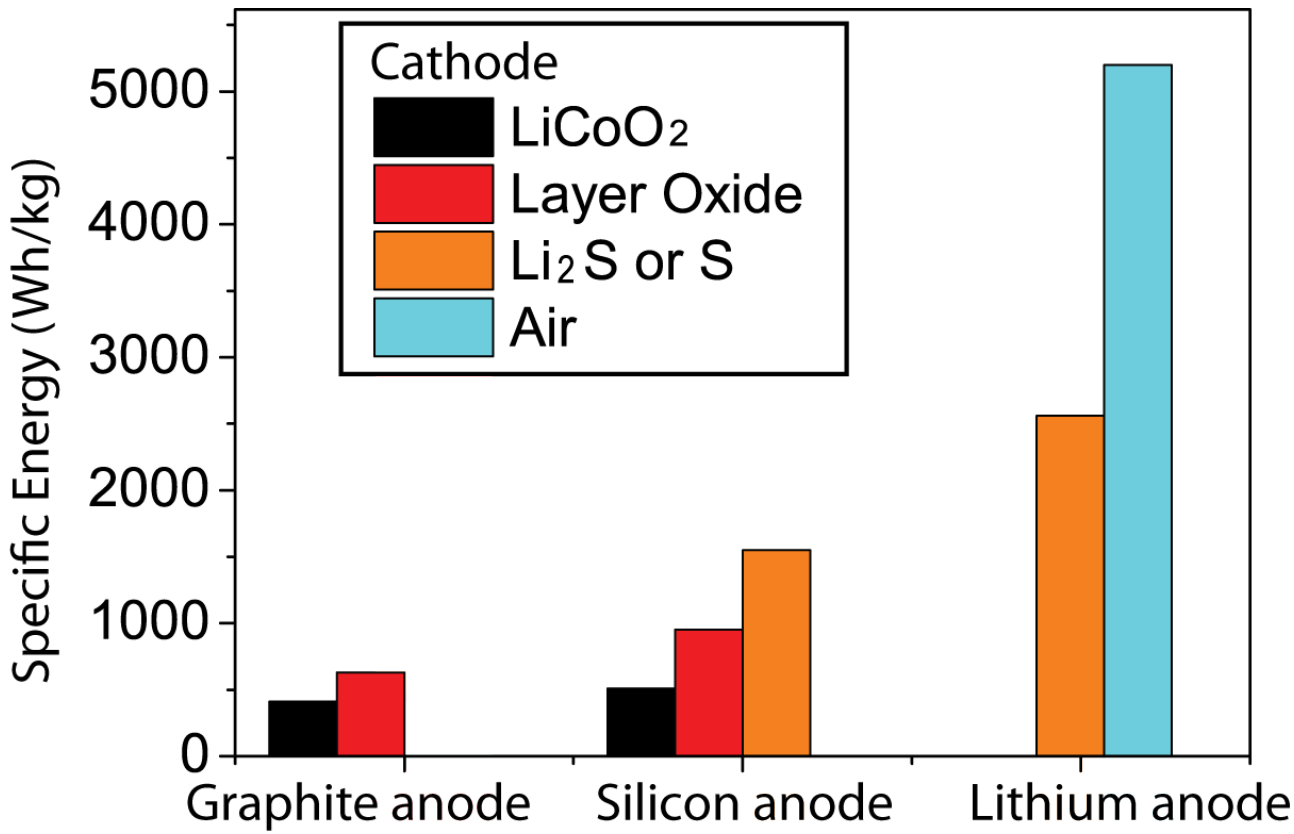
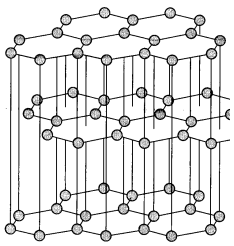
Li Metal Anodes and Sulfur Cathodes through Nanomaterial Design

Guangyuan Wesley Zheng
Stanford University

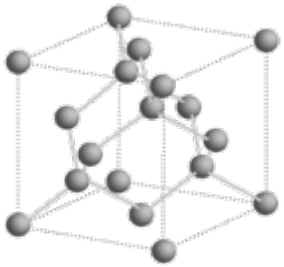
June, 2, 2015


Cathode
LiCoO2
Layer Oxide
Li2S or S
Air
Specific Energy (Wh/kg)
0
1000
2000
3000
4000
5000
Graphite anode
Silicon anode
Lithium anode

Anode Material Properties



$$6\ C + Li \rightarrow LiC_6 \quad \sim 10\ v\%$$



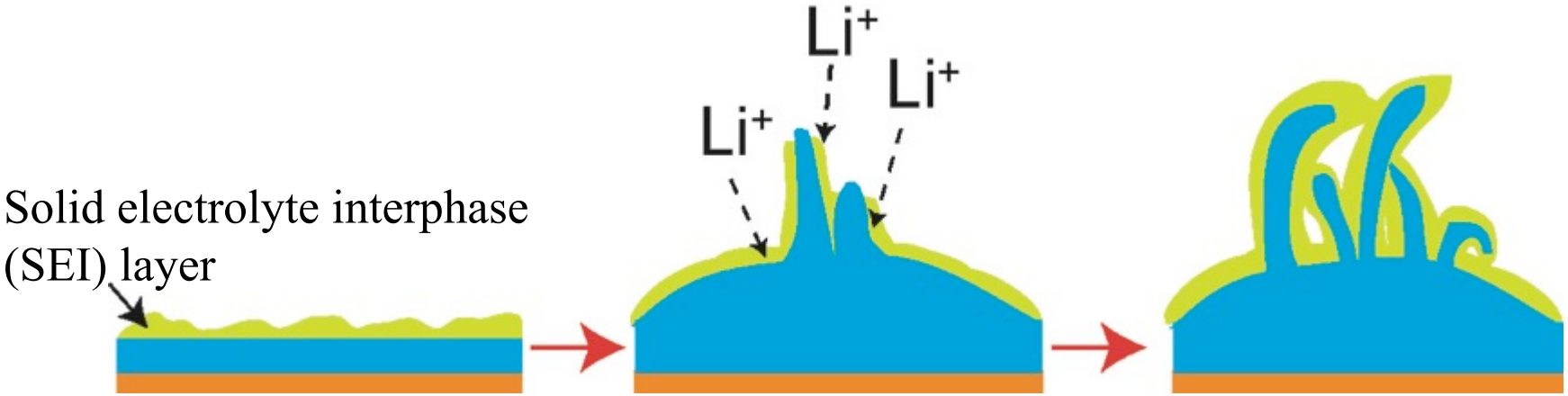
$$Si + 4.4\ Li \rightarrow Li_{4.4}Si \quad \sim 400\ v\%$$

Li

Virtually infinite

Lowest anode potential: -3.04 vs SHE

Issues of Lithium Metal Anode



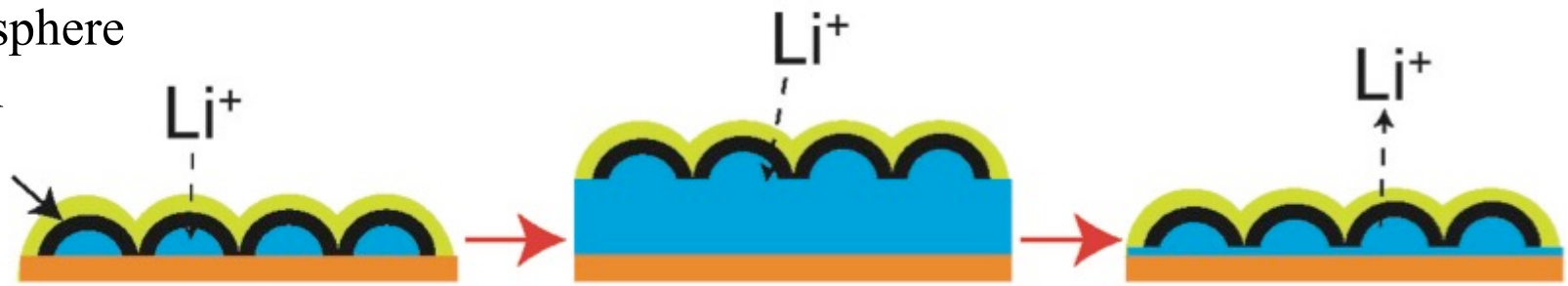
Low Coulombic Efficiency

Dendrite formation

- **Chemically stability**
- **Mechanically strength**
- **Accommodation of volumetric expansion**

