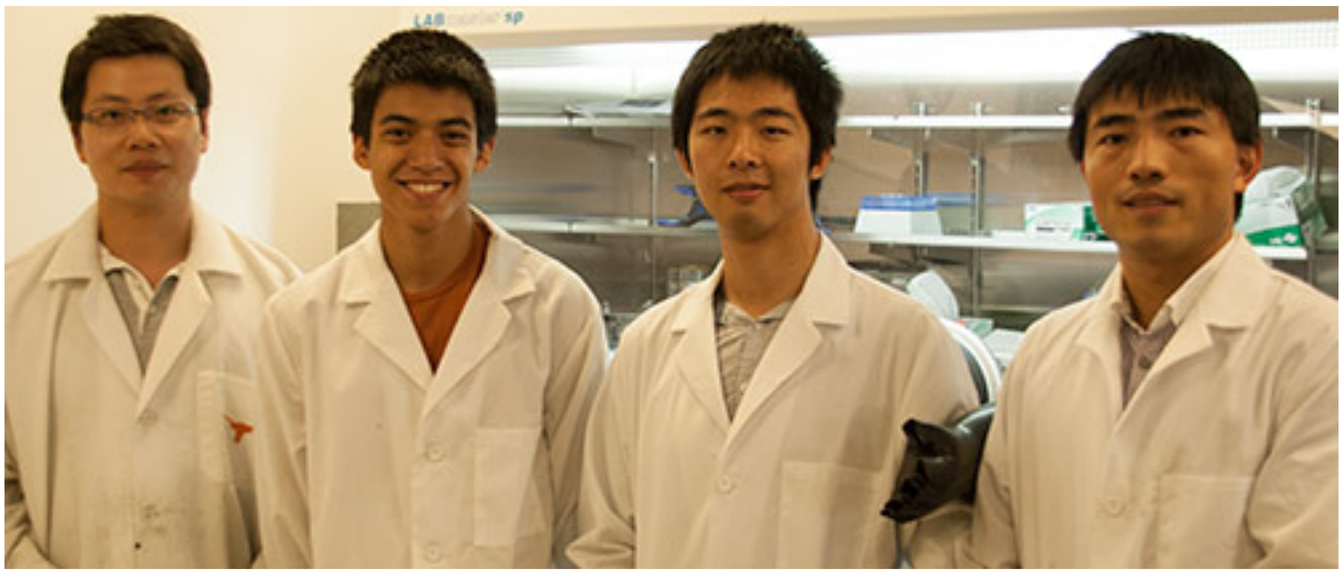
Guihua Yu's Anode Material for Lithium-ion Batteries

AUSTIN, TEXAS—January 30, 2014



Dr. Yu and his research team. Left to Right: Yu Zhao, Vincent Teran, Borui Liu, and Dr. Guihua Yu.

Lithium-ion battery longevity is a frustrating problem that most everyone with a cell phone has experienced, and it is slowing the adoption of electric vehicles as it affects the vehicle range. **Dr. Guihua Yu** and his research group are designing a material that looks promising for dramatically extending battery life and energy storage density, needed for evermore complex digital devices and electric vehicles.

A Better Anode Material for Lithium-ion Batteries

Guihua Yu, an assistant professor in the Department of Mechanical Engineering at The University of Texas at Austin recently had a paper published in the prestigious research online journal Nature Communications on the production of a silicon-laced hydrogel for use in lithium-ion batteries. Since that time, he has modified the initial process, which used silicon nanoparticles to include carbon nanotubes for increased performance. In Dr. Yu's hydrogel, he is suspending nanoparticles and carbon nanotubes in a three-dimensional network inside the gel. With this anode, they demonstrate a cycle life of 2,000 cycles with about 90% capacity retention— signficantly better than that of graphite, the traditional material now used in most lithium-ion anodes (the negative electrode). Graphite (a form of carbon) alone does not meet the high-energy needs required to improve battery longevity, causing the batteries to degrade completely in two to three years.

