Manufacturing Science and Technology
Room 103A - Session MS-MoM

Manufacturing for Next-Generation Energy Solutions
Moderator: Erik B. Svedberg, The National Academies

9:00am **MS-MoM3 Manufacturing Challenges in Batteries: Lessons from Current Technology for Future Energy Storage Developments***, **Yet-Ming Chiang**,* MIT **INVITED**

The evolution of today's highly successful lithium ion battery manufacturing technology over 25 years provides many useful lessons, pro and con, for future storage technologies. Along with the development of higher performance/lower cost cathodes, anodes, electrolytes or other cell components, efficient cell designs and low cost/highly scalable manufacturing techniques are needed for any new technology to suceed. This talk will discuss prevailing Li-ion cell design and manufacturing methods which, despite evident success, have inherent inefficiencies which in the author's view have prevented the full exploitation of Li-ion chemistry. A "clean sheet" redesign developed at MIT and 24M Technologies will be discussed, based on a new semi-solid electrode form that enables manufacturing of high performance Li-ion cells by radically simpler and lower-cost methods. Concepts from this case study that may be transferable to new storage technologies include the need to minimize of non-energy-storing materials content in any device design; the benefits of reducing the tortuosity of ion transport pathways; how multiple functions can be served by a single component, and the importance of developing manufacturing processes that are cost-effective at small production scale, yet can be readily scaled to GWh volumes.

Support for this work by the U.S. Department of Energy through the ARPA-E program, the Vehicle Technologies Office of EERE, and the Advanced Battery Materials Research (BMR) program is gratefully acknowledged.

9:40am **MS-MoM5 Efficient Manufacturing of Nano-structured Lithium Sulfide for Next Generation Batteries***, X. Li, Y. Yang, **Colin Wolden**,* Colorado School of Mines

Lithium ion batteries (LIBs) currently dominate the market and are expected to for another decade due to incremental improvements. However, with performance approaching intrinsic material limits, LIBs cannot meet the increasing demands of electric vehicles and stationary storage. In the next decade both solid state and lithium–sulfur (Li-S) batteries will begin displacing LIBs. Central to both technologies is Li_2S, which serves as the active cathode material in Li-S batteries and is the key precursor and cost driver for leading solid-state electrolytes. In both applications Li_2S has demonstrated excellent performance when used in nanoparticle (NP) form. However, Li_2S is very costly and commercially available only as micropowders with impurities being a major concern, reflecting the energy-intensive carbothermal reduction processes currently used for synthesis. In this paper we describe a green chemistry-inspired approach for synthesizing alkali sulfide (M_2S, M = Li and Na) NPs through the reaction of hydrogen sulfide (H_2S) gas with alkali metal-organic (M-R) complexes dissolved in solution. This thermodynamically favorable reaction occurs spontaneously and proceeds rapidly to completion with near 100% atom efficiency at ambient temperature, forming phase-pure, anhydrous M_2S nanopowders that are readily separated from solution. H_2S, a major industrial waste, is completely abated and the valuable hydrogen stored therein may be fully recovered as H_2. The overall stoichiometry of the two step process is:

$2M (s) + H_2S (g) \Rightarrow M_2S (s) + H_2 (g)$

As such, this innovative synthetic approach is expected to be scalable, energy-efficient, and cost-effective. In this presentation we describe the process chemistry, focusing on the role of the complexing agent (R) and solvent to control the yield, size, and morphology of the resulting M2S NPs.

10:00am **MS-MoM6 Anode Protection for Advanced Energy Storage Systems *via* Atomic Layer Deposition***, **Chuan-Fu Lin**, M. Noked,* Institute for System Research, University of Maryland*; A.C. Kozen,* Naval Research Laboratory*; A.J. Pearse,* University of Maryland, College Park*; K. Gregorczyk,* Institute for System Research, University of Maryland*; S.B. Lee,* University of Maryland College Park*; G. Rubloff,* Institute for System Research, University of Maryland

To meet the demand for higher capacity longer life batteries in a "next-generation batteries" technology, anodes with substantially higher energy density than current graphite are needed. One class - metal anodes (particularly Li) - offers far higher energy density, but to date their utilization has been impeded by their high surface reactivity (especially to the organic electrolyte) and tendency to form dendritic Li (a shorting and safety hazard). Another category - conversion materials, also high energy density – involves complex material reactions as part of lithiation/delithiation, degrading the material during cycling.