Ideal Interfacial Layer

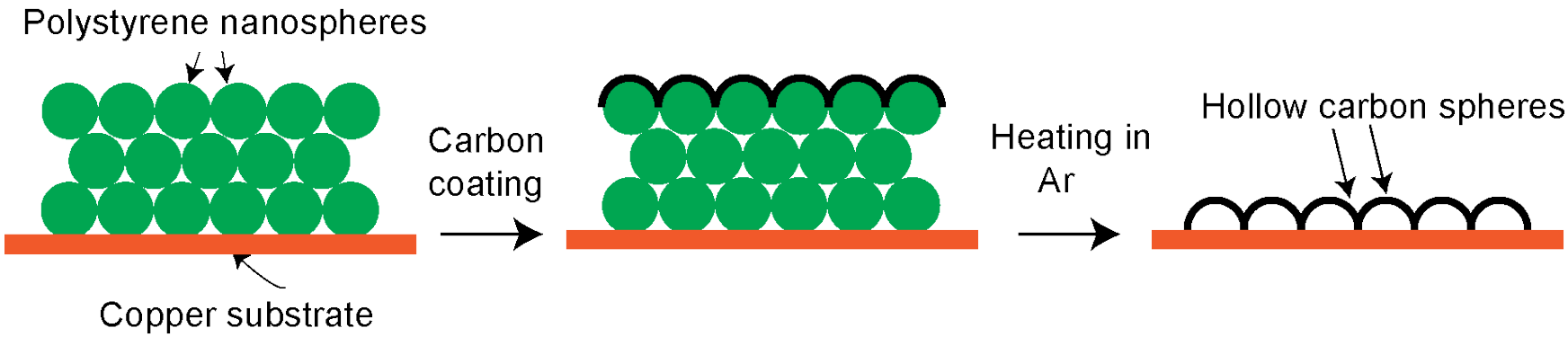
Carbon sphere
thin film

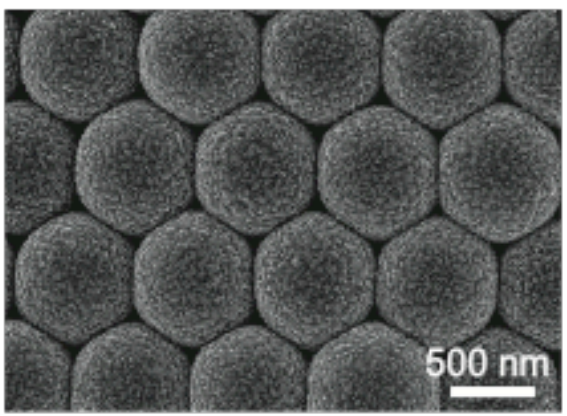


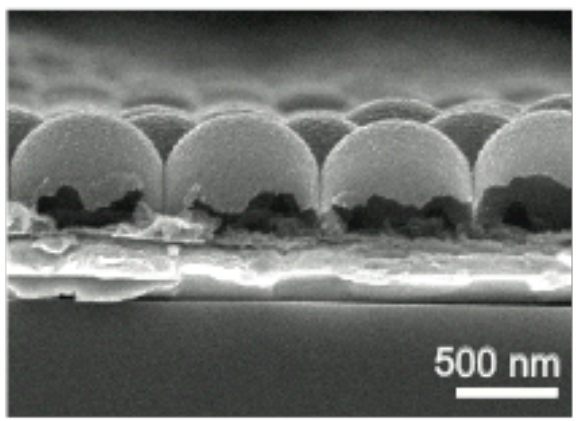
- **Chemically stability**
- **Mechanically strength**
- **Accommodation of volumetric expansion**

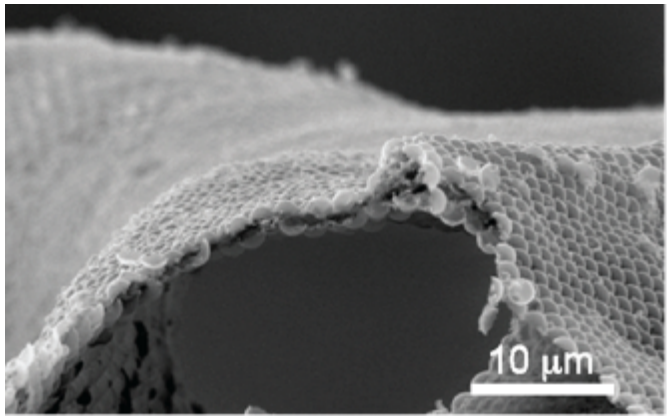
G. Zheng, S. W. Lee, Z. Liang, H-W Lee, K. Yan, H. Yao, H. Wang, W. Li, S. Chu, Y. Cui.
Nature Nanotechnology, 9, 618–623 (2014)

Fabrication of Electrode



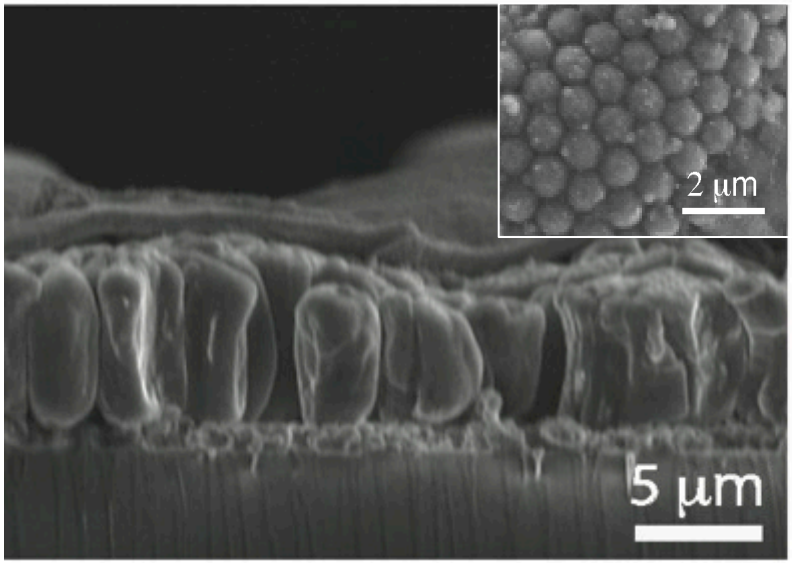


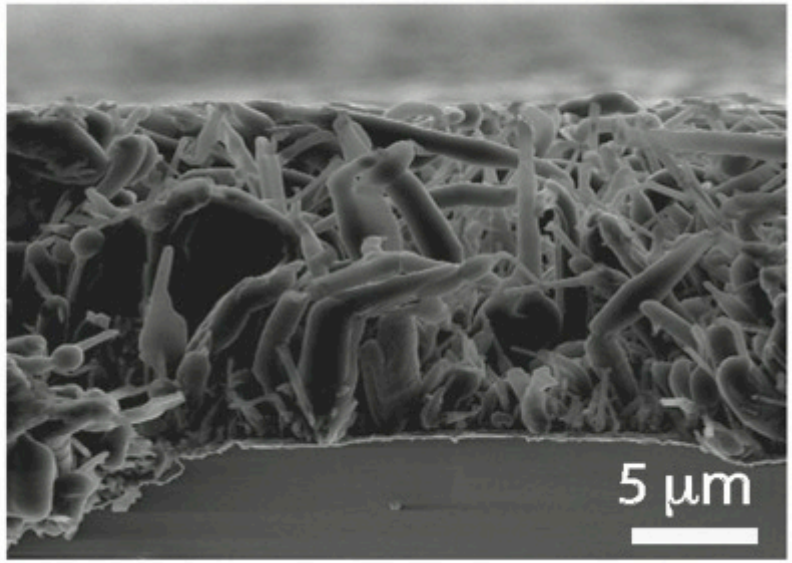




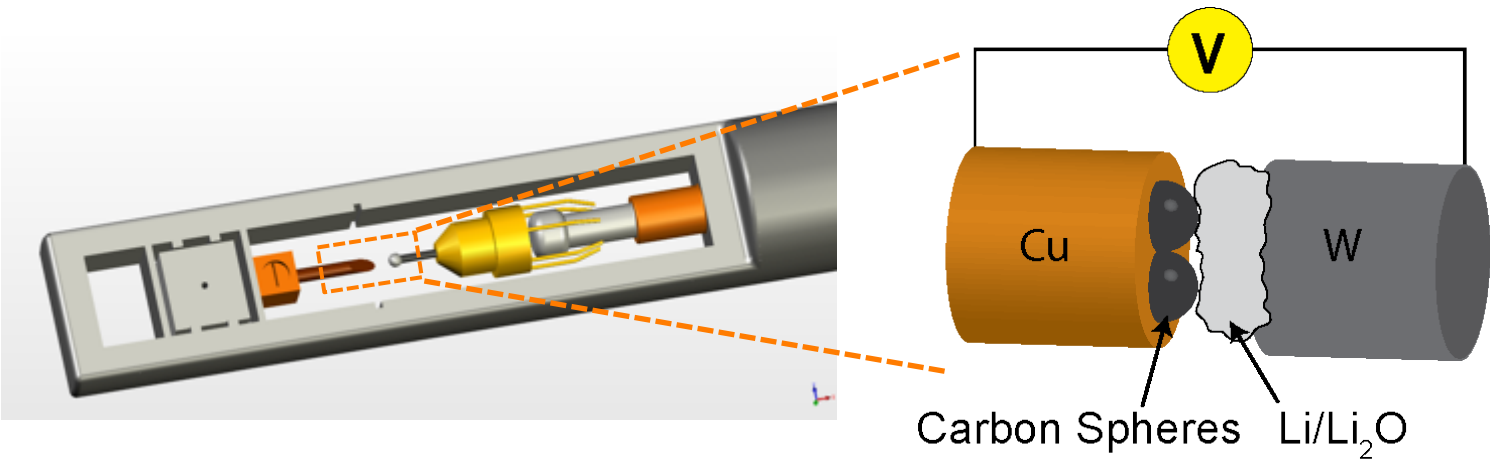
G. Zheng, S. W. Lee, Z. Liang, H-W Lee, K. Yan, H. Yao, H. Wang, W. Li, S. Chu, Y. Cui.
Nature Nanotechnology, 9, 618–623 (2014)

