Academic Research Leads To Solid Electrolyte Lithium-Ion Batteries Without Achilles' Heel

Lawrence Berkeley Natl Lab

Most of the major automotive companies are developing them. Demand for their crucial ingredient is poised to take off. And the mainstream public is enamored with the products they power.

The focus of all this attention is a battery with core material — lithium, a soft, lightweight silver-white metal. Lithium-ion (Li) batteries, which have ushered in a new age of portable electronics, hold out a promise of mass-market electric vehicles, EVs for short. They are poised to overtake the nickel-metal hydride (NiMH) batteries used in the famous electric-gasoline hybrid Toyota Prius that's come to stand for green motoring in the consumer's eye.

Advocates claim new advances in technology have enabled the lithium-ion battery to leap frog the lead-acid or NiMH versions because it carries more energy with less weight than other materials. But before EVs can ever surpass gasoline powered vehicles, researchers need to address weight, as well as a propensity to catch fire and explode — the long-term Achilles' heel in battery technology.

One approach to reduce the weight of the battery is to replace the graphite electrode in current lithium-ion batteries with a lithium metal electrode. The problem with this battery is the growth of minute metallic lithium spikes, called dendrites, that grow on the lithium metal electrodes with repeated charge and discharge cycles, especially if the battery is charged quickly. The dendrites reduce battery life and can cause electrical short circuits that make the battery overheat and catch fire. This is a major problem that must be solved before the next generation of lithium batteries can safely be used in a wide range of applications.

A Lightweight Polymer-Based Solution

For years, researchers have explored ways to improve the reliability and safety of lithium batteries. They've tried to replace the volatile liquid electrolytes in use today with a stiff polymer electrolyte to prevent the dendrites from forming. Unfortunately, stiff polymer electrolytes have never provided the high conductivity needed to justify the development of this type of battery — until now.

> *Seeo Inc., a Berkeley, Calif.-based battery startup company founded in 2007, believes it has found the perfect lithium chemistry to make batteries that can hold lots of energy, are cheap to make and safer to use than current lithium-ion batteries on the market.*

A team of scientists at Seeo has developed a nanostructured solid-state battery with no flammable or volatile components, which makes it ideal for use in:

- Batteries for electrically powered vehicles
- Electrical-grid load-leveling devices
- Medical and other specialty devices

Seeo claims its battery can deliver an energy density beyond 250 watt hours per kilogram (Wh/kg) today with a research and development (R&D) path toward 400 Wh/kg vs. today's lithium-ion batteries that normally deliver less than 200 Wh/kg. Seeo also says its battery can operate at higher temperature than standard lithium-ion batteries, making it a good choice for more rugged, outdoor applications attached to a solar energy system.

At the core of this battery technology is a novel solid polymer electrolyte material that can transport lithium ions while providing inherently safe and stable support for very high-energy electrode chemistries. Seeo has an exclusive license to this advanced technology from Lawrence Berkeley National Laboratory (Berkeley Lab), a U.S. Department of Energy (DOE)- funded national laboratory managed by the University of California.

"The novelty of the technology is in the perfect marriage of materials engineering, polymer science and electrochemistry. World-renowned experts from these disciplines were able to share their ideas and collaborate under the prestigious Batteries for Advanced Transport Technologies (BATT) Program at Berkeley Lab to come up with a new platform for Li batteries," says Mohit Singh, who led the academic research project as a postdoctoral student at the University of California, Berkeley (UC Berkeley) under the guidance of Nitash Balsara, Ph.D., a scientist in Berkeley Lab's Materials Sciences Division and a researcher with the Lab's Environmental Energy Technologies Division. "We had the opportunity to collaborate with some of the top battery scientists in the world and ensure that the research never lost practical relevance."

Singh, who received a doctorate degree in chemical and biomechanical engineering with a focus on the self-assembly of soft materials such as biosurfactants and polymers, went on to co-found Seeo in 2007 with Balsara and fellow doctoral student Hany Eitouni, who received a doctorate degree in chemical engineering with a focus on polymer materials and specialized expertise in ionic transport through polymers. Today, Singh and Eitouni are vice president of R&D and engineering and director of materials development, respectively.

Academic Research at the Core

Balsara and his research team of talented students refined techniques and developed an unusually hard ion conductor — 50-nanometer channels composed of a softer polymer laced with lithium salts encased in a hard polymer matrix. Since a lithium dendrite is 20 times as large as the soft polymer channels, it is too large to force its way into the material. Their technology offers:

• High thermal stability

• Low rate of self-discharge

• Safe, stable operation in a wide range of environmental conditions

• Flexibility to novel forms and packaging

• Manufacturing capabilities with conventional polymer processing methods

"I came to Berkeley and challenged my students: What can we do with polymers that we don't do today? We decided to look at how ions flow through polymers," says Balsara, who also is a professor in the Department of Chemical Engineering at UC Berkeley. "The relevancy of our research on batteries didn't hit until after we started."