The Upside and Downside of Silicon as an Anode Material

Dr. Yu is interested in silicon as it is readily available, cheap, non-toxic and displays a relatively low discharge potential. The downside is that silicon films tend to expand upwards to 400% when absorbing lithium ions during charging, and shrink again when releasing lithium ions during discharge. This leads to pulverization and fracturing of the anode and a short life for the battery. Silicon is a good material choice, but it doesn't work alone. To work well it has to be combined with other materials.

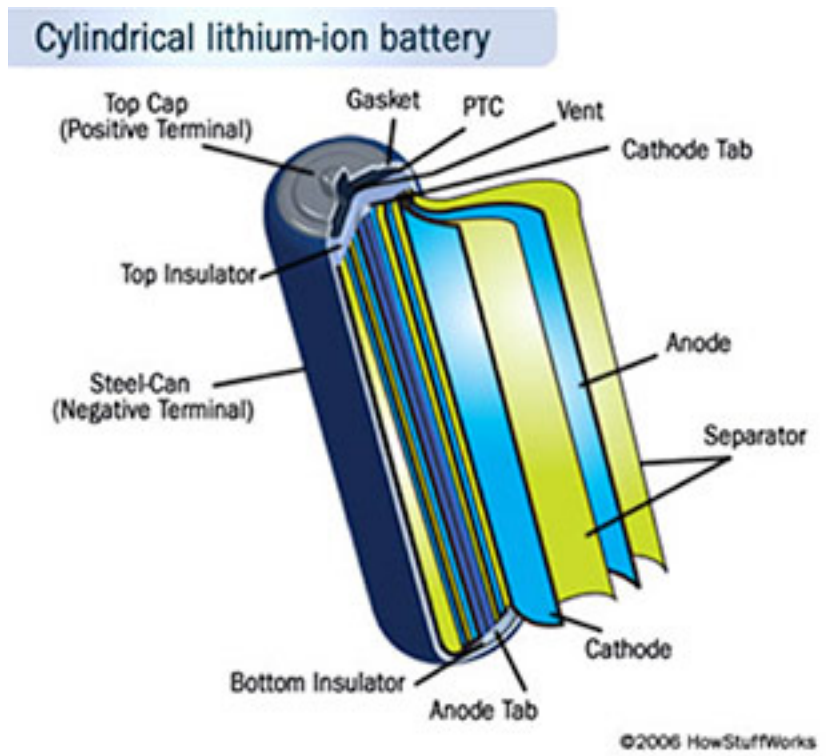
Suspension of Silicon and Carbon Nanotubes in a 3D Framework

Yu and his team are using a conductive polymer matrix that is made of polypyrrole and incorporates silicon nanoparticles and a tiny amount of carbon nanotubes to replace graphite as the anode material. Yu's polypyrrole hydrogel is 96% water and is similar to a hydrogel used in medical applications such as soft contact lenses. However, the material Dr. Yu's team has developed is a novel variation of the medical material and has not been used for energy

Related Links

- Dr. Guihua Yu's Faculty Bio
- Dr. Yu's Research Site
- Nanotechweb.org: 3D nanostructured composite makes good battery anode
- Nano Letters Paper: Three-Dimensional Hierarchical Ternary Nanostructures for High-Performance Li-Ion Battery Anodes
- Energy & Environmental Science Article: 3D nanostructured conductive polymer hydrogels for high-performance electrochemical devices

How Lithium-ion Batteries Work 101



From Physics Central and Howsuffworks.com:
This metal case holds a long spiral comprising three thin sheets pressed together:
A ***Positive electrode***
A ***Negative electrode***
A ***separator***
Inside the case these sheets are submerged in an organic solvent that acts as the electrolyte. Ether is one common solvent. The separator is a very thin sheet of microperforated plastic. As the name implies, it separates the positive and negative electrodes while allowing ions to pass through.
The positive electrode is made of Lithium cobalt oxide, or $LiCoO_2$*. The negative electrode is made of carbon. When the battery charges, ions of lithium move through the electrolyte from the positive electrode to the negative electrode and attach to the carbon. During discharge, the lithium ions move back to the* $LiCoO_2$ *from the carbon.*