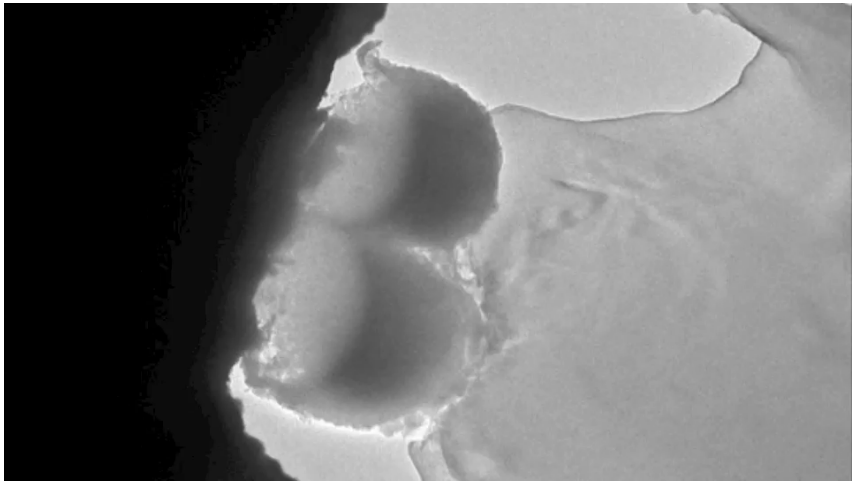
Stable Interface



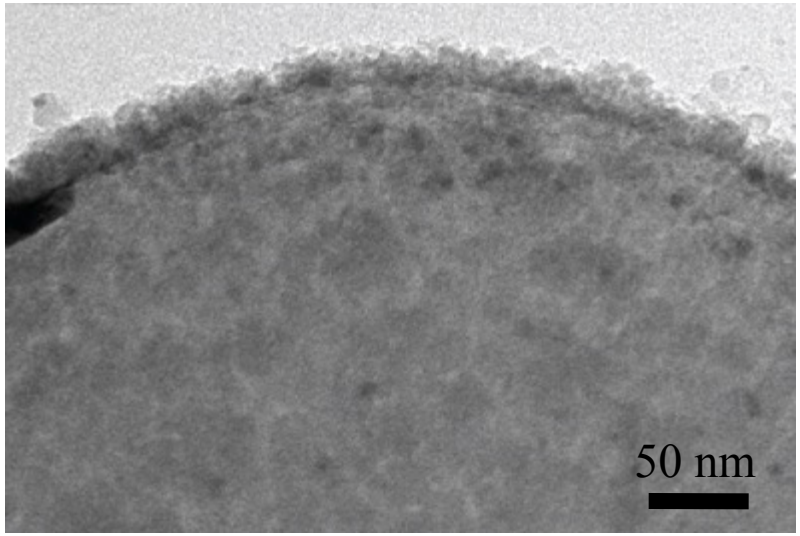


In-situ TEM Study

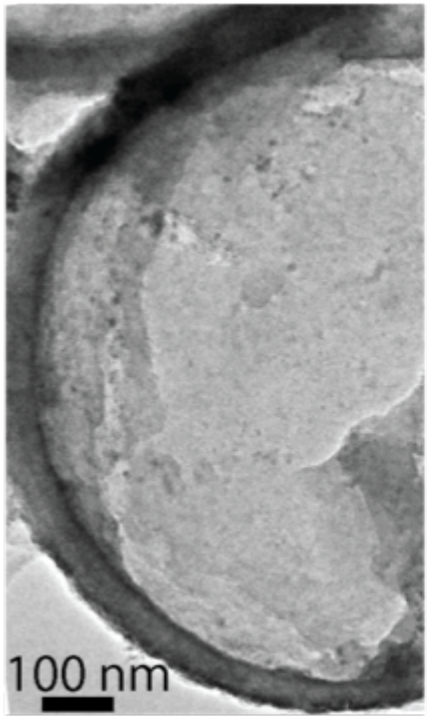




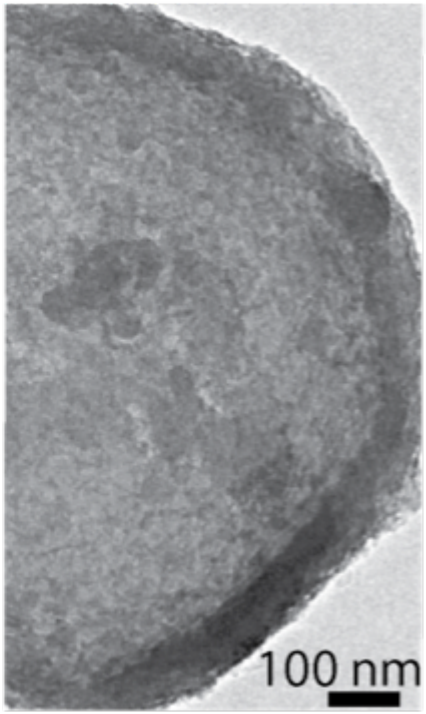
Stable Solid Electrolyte Interphase



Before reaction

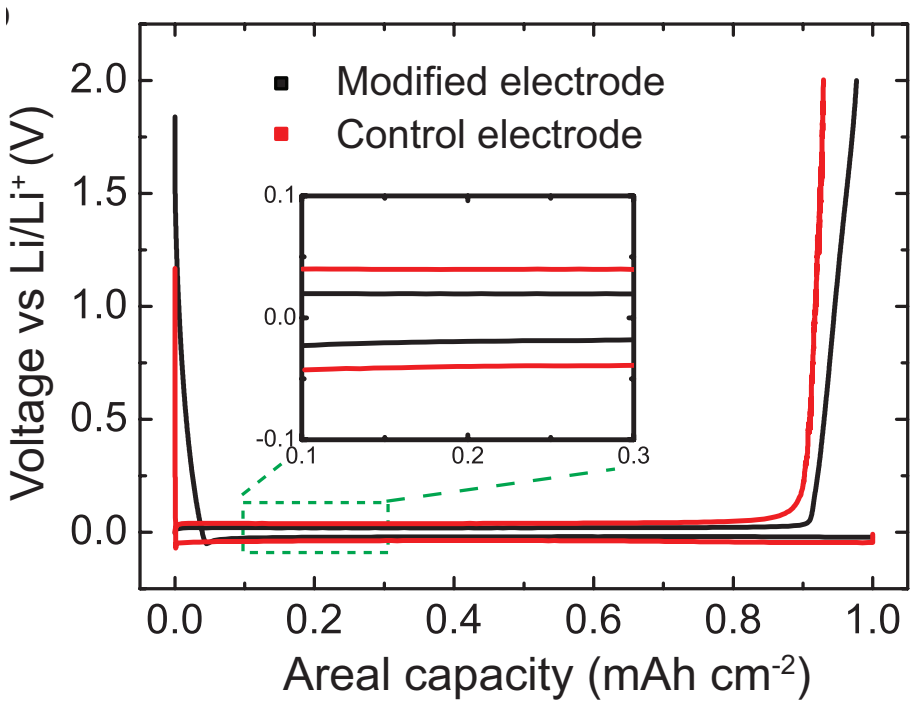


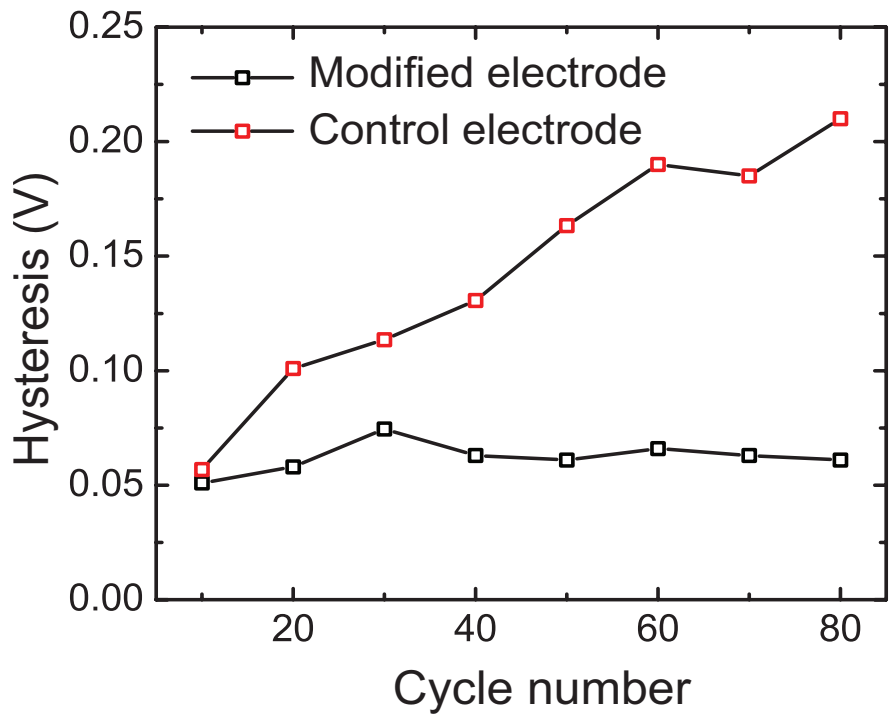
