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Powered by seaweed: Polymer from algae may improve battery performance

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Igor Luzinov. Image by: Clemson University

(PhysOrg.com) -- By looking to Mother Nature for solutions, researchers have identified a promising new binder material for lithium-ion battery electrodes that not only could boost energy storage, but also eliminate the use of toxic compounds now used to manufacture the components.

Known as alginate, the material is extracted from common, fast-growing brown algae. In tests so far, it has helped boost energy storage and output for both graphite-based electrodes used in existing batteries and silicon-based electrodes being developed for future generations of batteries.

The research, the result of collaboration between scientists and engineers at Clemson University and the Georgia Institute of Technology, will be reported Sept. 8 in Science Express, an online-only publication of the journal *Science* that publishes selected papers in advance of the journal. The project was supported by the two universities as well as by a Honda Initiation Grant and a grant from NASA.

"Making less-expensive batteries that can store more energy and last longer with the help of alginate could provide a large and long-lasting impact on the community," said Gleb Yushin, an assistant professor in Georgia Tech's School of Materials Science and Engineering. "These batteries could contribute to building a more energy-efficient economy with extended-range electric cars, as well as cell phones and notebook computers that run longer on battery power — all with environmentally friendly manufacturing technologies."

Working with Igor Luzinov at Clemson University, the scientists looked at ways to improve binder materials in batteries. The binder is a critical component that suspends the silicon or graphite particles that actively interact with the electrolyte that provides battery power.

"We specifically looked at materials that had evolved in natural systems, such as aquatic plants which grow in saltwater with a high concentration of ions," said Luzinov, a professor in Clemson's School of Materials Science and Engineering. "Since electrodes in batteries are immersed in a liquid electrolyte, we felt that aquatic plants — in particular, plants growing in such an aggressive environment as saltwater — would be excellent candidates for natural binders."

Finding just the right material is an important step toward improving the performance of lithium-ion batteries, which are essential to a broad range of applications, from cars to cell phones. The popular and lightweight batteries work by transferring lithium ions between two electrodes — a cathode and an anode — through a liquid electrolyte. The more efficiently the lithium ions can enter the two electrodes during charge and discharge cycles, the larger the battery's capacity will be.

Existing lithium-ion batteries rely on anodes made from graphite, a form of carbon. Silicon-based anodes theoretically offer as much as a tenfold capacity improvement over graphite anodes, but silicon-based anodes so far have not been stable enough for practical use.

Among the challenges for binder materials are that anodes to be used in future batteries must allow for the expansion and contraction of the silicon nanoparticles and that existing electrodes use a polyvinylidene fluoride binder manufactured using a toxic solvent.

Alginates — low-cost materials that already are used in foods, pharmaceutical products, paper and other applications — are attractive because of their uniformly distributed carboxylic groups. Other materials, such as carboxymethyl cellulose, can be processed to include the carboxylic groups, but that adds to their cost and does not provide the natural uniform distribution of alginates.

The alginate is extracted from the seaweed through a simple soda-based (Na_2CO_3) process that generates a uniform material. The anodes then can be produced through an environmentally friendly process that uses a water-based slurry to suspend the silicon or graphite nanoparticles. The new alginate electrodes are compatible with existing production techniques and can be integrated into existing battery designs, Yushin said.

Use of the alginate may help address one of the most difficult problems limiting the use of high-energy silicon anodes. When batteries begin operating, decomposition of the lithium-ion electrolyte forms a solid electrolyte interface on the surface of the anode. The interface must be stable and allow lithium ions to pass through it, yet restrict the flow of fresh electrolyte.

With graphite particles, whose volume does not change, the interface remains stable. However, because the volume of silicon nanoparticles changes during operation of the battery, cracks can form and allow additional electrolyte decomposition until the pores that allow ion flow become clogged, causing battery failure. Alginate not only binds silicon nanoparticles to each other and to the metal foil of the anode, but they also coat the silicon nanoparticles themselves and provide a strong support for the interface, preventing degradation.

Thus far, the researchers have demonstrated that the alginate can produce battery anodes with reversible capacity eight times greater than that of today's best graphite electrodes. The anode also demonstrates a coulombic efficiency approaching 100 percent and has been operated through more than 1,000 charge-discharge cycles without failure.

For the future, the researchers — who, in addition to Yushin and Luzinov, included Igor Kovalenko, Alexandre Magasinski, Benjamin Hertzberg and Zoran Milicev from Georgia Tech; and Bogdan Zdyrko and Ruslan Burtovyy from Clemson — hope to explore other alginates, boost performance of their electrodes and better understand how the material works.

Alginates are natural polysaccharides that help give brown algae the ability to produce strong stalks as much as 60 meters long. The seaweed grows in vast forests in the ocean and also can be farmed in wastewater ponds.

"Brown algae is rich in alginates and is one of the fastest-growing plants on the planet," said Luzinov, who also is a member of Clemson's Center for Optical Materials Science and Engineering Technologies (COMSET). "This is a case in which we found all the necessary attributes in one place: a material that not only will improve battery performance, but also is relatively fast and inexpensive to produce and is considerably more safe than the some of the materials that are being used now."

Provided by Clemson University

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