The team found out the idea of mixing polymers with ions wasn't new. Researchers in the 1990s tried to make ions conduct, but soon abandoned their research because the:

• Solids they were experimenting with wouldn't conduct and

• Plasticizers and/or solvents added to the host polymer matrix to achieve high conductivities deteriorated the mechanical properties needed to ensure the electrolyte could be manufactured, stored and used.

They also uncovered research articles with "fuzzy" conclusions that the nonconductive part of a battery needed to be soft to assist conduction of the ions in the conducting part. This later research helped the team decide to construct a nanostructure ion electrolyte using ordinary polymers. Their Berkeley Lab-funded research allowed them to completely decouple the electrical and mechanical properties of the polymer electrolyte materials, which allowed them to optimize both these properties at the same time.

"We revisited one of the longest-standing challenges in Li-batteries: stabilizing the Li-electrolyte interface and making the switch to a higher energy density system safer," Singh says. "We started with research conducted by a UC Berkeley chemical engineering group, led by Professor John Newman, that essentially explained why polymers that conduct ions can't stabilize the Li-electrolyte interface. The conclusion of the research was that ion-conducting polymers don't have sufficient mechanical strength to stabilize Li-electrolyte interface, as there is an inverse relationship between mechanical properties and ionic conductivity.

"So, we approached the issue from a different angle: We asked how we can make a very mechanically stable polymer conduct ions? We came up with what I think is an elegant approach of using a nanostructured polymer electrolyte to decouple mechanical properties from ion conduction."

'Something Weird' Led to Technology Transfer

“As we were writing the paper about our discovery, something really weird happened,” Balsara explains. “We said wait a minute, we may be on to something that has implications beyond an academic paper.”

At this point, Balsara and his team found out about Berkeley Lab’s Technology Transfer and Intellectual Property Management Department.

“Initially, I thought we were going to find out about a mountain of stuff that we weren’t interested in doing,” Balsara says. “The reality is they were very helpful in taking the paper we were writing and molding it into what we needed to file for a patent.”

Berkeley Lab marketed the technology to a number of companies working in the lithium-ion battery arena. This nanostructured polymer electrolyte technology was competitive because it won one of R&D Magazine’s prestigious R&D 100 Awards for 2008 and was expected to meet the energy density goal established by the DOE for electric vehicles — the highest hurdle for battery technology.

In addition, predictions based on recent tests indicate that Seeo batteries will achieve the United States Advanced Battery Consortium goal of 5,000 cycles.

“We knew this technology had potential,” says Berkeley Lab’s Virginia de la Puente, a senior licensing associate in Technology Transfer and Intellectual Property Management. “We had about 15 prospects but no one was willing to take a risk on an academic-based technology except one venture capital firm focused on early stage companies.”

Academic Adds Entrepreneur to Resume

Balsara hooked up with Khosla Ventures (KV), which was established by Silicon Valley’s influential Vinod Khosla. Taking a sabbatical, Balsara convinced his former students, Singh and Eitouni, to join him and co-found Seeo with about $2 million in funding from KV. Seeo also raised an additional $3 million in 2008 from KV and $8.6 million in 2009 from a group of investors including GSR ventures and Google.

“If it weren’t for Professor Balsara getting the early stage government funding for his battery research and a gestation period over a couple years with interesting results, this team might not have come up with something no one has seen before,” says Atiq Raza, a serial entrepreneur who served as the chief operating officer and the president of AMD and now is the chair of the board at Seeo.

“But Seeo is not just a story about funding. We’re also the product of timing and the ability to make things happen — the opportunity to introduce an innovation in energy that promises to solve a problem with one of the strongest material development groups and scientists in the country that have made leaps and bounds in taking a concept and building batteries, which, we hope, will go into the next generation of cars and grid backup solutions.”

One new area where the team at Seeo is looking to make things happen involves a DOE Smart Grid Demonstration Project for which the company has received $6 million to develop and deploy a 25 kilowatt-hour (kWh) prototype battery system based on its proprietary nanostructured polymer electrolytes. The award is designed to demonstrate the substantial improvements offered by solid-state lithium-ion technologies, which would be targeted for utility-scale operations, particularly Community Energy Storage projects.

“Sometimes you can have a really promising technology, but the only party that’s willing to take a risk is a startup company,” says Berkeley Lab’s de la Puente. “For this technology, the best placement was a small company. Established companies sometimes don’t have the level of intensity required to develop and commercialize an innovation like this."

Today, Balsara is back on campus. Singh says he is still involved, offering "optimism and support through his insights and contacts" that help to lead the charge in a lot of directions the Seeo group is going. But the fundamental goal for the scientists and engineers is to improve the reliability and safety of lithium-ion batteries, which both business and society appear ready to embrace as the next crucial source of mobile energy.

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