SEI formation



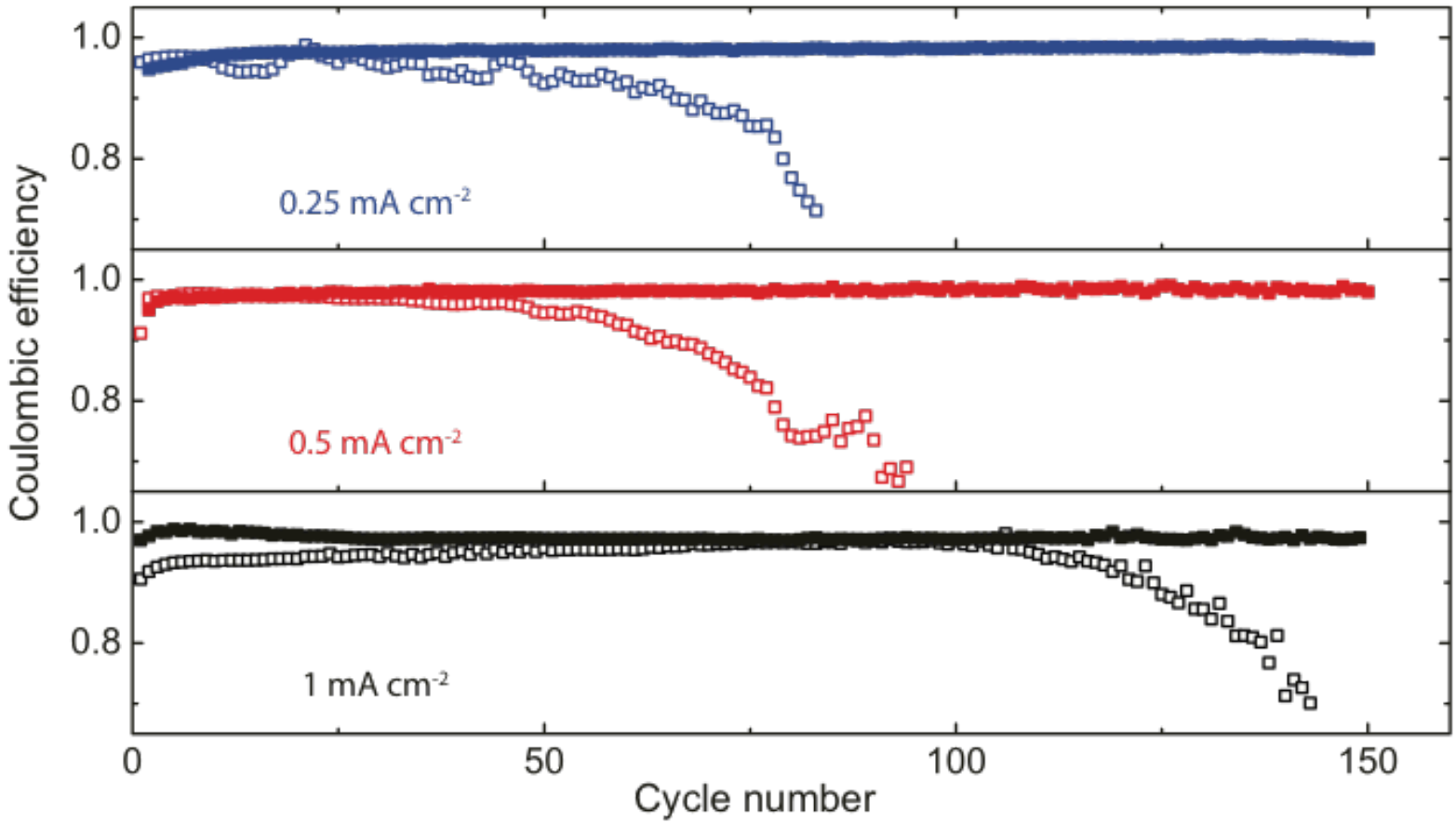
After cycling

Stable Hysteresis



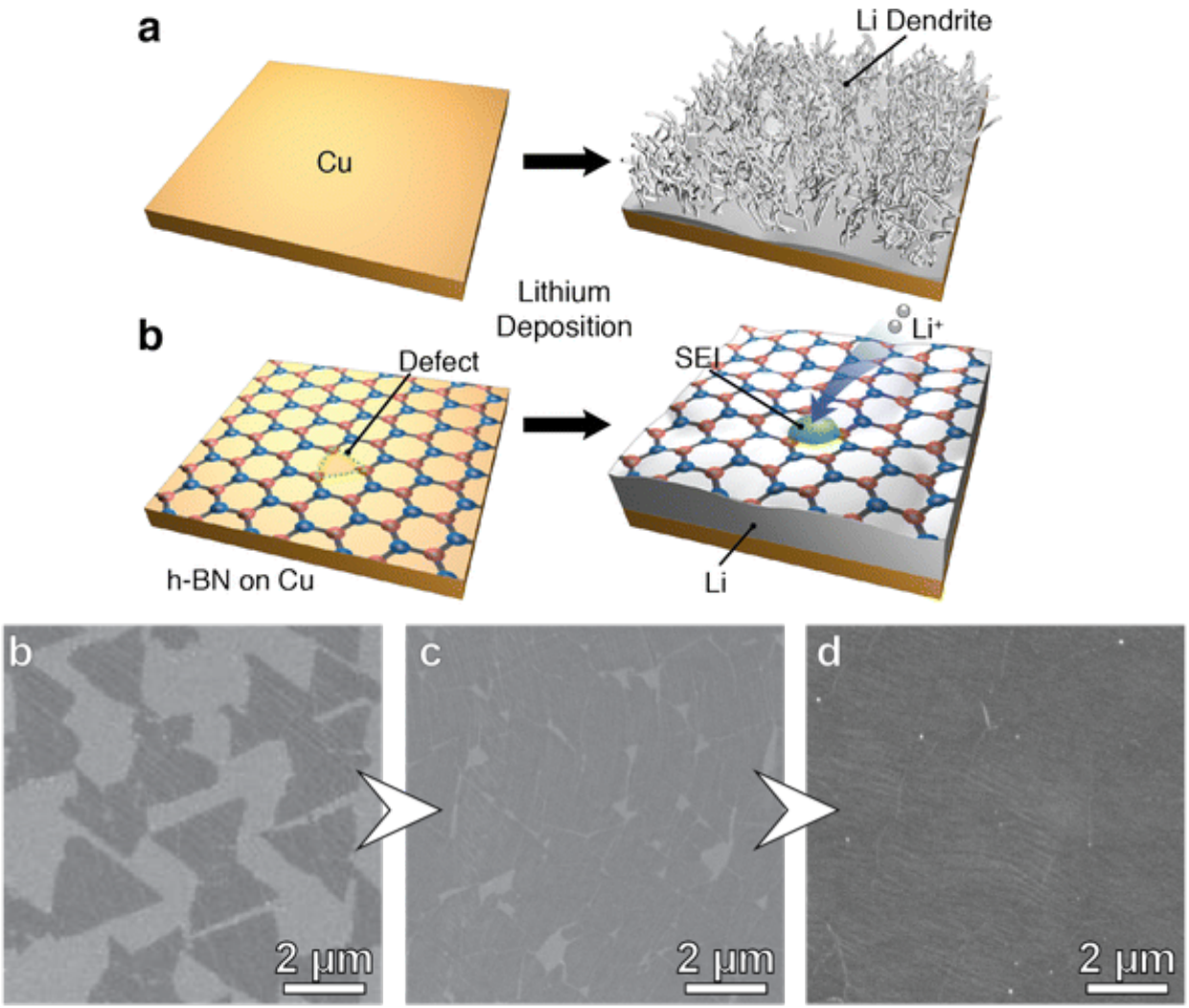


Excellent Cycling Performance



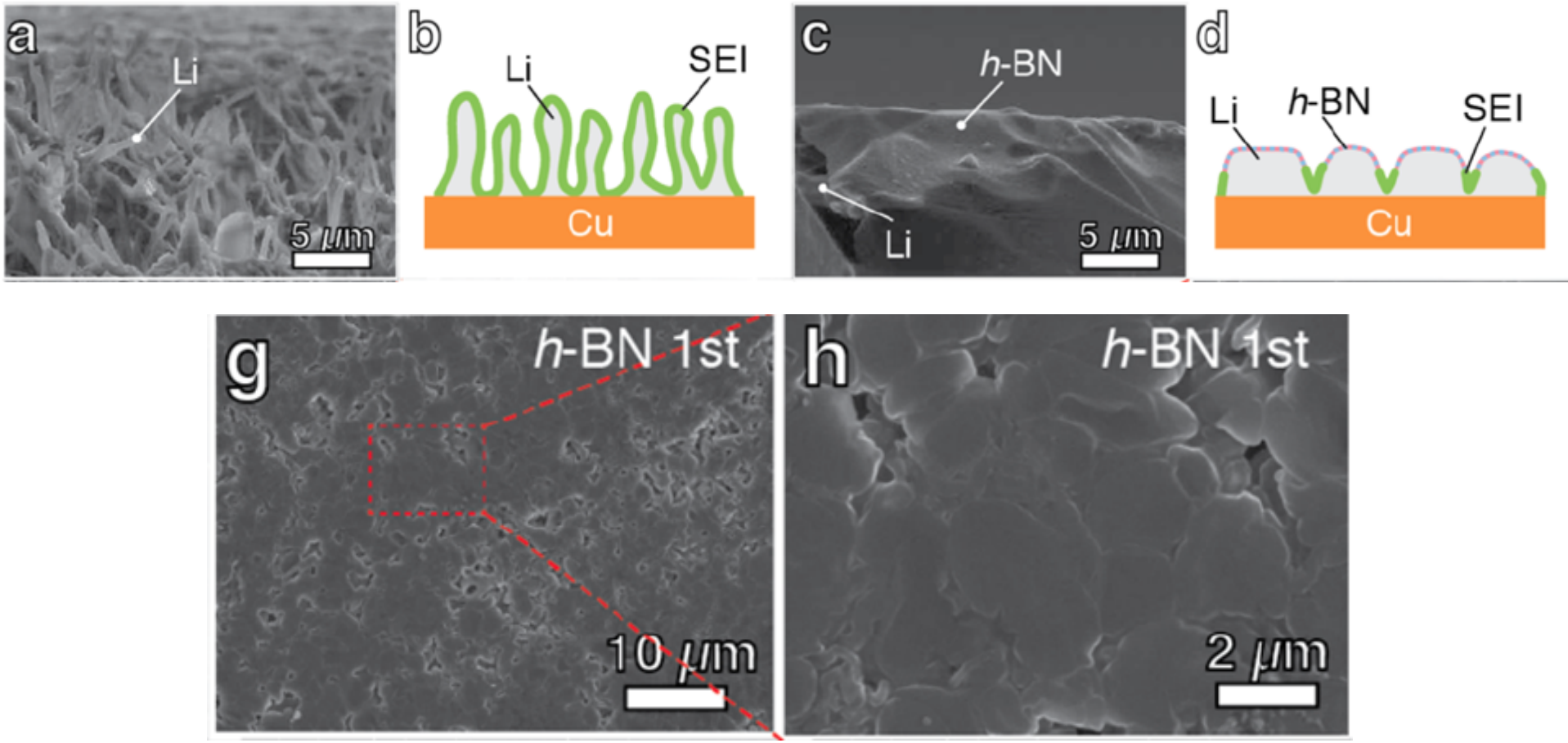
G. Zheng, S. W. Lee, Z. Liang, H-W Lee, K. Yan, H. Yao, H. Wang, W. Li, S. Chu, Y. Cui.
Nature Nanotechnology, 9, 618–623 (2014)

