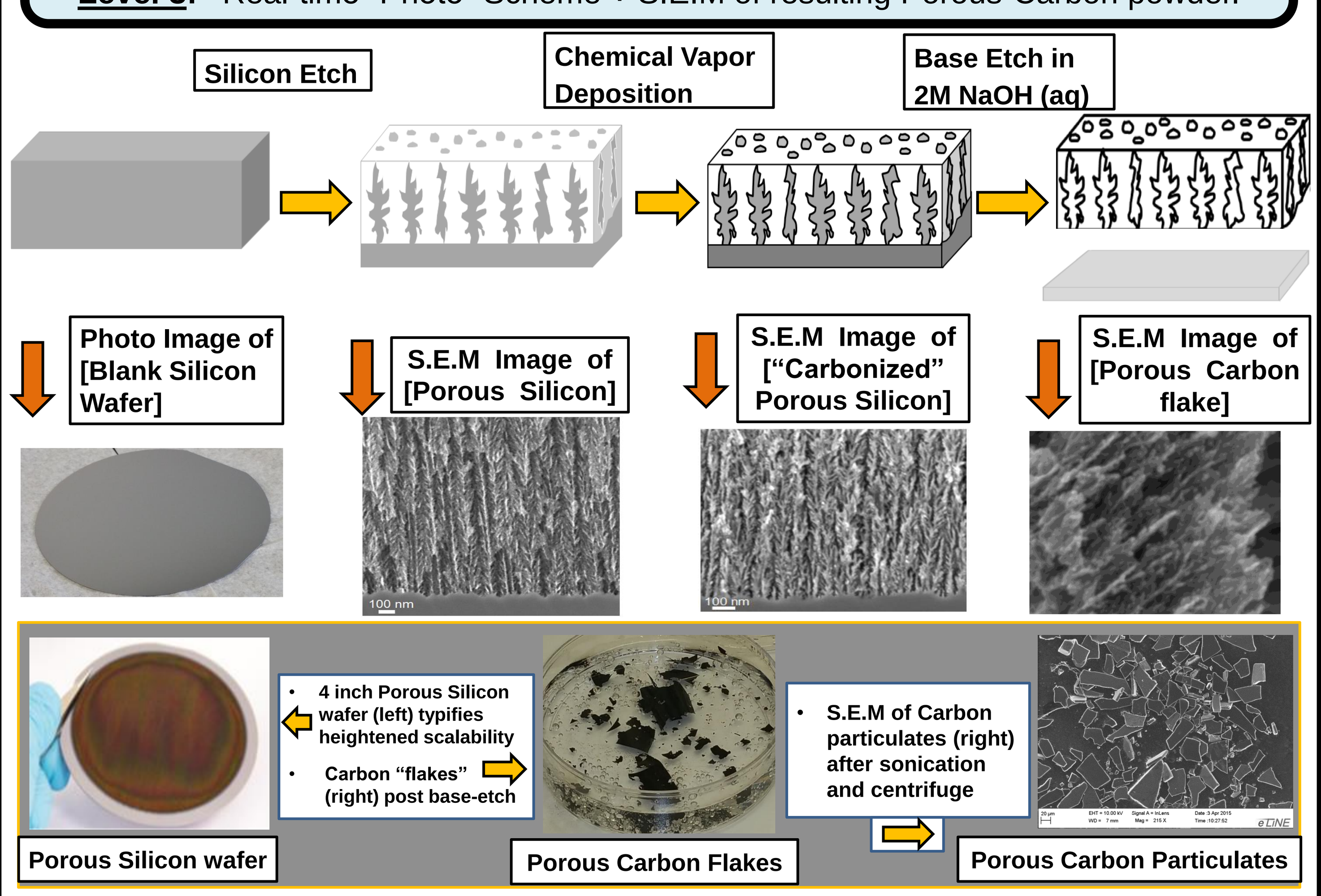
S. Li, et al. *The Electrochemical Society*, 2011.