We have used atomic layer deposition (ALD) to create highly controlled, thin protective layers on Li metal anodes and on RuO_2 conversion anodes, testing their efficacy by cycling in batteries. ALD protection layers, including Al_2O_3 and the solid electrolyte LiPON (lithium phosphous oxynitride), were directly deposited on the anodes in controlled inert ambient conditions. For Li metal anode protection, both Al_2O_3 and LiPON markedly suppress corrosion and degradation, as evaluated in Li-S cells by charge/discharge cycling and a variety of other characterization methods, with considerably higher capacity for the LiPON. The ALD films also stabilize the Li metal surface, preventing Li dendrite formation upon repeated cycling above the threshold current density for dendrite formation. For the conversion anode, the ALD coatings suppress electrolyte decomposition, thereby enhancing capacity retention during cycling, and lowering overpotentials required for delithiation, effects attributed to the layers mechanically constraining the RuO_2 the lithiation products Li_2O and Ru, preserving structural integrity.

These results demonstrate promise for achieving high energy density anodes with significantly enhanced chemical stability, electrochemical cyclability, and dendrite protection as needed for a viable beyond Li ion battery technology.

10:40am **MS-MoM8 Controlling Nanomaterial Assembly to Improve Material Performance in Energy Storage Electrodes using Electrophoretic Deposition***, **Landon Oakes**, R.E. Carter, A.P. Cohn, C.L. Pint,* Vanderbilt University

Electrophoretic deposition (EPD) provides a promising tool for large-scale manufacture of nanomaterial systems using conventional liquid processing techniques. One major roadblock to commercially viable applications of nanomaterials, such as in energy storage devices, is the ability to cost-effectively manufacture electrode-scale films while still maintaining precise control over the nanoscale and microscale morphology. We emphasize the ability of EPD to control nanoscale assembly for high throughput battery manufacturing through the design of a benchtop roll-to-roll platform. Using this approach, we fabricate electrodes for a range of battery technologies, such as lithium-ion batteries, lithium-sulfur batteries, and lithium-oxygen batteries. This makes possible the development of binder-free, electrode assemblies with uniformity and control that enables improved performance across all of these battery platforms. Specifically, for lithium-sulfur batteries, we fabricate binder-free electrodes that achieve over 75% sulfur loading with a capacity greater than 1,200 mAh/g that retains more than 80% of the initial capacity after 100 cycles. For lithium-oxygen batteries, we demonstrate electrodes with improved overpotential of 50 mV during oxygen reduction and 130 mV during oxygen evolution in addition to a nearly 2X improvement in durability compared with conventional assembly methods. Overall, as battery manufacturing remains a critical barrier separating state-of-the-art research efforts from practical commercial energy storage innovations, we emphasize EPD as a versatile process able to provide the scalability, high throughput, and nanoscale control that are necessary to advance battery systems manufacturing.

11:00am **MS-MoM9 3D Architectures for Thin Film Batteries – from Science to Manufacturing***, **Gary Rubloff**, C. Liu, E. Hitz, S.B. Lee,* University of Maryland College Park*; K. Gregorczyk,* University of Maryland, College Park

Recent research has elucidated several guidelines for energy storage approaches to achieve higher power at high energy density along with good capacity retention during cycling. These guidelines address electrode surface areas and active storage layer thicknesses, integration of current collecting features with active layers, and overall structure of 3D electrode features at the micro or nano scale. Here we consider solid state thin film battery architectures fabricated by thin film processes, where the solid electrolyte enables complex interdigitated electrode arrangements. We report projected performance in power and energy density for several configurations as a function of design parameters, including scaling of nanopore batteries already achieved experimentally. Finally, we consider manufacturability aspects in terms of (1) process sequence complexity and (2) comparison to that of other existing technologies based on thin film processing.

11:20am **MS-MoM10 Advanced Manufacturing R&D for Clean Energy in the US Department of Energy***, Mark Johnson,* Advanced Manufacturing Office, U.S. Department of Energy **INVITED**

Manufacturing is a critical component of the U.S. economy, responsible for 12.5% [1] of GDP, direct employment for over 12 million people [1], and close to 75% [2] of U.S. exports of goods. The U.S. manufacturing sector, while it produces 17% [3] of the world's manufacturing output, also represents a quarter of the country’s energy consumption [4]. On the R&D side, it is responsible for 70% of all business R&D performed (in 2010 and 2011) and nearly 60% of patent applications [5]. As such, DOE has a vested interest in broadly applicable energy efficiency technologies for use in energy intensive manufacturing, as well as platform materials and processes for use in the manufacturing of clean energy technologies.

This talk will review the Advanced Manufacturing Offices work towards making the U.S. manufacturing sector more energy productive—and the U.S. clean energy manufacturing sector more competitive—through targeted R&D and partnerships with industry, academia, technology incubators and other stakeholders.

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