Scientists increase lithium-sulfur battery lifetime by a factor of 10

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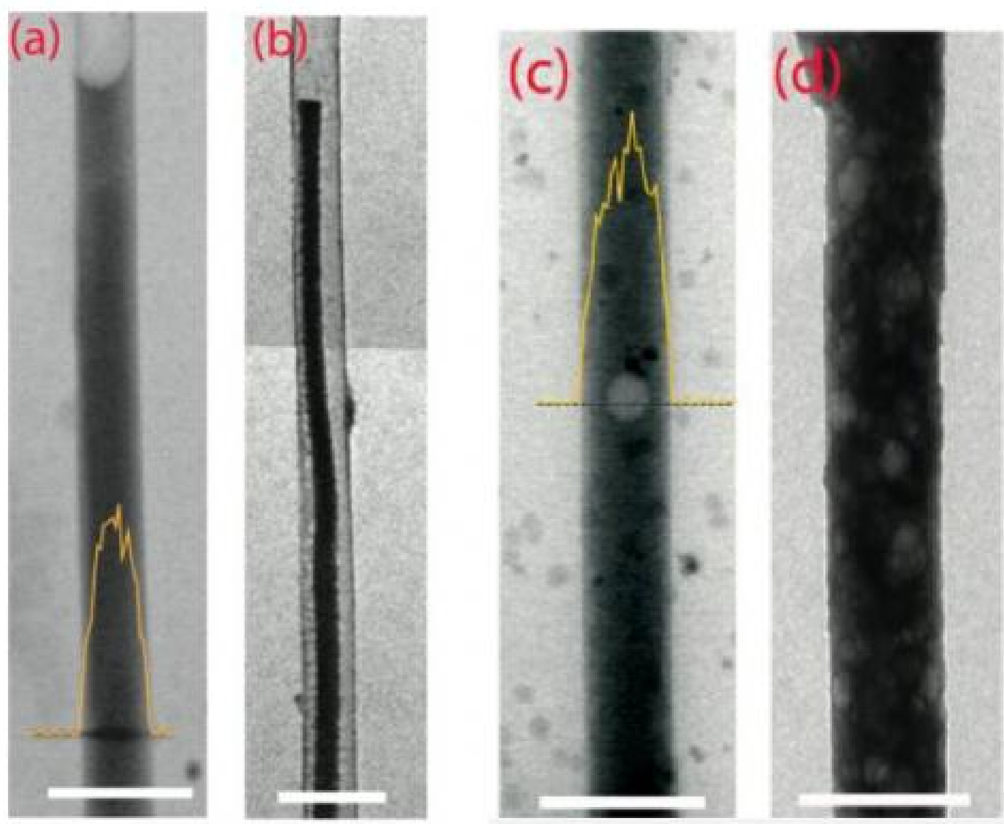

(a) TEM image of the sulfur cathode before discharge. The lithium sulfide (dark) is bonded to the inner wall of the hollow nanofiber (transparent). (b) TEM image of the sulfur cathode after full discharge. The lithium sulfide has shrunk away from the carbon wall, resulting in a loss of electrical contact and capacity decay. (c) TEM image of the polymer-modified sulfur cathode before discharge. (d) TEM image of the polymer-modified sulfur cathode after full discharge. The lithium sulfide remains attached to the carbon wall, improving capacity retention. Credit: Guangyuan Zheng, et al. ©2013 American Chemical Society

(Phys.org)—The world of rechargeable batteries is full of trade-offs. While lithium-ion (Li-ion) batteries are currently the most commercially successful, their low energy density doesn't allow for a long driving range. They are also very expensive, often accounting for half the price of electric vehicles. One alternative is lithium-sulfur (Li-S) batteries, which are attractive for their high gravimetric energy density that allows them to store more energy than Li-ion batteries. And although they still use some lithium, the sulfur component allows them to be much cheaper than Li-ion batteries. But one of the biggest drawbacks of Li-S batteries is their short cycle life, which causes them to lose much of their capacity every time they are recharged.

Now a team of researchers led by Yi Cui, a professor of materials science and engineering at Stanford University, has developed a Li-S battery that can retain more than 80% of its 1180 mAh/g capacity over 300 cycles, with the potential for similar capacity retention over thousands of cycles. In contrast, most Li-S batteries lose much of their capacity after a few tens of cycles.

To achieve this improvement, the researchers first identified a new mechanism that causes capacity decay in Li-S batteries after cycling. In order for a Li-S battery to successfully recharge, the lithium sulfide in the cathode must be bound to the cathode surface—in this case, the inner surface of the hollow carbon nanofiber that encapsulates it. This binding creates a good electrical contact to allow for charge flow. But the researchers found that, during the discharge process, the lithium sulfide detaches from the carbon, resulting in a loss of electrical contact that prevents the battery from fully recharging.

Before now, it has been very challenging to study the sulfur cathode at the nanoscale due to the sulfur compound's sensitivity to air and moisture, as well as its tendency to sublime under a vacuum. But the hollow carbon nanofiber structure of the anode—which the researchers developed in a previous study—protects the sulfur, which allowed the researchers to view the cathode using a transmission electron microscope (TEM) without significantly damaging the sample.

After identifying the problem, the researchers set about fixing it by adding polymers to the carbon nanofiber surface in order to modify the carbon-sulfur interface. The polymers are amphiphilic, meaning they are both hydrophilic (water-loving) and lipophilic (fat-loving), similar to soap. This property gives the polymers anchoring points that allow the lithium sulfides to bind strongly with the carbon surface in order to maintain strong electrical contacts.

As experiments showed, sulfur cathodes containing the amphiphilic polymers had very stable performance, with less than 3% capacity decay over the first 100 cycles, and less than 20% decay for more than 300 cycles.

Although the improvement is a big step forward, the capacity retention still doesn't compare to Li-ion batteries, some of which have lifespans approaching 10,000 cycles. In order to avoid having to replace the battery every few years, electric vehicles require these longer lifespans. But Cui says that Li-S batteries have the potential to close this gap in the foreseeable future.

"Using the amphiphilic polymer idea here in this paper, together with nanoscale materials design and synthesis, it is possible to improve the cycle life up to 10,000 cycles," Cui told *Phys.org*. "My group is working on this. Our recent results on nanomaterials design already improved to 1000 cycles."

In the future, Cui think Li-S batteries will give Li-ion batteries some serious competition.

"The Li-S batteries become pretty promising for electric vehicles," he said. "The life cycle needs to improve further. The lithium metal anodes' safety problem needs to be solved. It is possible to get around Li metal anodes with Si anodes."

More information: Guangyuan Zheng, et al. "Amphiphilic Surface Modification of Hollow Carbon Nanofibers for Improved Cycle Life of Lithium Sulfur Batteries." *Nano Letters*. DOI: 10.1021/nl304795g