Goals

- We aim to promote an economically innovative means of fabricating high-performance electrode material, through the implementation of scalable processes and utilization of low-cost process materials: Silicon and Carbon.
- Optimize Device performance by addressing the main conundrum in Li-S battery research: poor cycle performance caused by irreversible anode reaction of higher-order lithium poly-sulfides

Material Synthesis

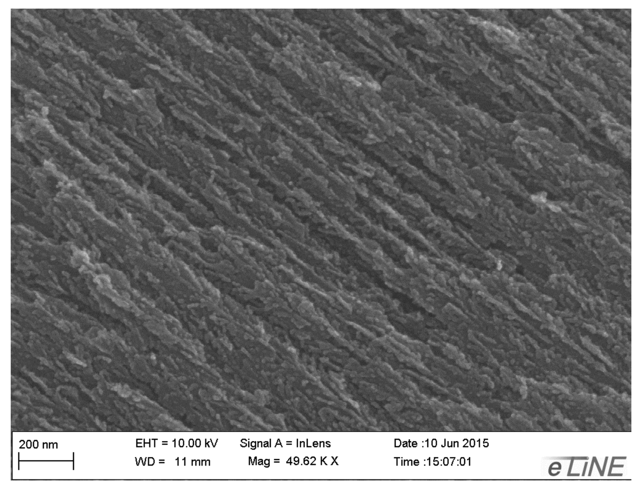
- **Level 1**: Scheme of Porous Carbon Fabrication [From Pristine Wafer to Base Etch]
- **Level 2**: S.E.Ms of each stage of porous carbon synthesis
- **Level 3**: "Real-time" Photo- Scheme **+** S.E.M of resulting Porous-Carbon powder.



Li-S Battery Sulfonation Process

Pre-Sulfonation

Photo of "pre-Sulfonated" Porous Carbon



S.E.M of "Carbonized" Porous Silicon

Post-Sulfonation

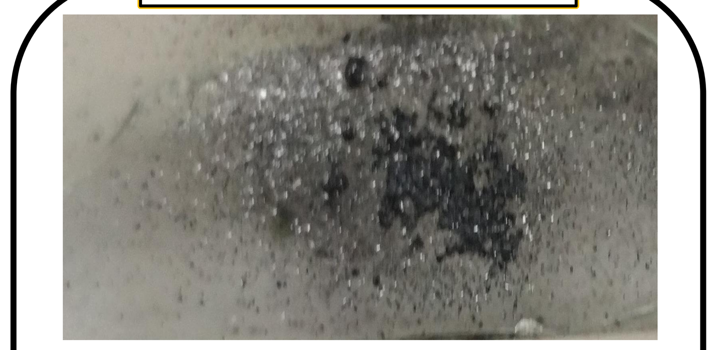
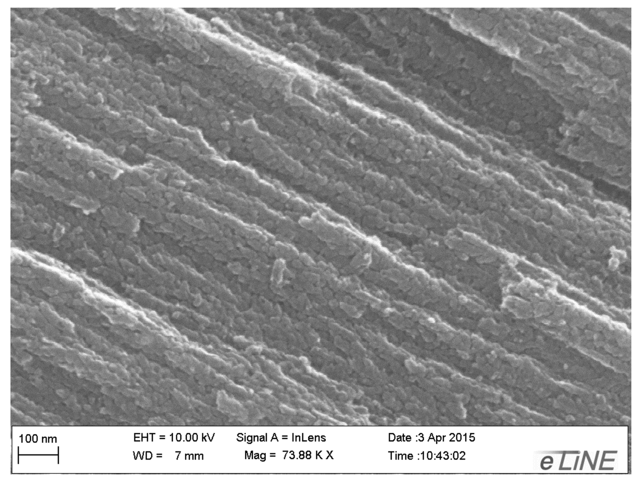


Photo of "Sulfonated" Porous Carbon



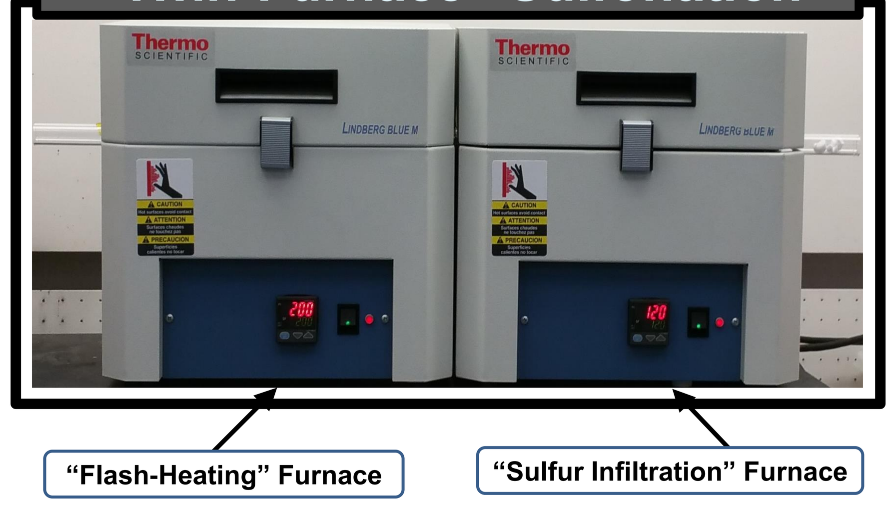
S.E.M of "Sulfonated" Porous Carbon

- The SEM of pre-sulfonated carbon (on left) gives a cross-sectional view of the porous nano-structure.
- SEM of the sulfonated carbon (right) shows clearly a fuller overall pore structure thus validating success of sulfur intrusion.