h-BN Protection Layer

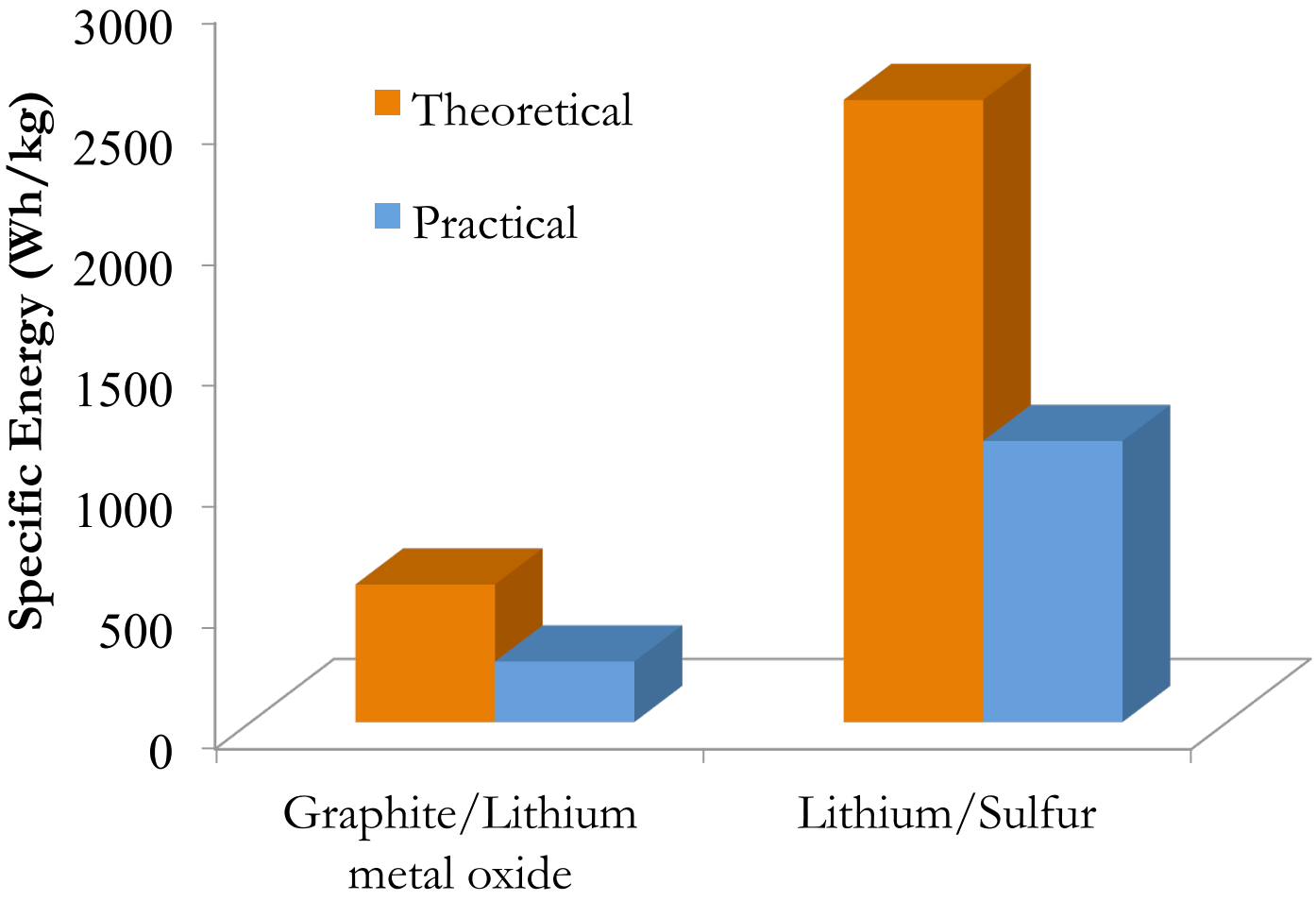


K. Yan *et al.,* Nano Lett. 2014, 14, 6016−6022

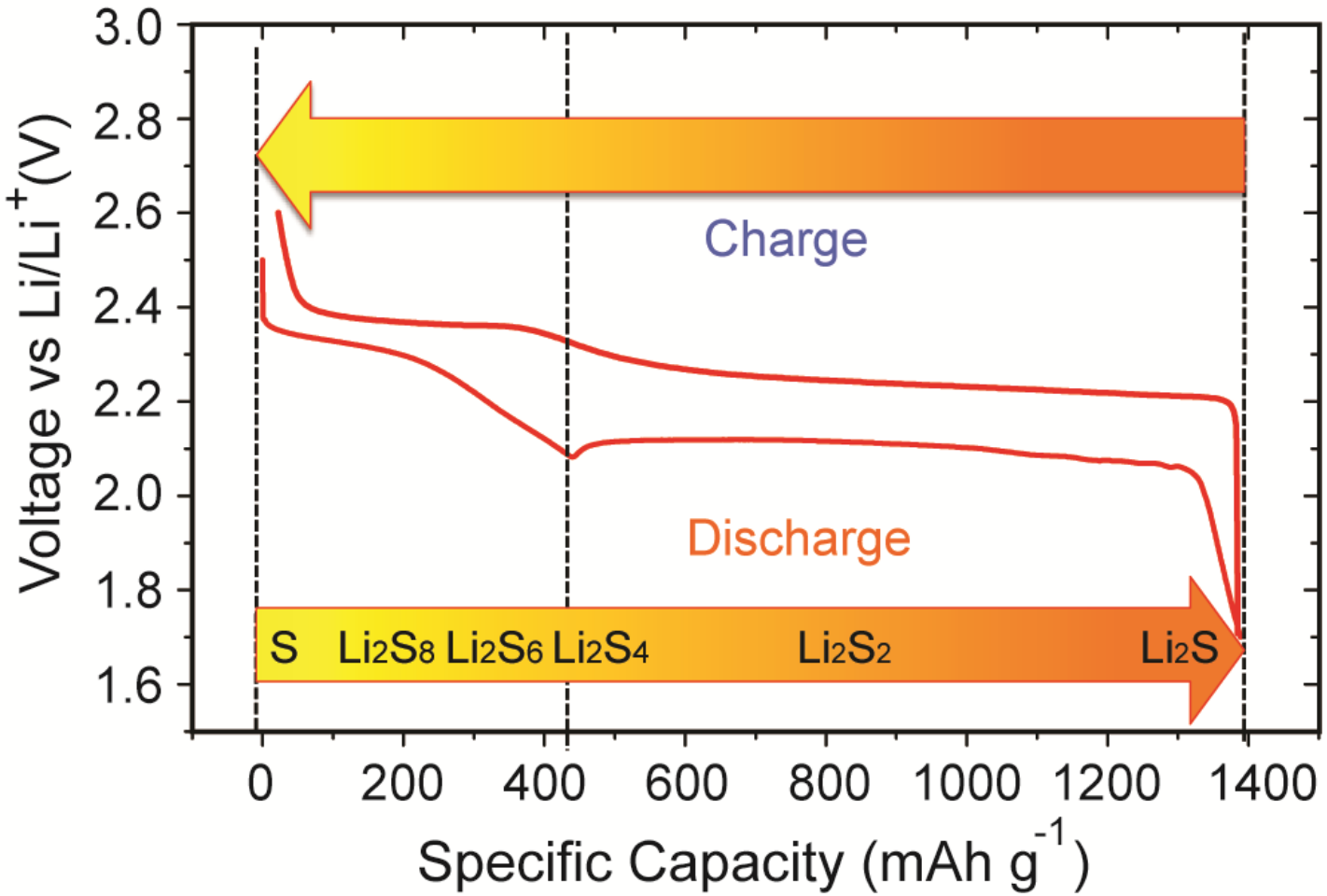
SEM and Electrochemical Characterization



Lithium Sulfur Batteries



Sulfur Cathode Chemistry

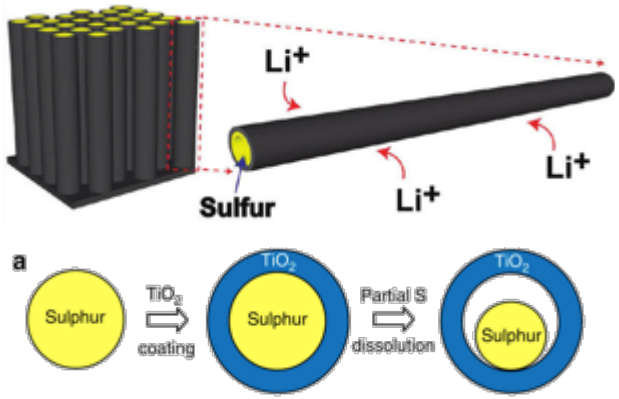


Y Yang, G Zheng, Y Cui. Chemical Society Reviews 42 (7), 3018-3032 (2013)

Problems

Solid	Liquid	Solid
S_8	**Polysulfide**	Li_2S
• Electrically insulating	• High Solubility	• Volume expansion • Ionically & electrically insulating

Sulfur Encapsulation



Nano Lett.,11, 4462-4467(2011)

Nano Lett.,13 (7), 3385–3390 (2013)

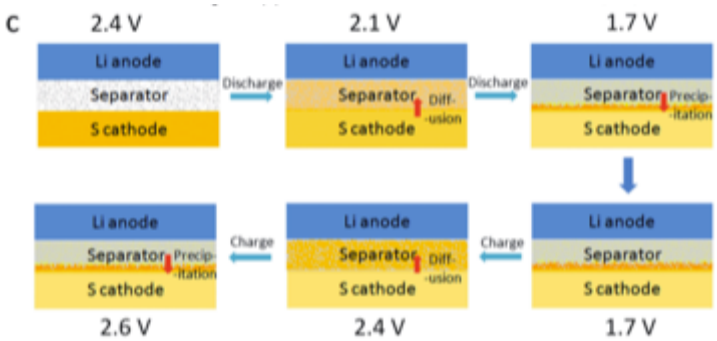
Nano Lett., 10, 1486-1491 (2010)

ACS Nano, 5 (11), 9187–9193 (2011)

PNAS., 110 (18), 7148-7153 (2013)

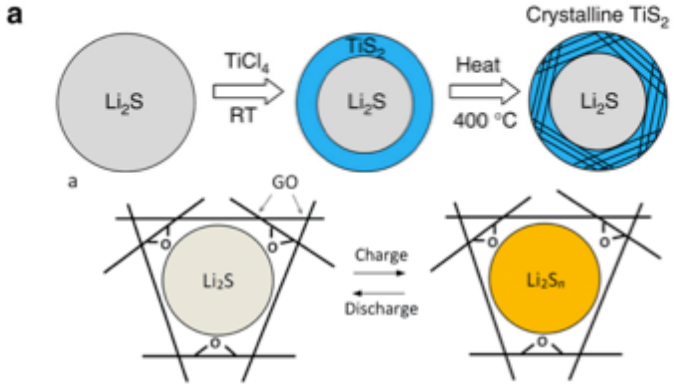
Nature Communications 4,1331 (2013)

