CHANGING WHAT'S POSSIBLE

NOVEL STRUCTURE FOR SOLID STATE LITHIUM-ION BATTERIES

Updated: January 14, 2018

TITLE: Safe, Low Cost, High Energy Density, Solid State Li-Ion Batteries

PROGRAM: Robust Affordable Next Generation Energy Storage Systems (RANGE)

AWARD: $4,683,452

TEAM: University of Maryland, University of Calgary, Ion Storage Systems, TransTech

TERM: January 2014 – January 2020

PRINCIPAL INVESTIGATOR (PI): Eric Wachsman

MOTIVATION

In 2017, 91% of U.S. transportation energy came from petroleum, nearly half of which came from foreign sources.[1] Widespread adoption of electric vehicles (EVs) can substantially reduce U.S. oil imports, increase the energy efficiency of transportation, and reduce greenhouse gas (GHG) emissions. To realize these benefits, EVs must compete with conventional vehicles in terms of price and driving range, both of which are influenced by the cost and storage capacity of the EV's battery. ARPA-E's RANGE program aims to maximize a battery's energy storage potential and minimize its cost at the vehicle system level. This will require robust energy storage chemistries and new battery cell and pack architectures. RANGE technologies seek to reduce the weight of vehicle energy storage systems while curtailing the need for added impact protection and enabling systems to perform additional functions.

TECHNICAL OPPORTUNITY

Current lithium-ion (Li-ion) technology consists of a graphite negative electrode coupled with a metal oxide positive electrode. This design suffers from performance limitations that incremental progress cannot address. Its energy density is limited by the amount of charge that can be practically stored inside its components; Li-ion's upper operating temperature of ~50°C requires expensive cooling systems; and current Li-ion cells use a flammable liquid electrolyte, prompting safety concerns.

Replacing the negative electrode with Li metal and the liquid electrolytes in the separator and the porous positive electrode with solid ion conductors can address these limitations.[2] An appropriate solid electrolyte separator can enable Li metal as the negative electrode by eliminating dendrites—small needles that cause cells to short and limit the use of high capacity Li-metal anodes. Non-combustible, solid-state electrolytes can also reduce temperature and flammability constraints, though they faced challenges in conducting lithium ions and interfacing with other cell components. Advances such as the synthesis of $Li_7La_3Zr_2O_{12}$ ("LLZO"), a new garnet-ceramic material with a room temperature Li-ion conductivity nearly equivalent to state-of-the-art Li-ion liquid electrolytes, could enable a new generation of safe batteries without sacrificing performance.

INNOVATION DEMONSTRATION

Garnet-ceramic-based solid-state batteries are highly conductive, stable, safe, and can prevent lithium dendrites from forming. However, garnet-electrolyte batteries have long faced challenges related to electrolyte thickness,

1 U.S. Energy Information Administration, Monthly Energy Review, Tables 2.5 and 3.8c, April 2017.

2 Albertus, P. Integration and Optimization of Novel Ion-Conducting Solids (IONICS) Funding Opportunity Announcement (2016); https://arpa-e-foa. energy.gov/FileContent.aspx?FileID=cfac9ce8-5a19-4623-b942-c3e65f3ccf77.

low surface area at the electrode/electrolyte interface, and inherently poor solid-solid interfacial contact. To address this, the University of Maryland (UMD) team combined expertise from disparate fields, including experience with solid oxide fuel cells, in-depth knowledge about the LLZO material, and battery manufacturing capability.

The team built a tri-layer electrolyte structure from LLZO that features a porous structure for both the positive and negative electrodes, with a dense, thin, solid electrolyte sandwiched between them. The thin, dense center layer prevents dendrite growth. The porous support on either side of the dense center layer provides mechanical strength and helps overcome electrode/electrolyte interfacial impedance by increasing the surface area between the two.

The team also leveraged a new atomic layer deposition technique in which a thin aluminum oxide (or other composition) coating is deposited onto the garnet electrolyte surfaces. The coating reduces LLZO resistance to both electrodes and prevents water from reacting with the lithium in the garnet, but does not increase cell resistance.

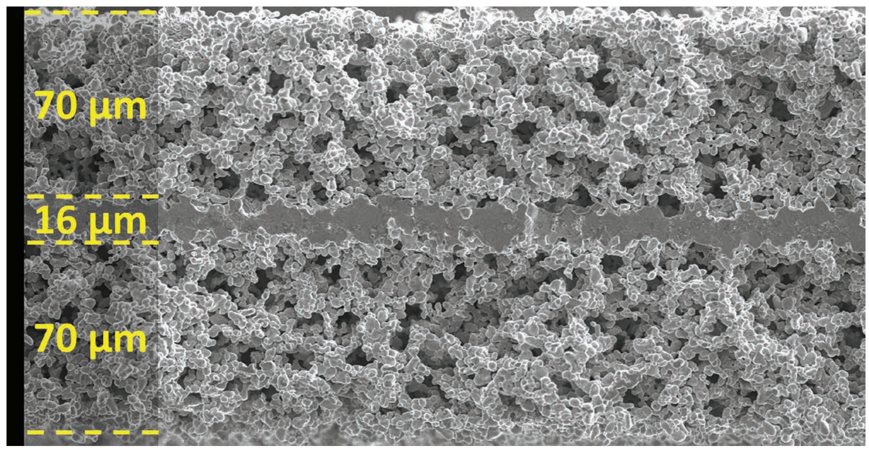

Figure 1: Sample unfilled garnet tri-layer porous electrolyte with dense interlayer.

Tests show that lithium ions can be shuttled across the separator layer with 100% coulombic efficiency (i.e. no loss of lithium) and with no increase in cell resistance for greater than 300 cycles. The team is working to scale up while refining their cost model, which indicates that with high-volume manufacturing, this solid-state system may be cost competitive with traditional Li-ion batteries with decreased weight thanks to fewer control and protection systems.

IMPACT PATHWAY

UMD has spun-off a company, Ion Storage Systems (ISS), which has begun fabricating sample cells and distributing them to potential customers. ISS is focusing on scale-up and manufacturing of supported garnet electrolytes with major ceramic manufacturer, TransTech, and coating developer, PneumatiCoat, for first sales. The technology has generated interest from the automotive, consumer electronic, and aerospace industries. Unmanned aerial vehicles (UAVs) are a likely first market, as these aircraft require higher energy density and can bear the costs associated with initial low-volume production. Additional funding has also been received, including three Department of Energy, Energy Efficiency and Renewable Energy (EERE) contracts and two NASA Game Changing Program contracts, as well as support from Lockheed Martin.

LONG-TERM IMPACTS

With the development of a highly conductive lithium electrolyte, a rigid, self-supporting architecture, and low internal resistance, the UMD team's battery has the potential to overcome the energy density plateau of Li-ion chemistry. Such a design could be used in large format battery manufacturing plants for EVs. Inexpensive and safe batteries using this technology could also be used for grid energy storage, consumer electronics, and UAVs. In the long term, the success of this technology will provide U.S. manufacturing a new battery platform with higher capacity, lower cost, and greater safety.

INTELLECTUAL PROPERTY AND PUBLICATIONS

As of January 2018, the UMD team's project has generated six invention disclosures to ARPA-E. One U.S. Patent and Trademark Office (PTO) patent applications is currently pending for these inventions. The team has