Pre-Sulfonation: Avg. Pore Diameter= 25 nm Avg. Pore Depth= 3.2 µm

Post-Sulfonation: Avg. Pore Diameter= 18 nm Avg. Pore Depth= 2 µm

"Twin-Furnace" Sulfonation

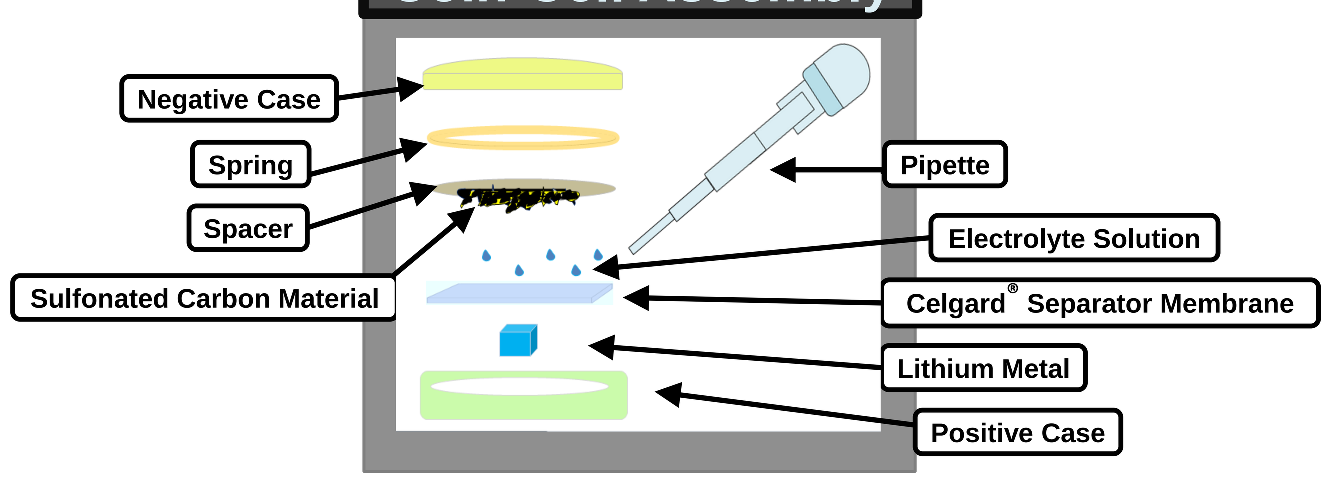


Two-Part Process

- **Part 1**: Sulfur Infiltration at 120°C (~ 5-6 hours).
- **Part 2**: Sulfur flash-heating at 200°C (preheated) for ~2 min.

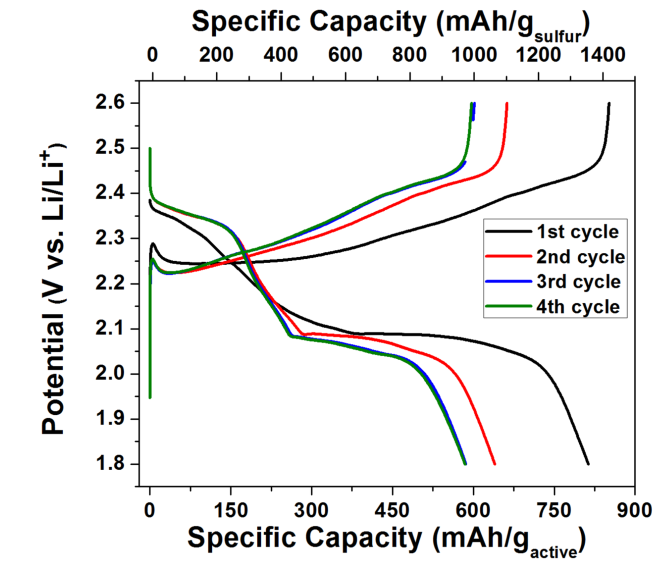
- **Sulfur coating of the Carbon mesopores (capillary action).**
- **Encapsulation of Sulfur permits volumetric expansion of high-order lithium poly-sulfides.**