Separator modification



Energy Environ. Sci., 2014, 7, 3381-3390

Lithium sulfide cathode



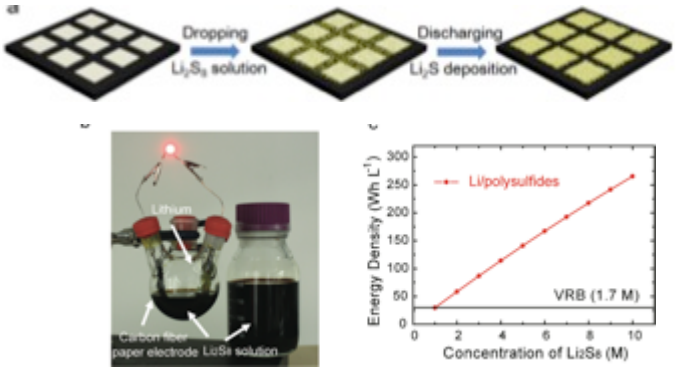
Energy & Environmental Science 7 (2), 672-676

Chemical Science 5 (4), 1396-1400

Nature Communications 5, Article number: 5017

Chemical Science 4 (9), 3673-3677

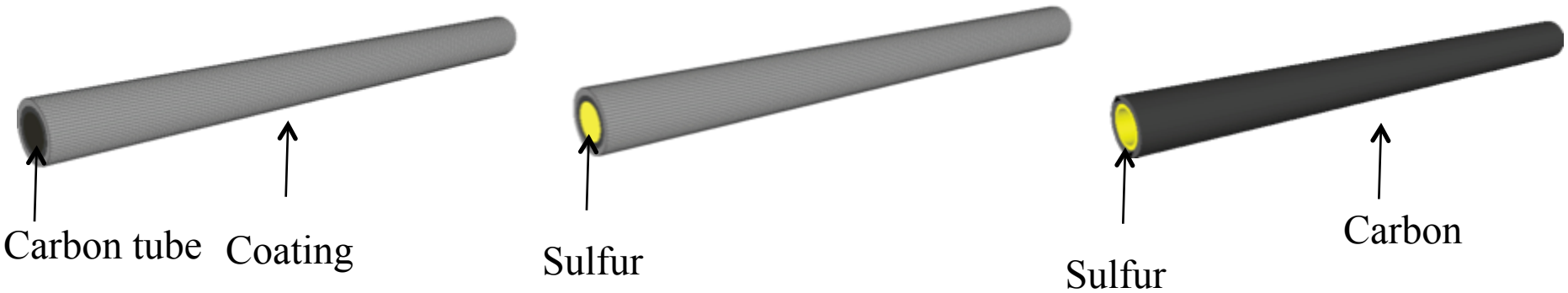
Liquid lithium polysulfide

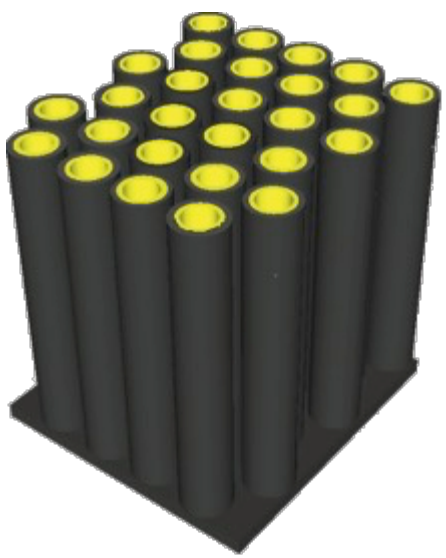


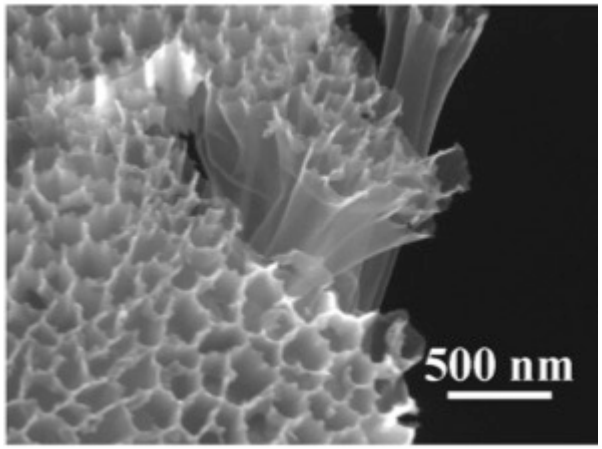
Energy Environ. Sci.,6, 1552-1558 (2013)

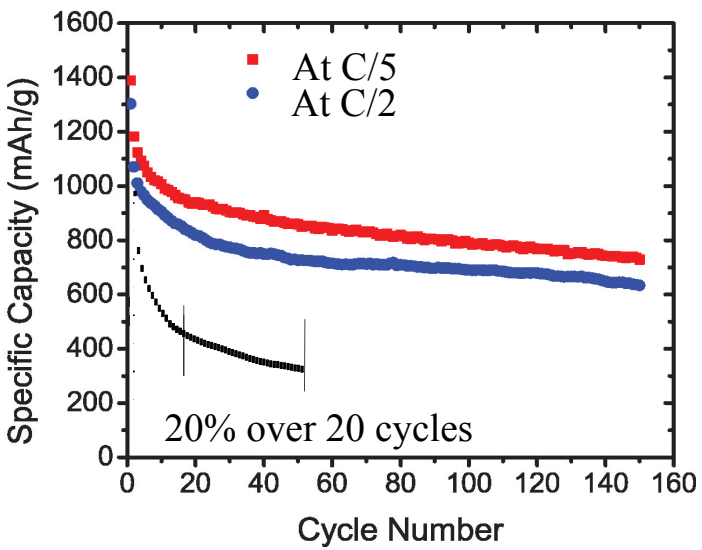
Nature Communications, 5, 3943 (2014)

Nanostructured Sulfur Cathode



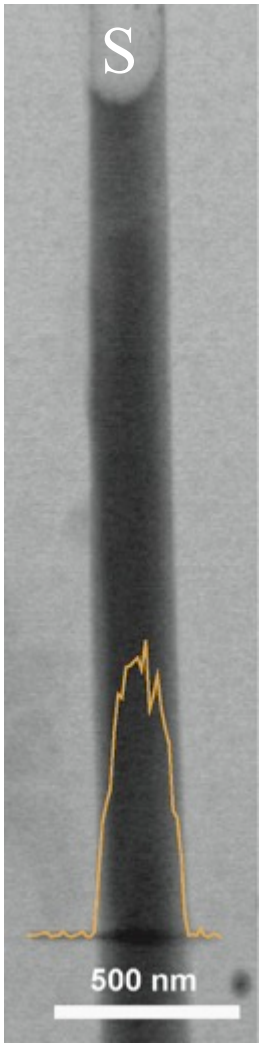




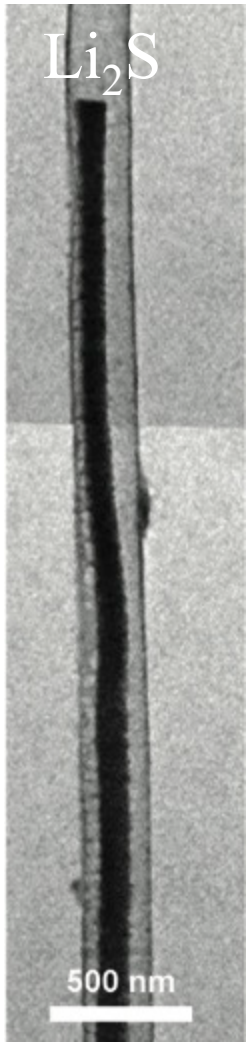


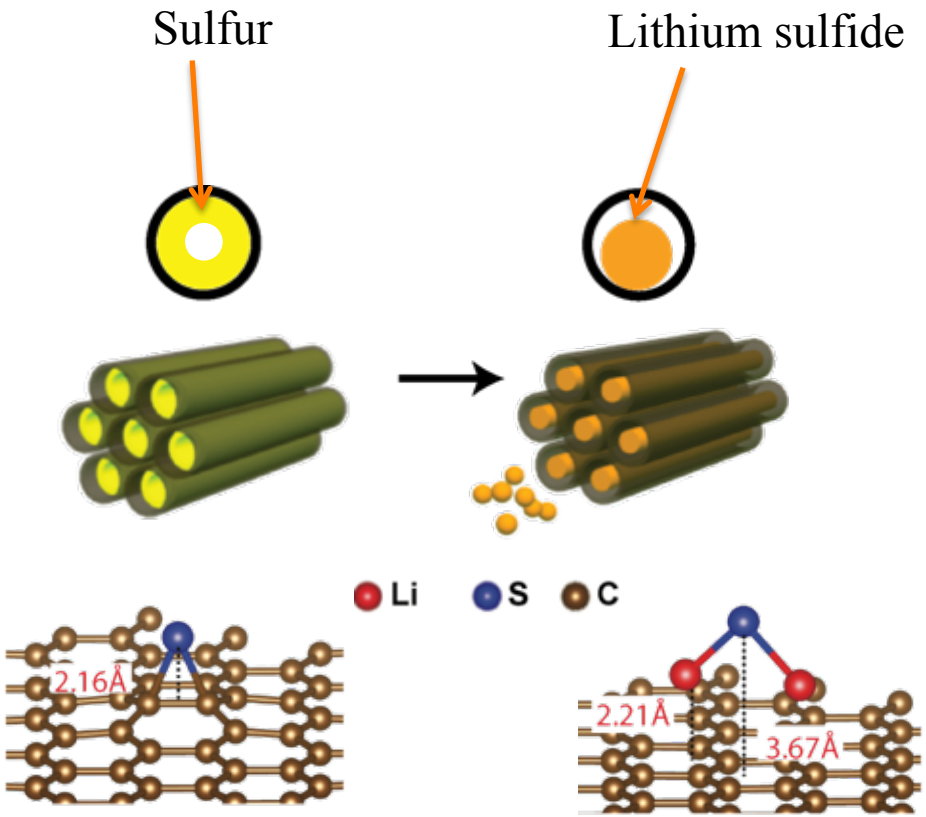
G Zheng, Y Yang, J J Cha, S S Hong, Y Cui. Nano Lett, 11 (10), pp 4462–4467 (2011)