Schematic video by BASF on Lithium-ion Batteries

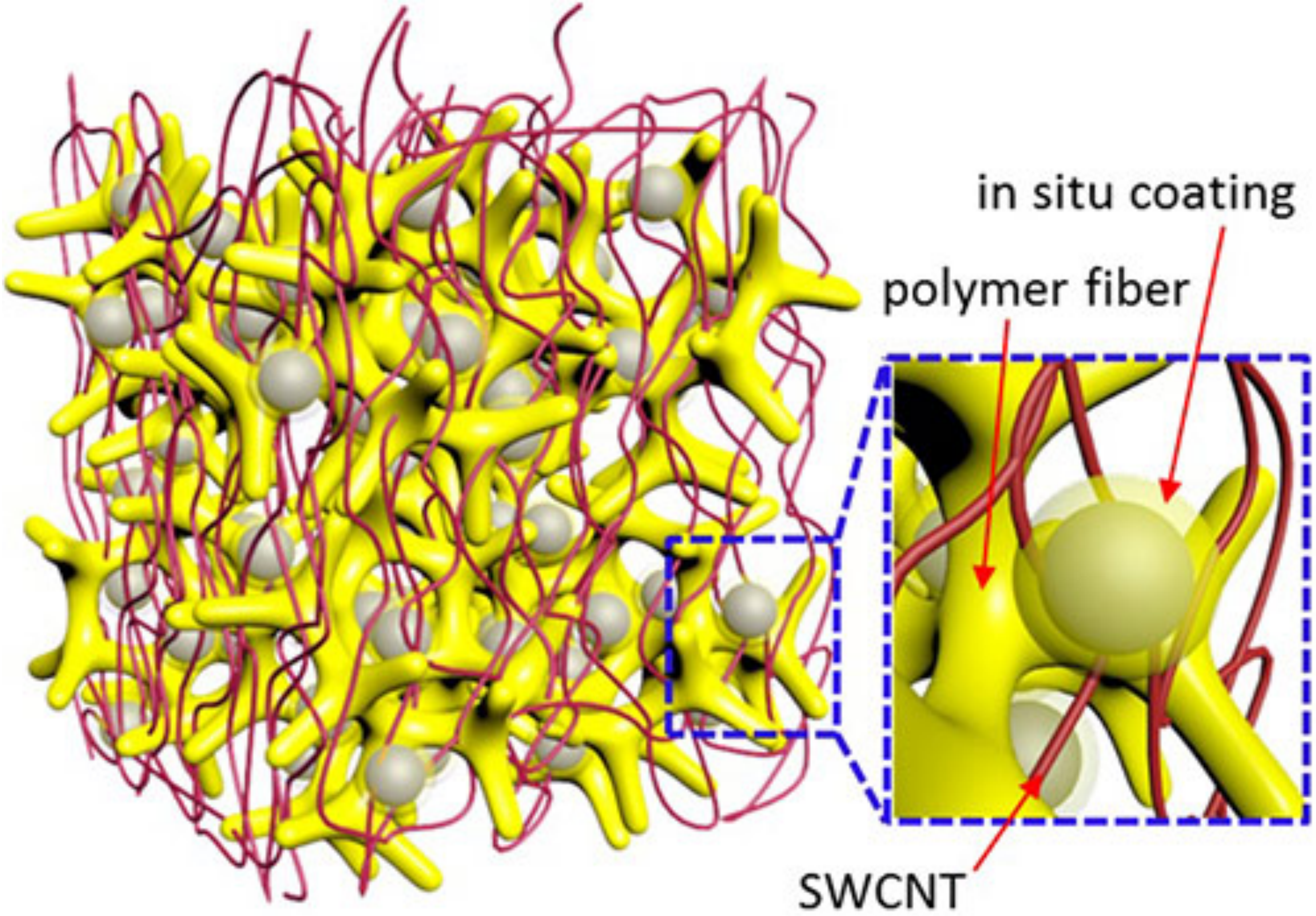


Diagram of Dr. Guihua Yu's anode material made with polypyrrole (an organic polymer), nano particles of silicon, phytic acid and carbon nanotubes. The yellow framework is the conductive polypyrrole which is made in situ (in place) in a hydrogel that is activated by a chemical reaction. The red lines are carbon nanotubes. The gray balls are silicon nanoparticles coated with polymer from a hydrogel. Adapted from Yu's Nano Letters Paper, Three-Dimensional Hierarchical Ternary Nanostructures for High-Performance Li-Ion Battery Anodes.