Coin-Cell Assembly

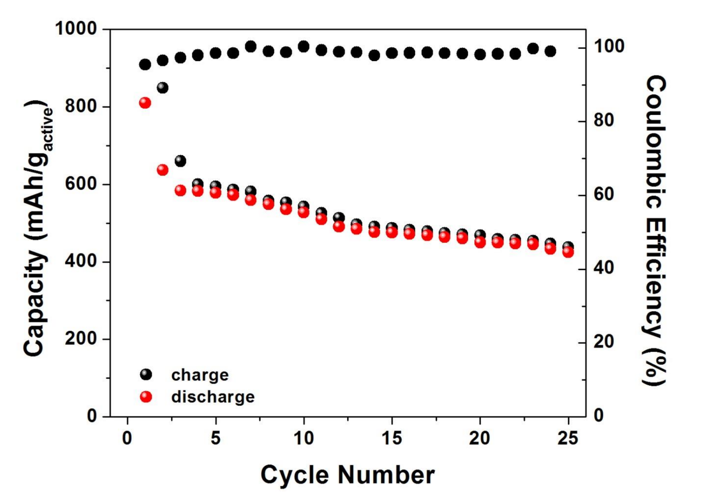


Results

Charge/Discharge Curves

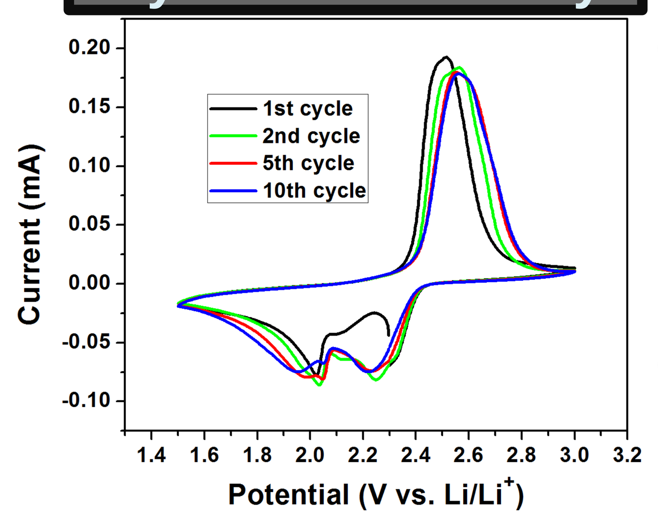


Cycle Behavior Plot



- These are the performance data for the devices that I made using the 120°C infiltration and 200°C "burn-off" sulfonation process.
- The charge/discharge curves (left) show an optimal initial capacity of ~1400 mAh-g_{sulfur}^{-1} (at a ~.1A/g current loading) and subsequent cycle capacities of ~850 mAh-g_{sulfur}^{-1} .
- The cycling behavior plot (right) shows high coulombic efficiencies of ~ 99 percent (almost negligible number of side reactions) and capacity retention of ~ 60 percent.

Cyclic Voltammetry



- The cyclic voltammetry plot suggests there is low overvoltage at work.
- As can be seen, reactions occur around the same potentials: oxidization (2V and 2.4V) and reduction (~ 2.5V)
- A noticeable occurrence is that of the two oxidization peaks (at 2V and 2.4V) which indicate the multiple stage discharge process exclusive to Li-S batteries.

Conclusions and Future Goals

Compared to state-of-the art advances in lithium sulfur batteries, we have demonstrated

1.) Comparable or better electrochemical performance (optimal:~1360 mAh-g_{sulfur}^{-1} ; average:~1000 mAh-g_{sulfur}^{-1}) that rivals or surpasses previous studies (i.e. **Sulfur-TiO_2 yolk-shell encapsulation**, Nat. Commun. Vol 4. Article:1331. 2013 and **mesoporous carbide derived carbon**, ACS Nano Vol 8. 12130-12140. 2014).

2.) A new porous silicon templated carbon material that is low-cost, scalable, and builds from common processes in semiconductor manufacturing, but boasts better tunability of the porous structure compared to previous materials that is critical to achieve optimized performance in lithium-sulfur cells.

- **Future Goals**: In future, we would like to showcase results using full-cell batteries.

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