Change in Interfacial Binding



Discharge





C+S

0.79 eV

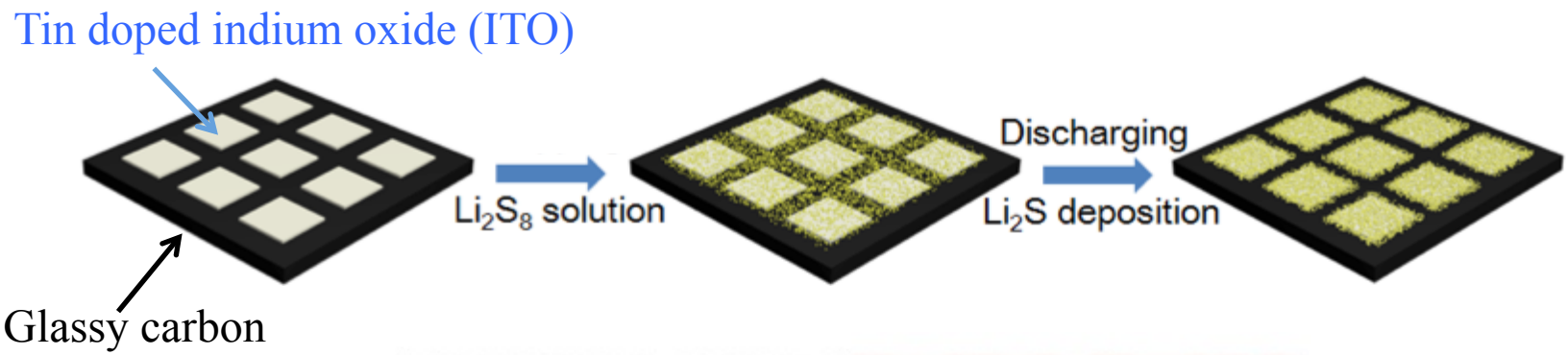
C+Li_2S

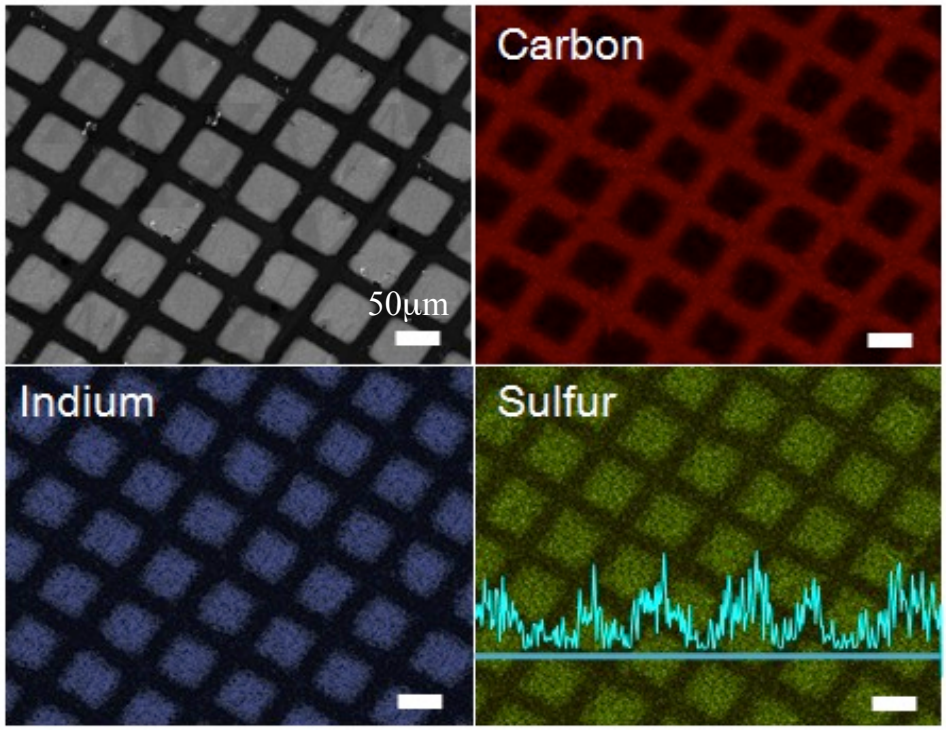
0.29 eV

Binding energy decreases

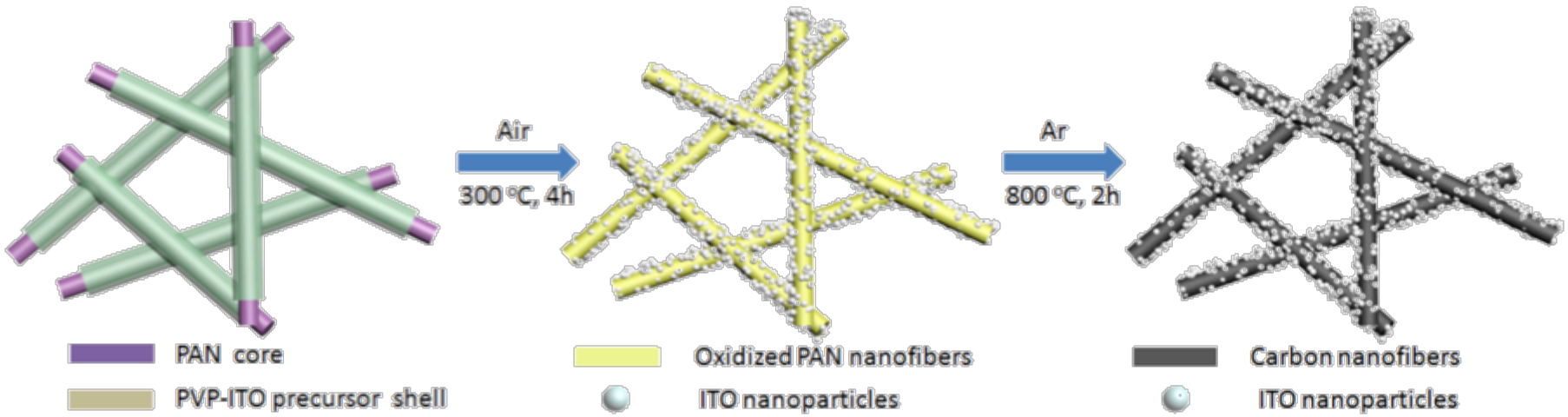
G Zheng, Q Zhang, JJ Cha, Y Yang, W Li, ZW Seh, Y Cui. Nano Lett., 13 (3), 1265-1270 (2013)

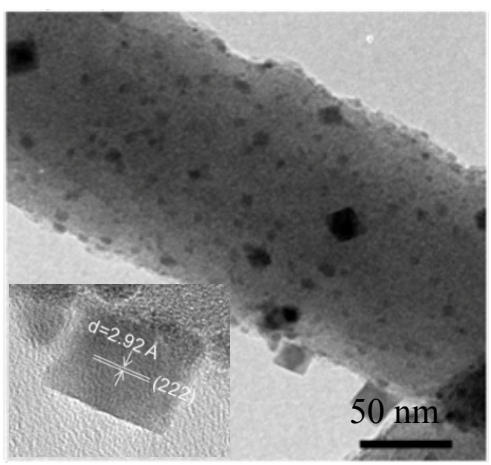
ITO Binding with Li_2S

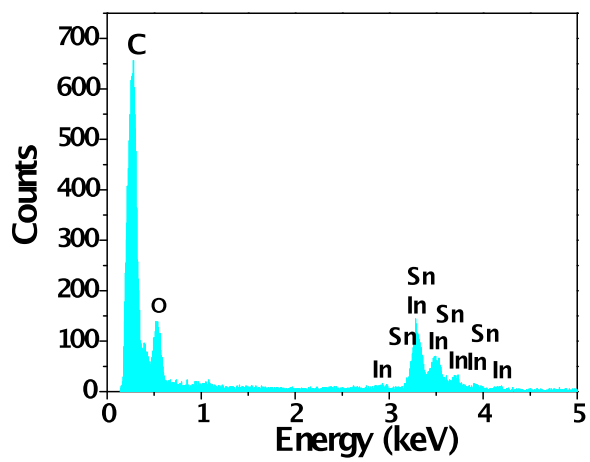




Fabrication of ITO-Carbon Electrode



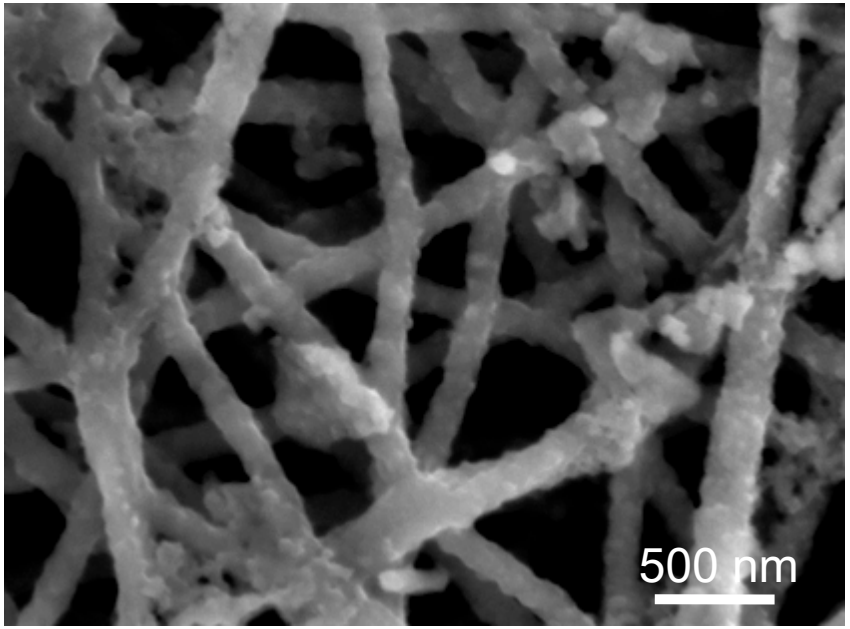




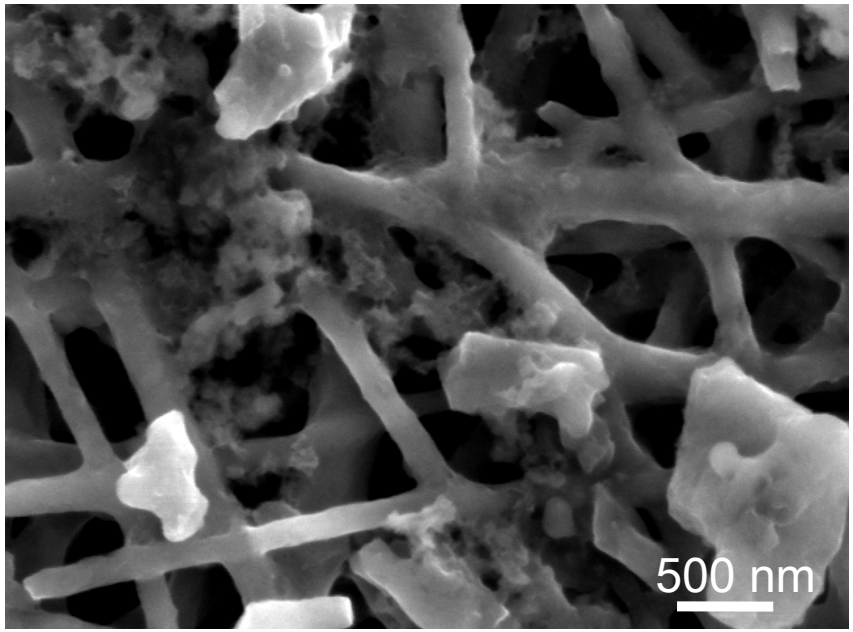
H Yao*, G Zheng*, PC Hsu, D Kong, JJ Cha, W Li, Z W Seh, MT McDowell, K Yan, Z Liang, V K Narasimhan, Y Cui. Nature Communications, 5, 3943 (2014)