The researchers mixed an aqueous solution made of a conductive polymer monomer and the cross-linker phytic acid (a storage form of phosphorous found in plants) with a second solution containing an initiator molecule, ammonium persulphate, a strong oxidizing agent. Silicon nanoparticles and carbon nanotubes were then added to the mix.

The initiator kick starts the polymerization reaction, forming a coating on the silicon surface and a 3D hydrogel network. After 10 minutes reaction time, the final slurry is ready to be coated onto a copper current collector for making anodes. ***Read more: 3D nanostructured composite makes good battery anode)***

storage in batteries or capacitors previously. A ternary composite, their material combines three elements—silicon, carbon nanotubes and polypyrrole.

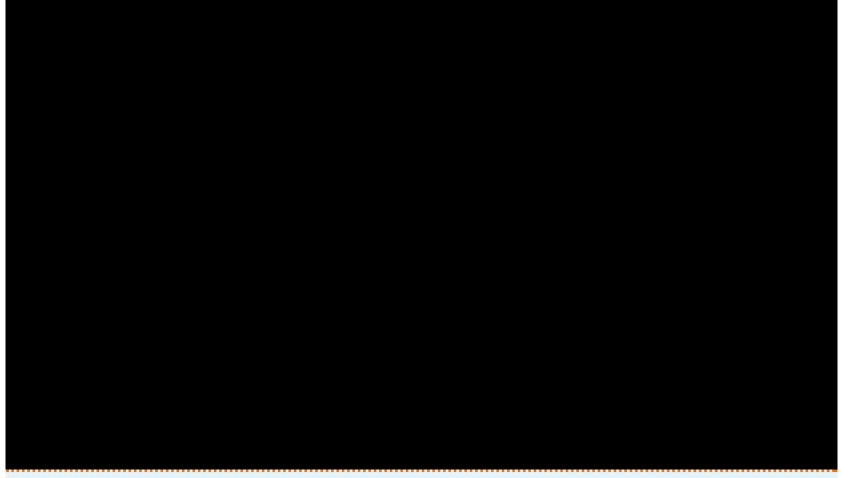
Lab sample of the hydrogel made by Yu and his team.

Making the Framework

The 20 nanometer thick polymer formed on the silicon nanoparticles in the slurry makes the finished electrode material more stable. After the first paper was written, the team experimented with adding carbon nanotubes to the slurry and found it enhanced the material further. Yu explained that the carbon nanotubes produce better capacity and cyclability by strengthening the mechanical properties of the composite electrode as they wrap around the silicon particles, as you can see in the illustration above.

Scalability of the process

Yu is excited about the possibility of large scale production of the process, as it is compatible with existing battery manufacturing methods. This type of electrode would greatly improve longevity and energy density in next-generation batteries. Moreover, this energy gel development has earned Yu an invitation for a recent perspective article in Energy & Environmental Sciences. The team is continuing work and refinement of the material and plans to partner with scientists at other labs in the near future. Stay tuned for more advancements in this exciting research and longer lifespans for all of our portable devices.



This video explains the concept behind how lithium-ion batteries work. View on YouTube.

Currently, lithium-ion batteries display poor cycling stability, meaning that as the battery is used and recharged multiple times in the cycling process. The cathode (positive electrode) in the battery is composed of lithium metal oxide, and the anode (negative electrode) is made of graphite. The materials are layers in sheets with the two electrode layers on the outside. Nested next to those are separator layers so that the two poles cannot be in electrical contact with each other. Sandwiched between those is a permeable transport layer used by the lithium ions to travel between the positive and negative poles (the cathodes and anodes).

During charging and discharging in rechargeable lithium-ion batteries, the lithium ions travel from the positive cathode to the negative anode and back, causing the battery to become less powerful with additional cycles as the battery degrades. The degradation is the result of the oxidation process, such as rust forming on iron, as the lithium metal oxide loses ions over time.