Chemical & Biological Engineering Seminar

March 6, 2019, 10 AM, Farris Engineering Center room 1000

Rational Design of Solid-liquid interphases and Nanocomposite Cathodes for Metal-sulfur Batteries

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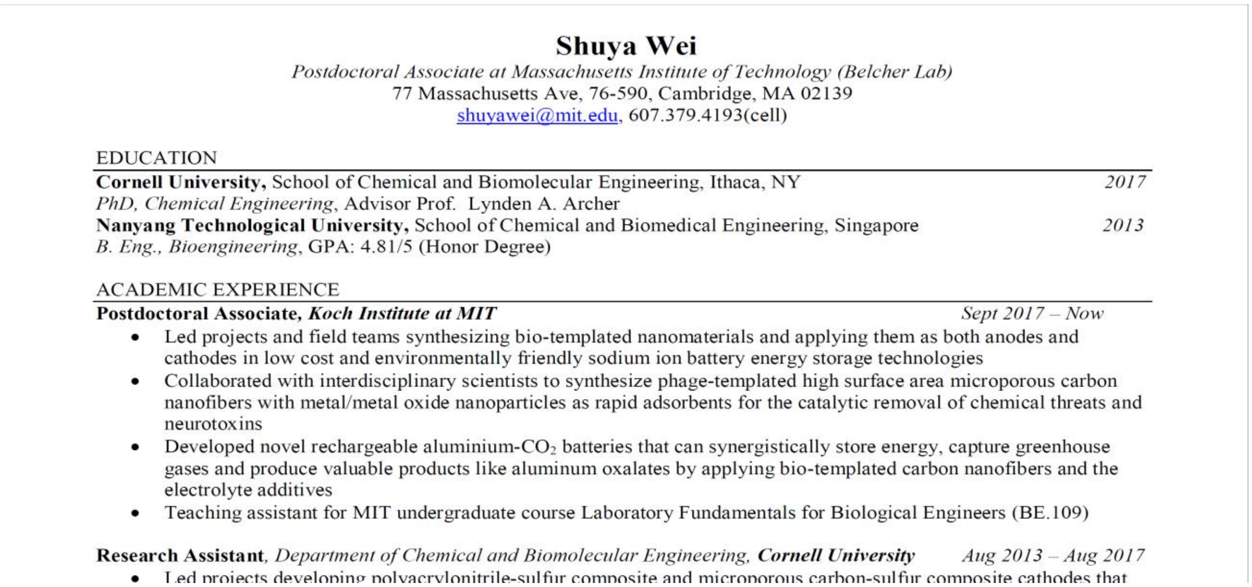
Advances in the basic science and engineering principles of electrochemical energy storage is imperative for significant progress in electronic devices. Metal based batteries comprising of a reactive metal (like Li, Na, Al) as the anode have attracted remarkable attention due to their promise of improving the anode-specific capacity by as much as 10-fold, compared to the current state-of-art Li-ion battery that uses a graphitic anode. Rechargeable sodium-sulfur (Na-S) batteries based on the metallic sodium anode and the elemental sulfur cathode that are able to operate stably at room temperature are among the most sought-after of these platforms because these cells take advantage of a two-electron-redox process to yield high storage capacity from inexpensive electrode materials. However, realization of practical Na-S batteries has been fraught with multiple stubborn transport problems ranging from unstable electrodeposition of the sodium anode during battery recharge to rapid loss of the active cathode material by dissolution into the electrolyte.

A persistent challenge with batteries based on the metallic anode, concerns their propensity to fail due to short-circuits produced by dendrite growth during battery recharge, as well as by runaway of the cell resistance due to internal side reactions with the liquid electrolyte. In this talk, I will discuss my research that utilizes ion transport modeling and contemporary experimental efforts to fundamentally understand and to thereby develop rational designs for electrode-electrolyte interphases that overcome these challenges. On the basis of a linear stability analysis of dendrite growth during metal electrodeposition, we have showed that a small fraction of immobilized anions near the electrodes is important in stabilizing metals against dendrite formation. To evaluate this proposal, we designed polymeric ionic liquid electrolytes with tunable molecular weight and quantified the stability of metal electrodeposition in these systems. Direct visualization of electrodeposition using these electrolytes showed remarkable agreement with the theoretical predictions. Furthermore, when operated in a battery, the polymeric ionic liquid electrolytes demonstrated stable galvanostatic polarization of sodium metal anodes for over a hundred hours.

In the second part of my talk, I will demonstrate a room temperature rechargeable Na-S battery that uses a sodium metal anode, a carbon-sulfur composite cathode, and a liquid electrolyte containing tethered ionic liquid silica nanoparticles as a deposition stabilizer. We showed that the Na-S cells with this configuration can cycle stably for over 100 cycles at relatively high current density with 600 mAh/g reversible capacity and nearly 100 percent Coulombic efficiency. By means of spectroscopic and electrochemical analysis, we find that the high stability and reversibility of the cells stem from at least two sources that related to both cathode and anode. First, on the cathode side, porous carbon materials play a key role that can constrain the electrochemical reaction between sodium ion and sulfur to the solid state. Second, the tethered ionic liquid silica nanoparticles spontaneously form a Na-ion conductive film on the anode, which appears to stabilize deposition of sodium and prevent electrolyte decomposition and depletion by providing a fraction of immobilized anions near the anode. This combination of electrolyte and carbon substrate can provide sufficiently strong association of sulfur in the cathode and at the same time stabilize the surface of the highly reactive sodium metal anode. On the basis of these studies, solid electrolyte interphase (SEI) and nanocomposite cathode designs will be proposed for alkali metal-sulfur batteries to enable reversible recharging and high capacity retention even in highly reactive liquid electrolytes.



Shuya Wei

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EDUCATION

Cornell University, School of Chemical and Biomolecular Engineering, Ithaca, NY *2017*
PhD, Chemical Engineering, Advisor Prof. Lynden A. Archer
Nanyang Technological University, School of Chemical and Biomedical Engineering, Singapore *2013*
B. Eng., Bioengineering, GPA: 4.81/5 (Honor Degree)

ACADEMIC EXPERIENCE

Postdoctoral Associate, *Koch Institute at MIT* *Sept 2017 – Now*

- Led projects and field teams synthesizing bio-templated nanomaterials and applying them as both anodes and cathodes in low cost and environmentally friendly sodium ion battery energy storage technologies
- Collaborated with interdisciplinary scientists to synthesize phage-templated high surface area microporous carbon nanofibers with metal/metal oxide nanoparticles as rapid adsorbents for the catalytic removal of chemical threats and neurotoxins
- Developed novel rechargeable aluminium-CO_2 batteries that can synergistically store energy, capture greenhouse gases and produce valuable products like aluminum oxalates by applying bio-templated carbon nanofibers and the electrolyte additives
- Teaching assistant for MIT undergraduate course Laboratory Fundamentals for Biological Engineers (BE.109)

Research Assistant, *Department of Chemical and Biomolecular Engineering, **Cornell University*** *Aug 2013 – Aug 2017*

- Led projects developing polyacrylonitrile-sulfur composite and microporous carbon-sulfur composite cathodes that