Deposition of Lithium Sulfide

Carbon-ITO fibers

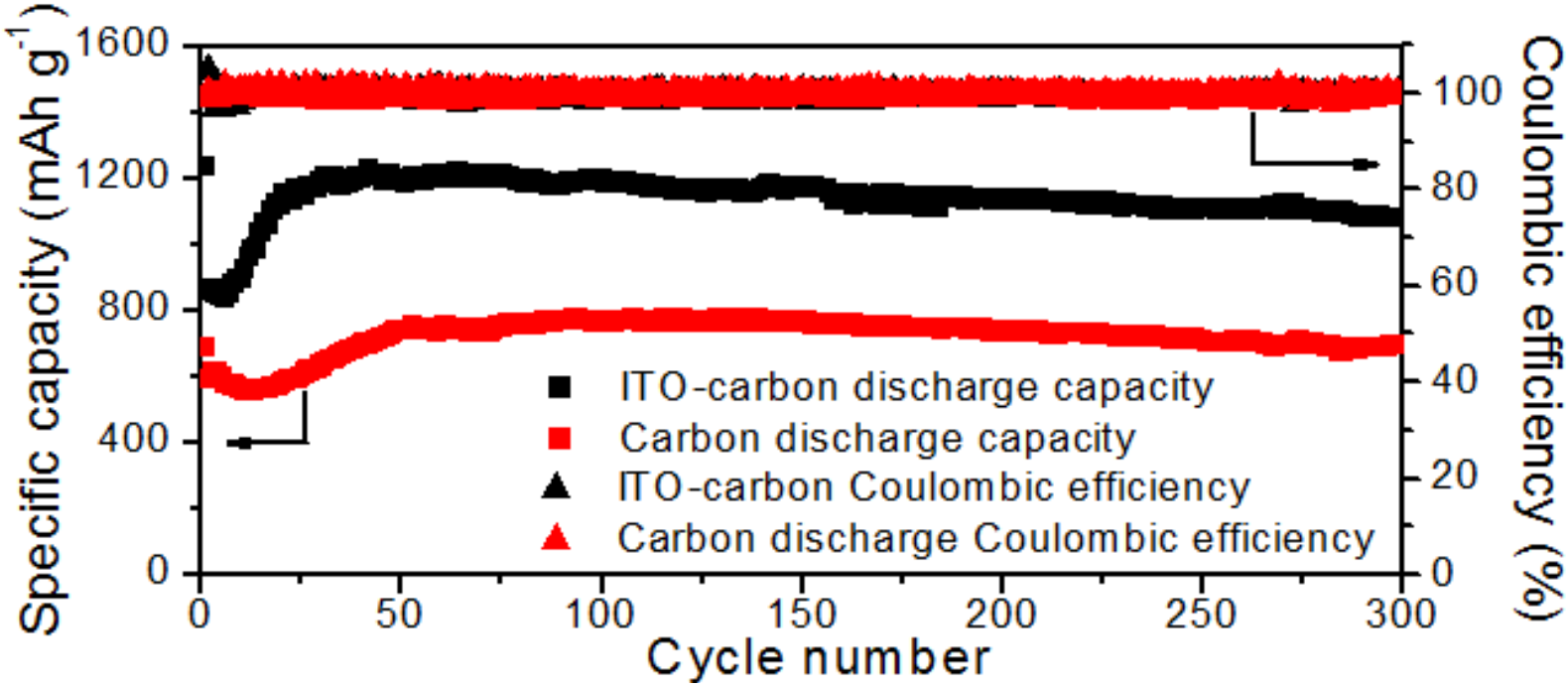


Carbon fibers



H Yao*, G Zheng*, PC Hsu, D Kong, JJ Cha, W Li, Z W Seh, MT McDowell, K Yan, Z Liang, V K Narasimhan, Y Cui. Nature Communications, 5, 3943 (2014)

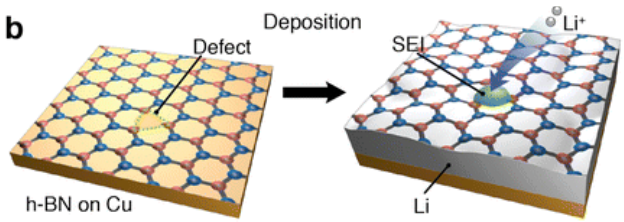
Excellent Performance



H Yao*, G Zheng*, PC Hsu, D Kong, JJ Cha, W Li, Z W Seh, MT McDowell, K Yan, Z Liang, V K Narasimhan, Y Cui. Nature Communications, 5, 3943 (2014)

Conclusion

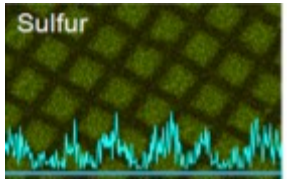
- Nanoscale interfacial layer could significantly improve lithium cycling performance
  - Lithium surface protection



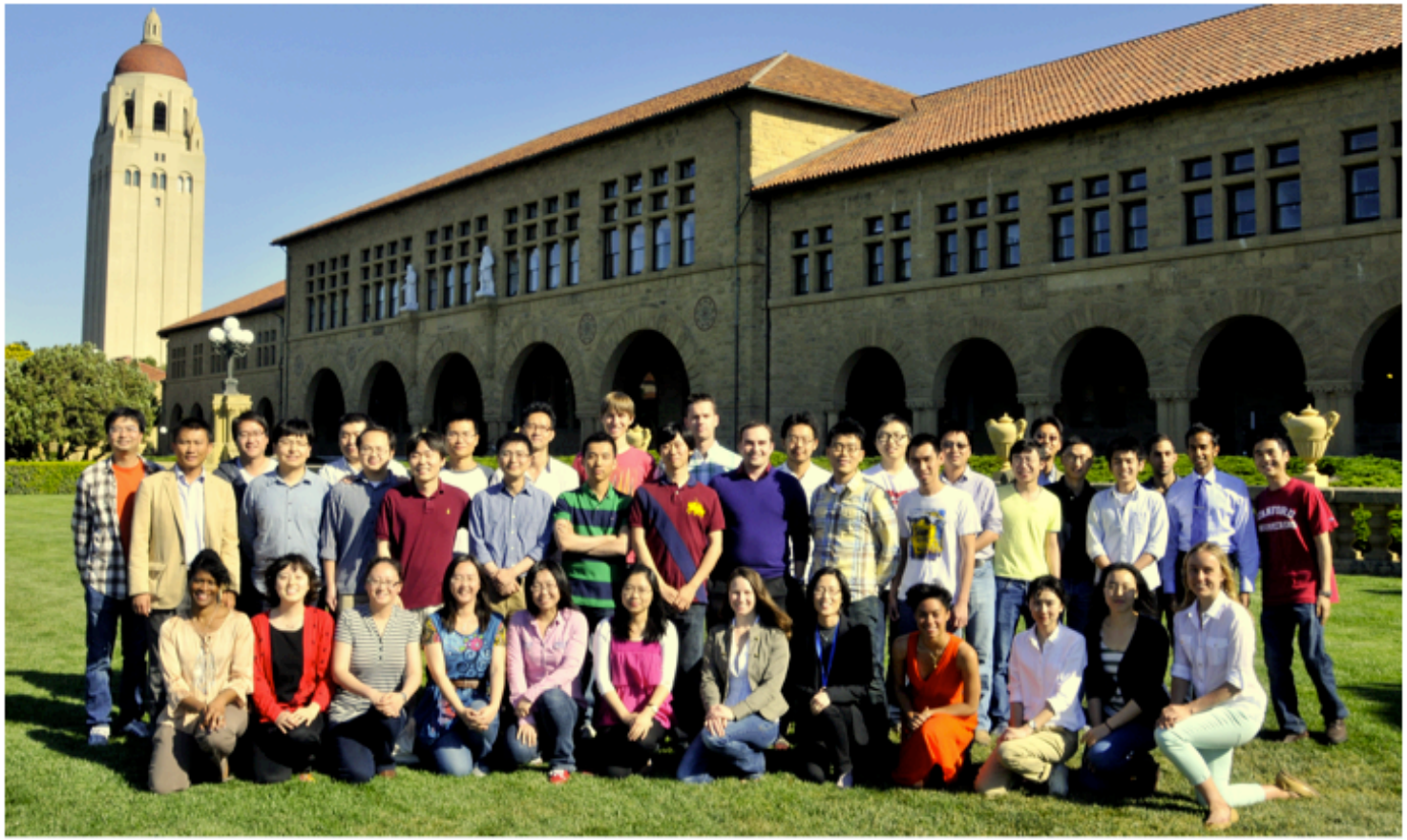
- Combining rational nanostructure design and interfacial binding can improve the sulfur cathode performance

• Nanostructure electrode

•Interfacial binding



Acknowledgement



Agency for Science, Technology and Research
SINGAPORE