Will lithium-sulfur batteries be in our future?

Monash University Associate Professor Matthew Hill, Dr. Mahdokht Shaibani, and Professor Mainak Majumder with the lithium-sulphur battery design.
Monash University

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The name “lithium-ion battery” seems to imply that lithium is the essential ingredient that dictates the battery’s performance characteristics. But that’s less true than it appears. The electrodes that the lithium shuttles between are critical for dictating a battery’s performance, which is why electrode materials played such a large role in the description of last year’s Chemistry Nobel. Different electrode materials dictate the battery’s performance in part based on dictating the energy difference between the charged and uncharged state. But they also determine how much lithium can be stored at an electrode, and through that the energy density of a battery.

There are a number of ideas floating around for new electrode materials that store lithium in fundamentally different ways: as solid lithium metal or as lithium oxide, which allows some of the electrode material to come from the air outside the battery. There are also chemicals that can store much more lithium per given area of volume. All of these options present serious issues (often more than one) that have kept them from

being adopted so far. But a recent paper is promising a major breakthrough in something that has always been an attractive option for lithium storage: sulfur.

Alternate electrodes

“Holds lots of lithium” isn’t a high bar to clear; if that was all we were looking for, some of these alternative electrode materials would be in use already. But there’s a whole host of other characteristics: cheap and easy to work with, compatible with the chemistry of the rest of the battery components, holds up to repeated charge cycles, and so on.

While sulfur clears the holds-a-lot-of-lithium hurdle, it stumbles badly for a couple of additional properties. One is that it’s not especially stable. Lithium-sulfur complexes can dissolve in the electrolytes used in typical lithium batteries, allowing it to diffuse away from the electrode. Over time, the storage capacity of the electrode will simply drift away, often winding up at the opposite electrode, gradually killing the battery. The problem is so widely recognized that it has a name—the polysulfide shuttle—and its own section on the lithium-sulfur battery Wikipedia entry.

That’s not the only problem. Lithium ions occupy space (duh). In some materials, the areas where they end up stored are largely unoccupied, so changing the charge state of the battery won’t cause it to expand or contract. Sulfur (and some other promising materials) aren’t like that. The incorporation of lithium into the sulfur’s structure causes it to expand dramatically, which can damage the battery’s structural integrity. Finally, sulfur doesn’t conduct very well, meaning that other materials are needed to move electrons around.

On the flip side, sulfur is very cheap and fairly easy to work with. Plus there’s the potential for much higher energy densities that motivated some early attempts at making lithium-sulfur batteries.

Room to breathe

The new work was done by an Australian-German team (with one Belgian thrown in for good measure). It tackles at least one of the issues mentioned above: the tendency to expand as lithium is stored. Existing lithium-sulfur batteries have frequently taken small particles of sulfur and embedded them in a mesh of material that both locks the particles into an electrode and allows electrons to travel to and from the lithium ions.

The density of this mesh, the researchers argue, causes two problems. One, it doesn't allow many of the sulfur particles breathing room to expand as lithium is stored. Should they expand anyway, this makes it likely that the electrode's structure will end up disrupted. Two, it covers much of the surface area of the particles, preventing lithium ions from interacting at those sites. In effect, it walls off parts of the sulfur, potentially limiting its capacity and slowing the lithium storage process.

Rather than form a dense mesh, the team decided to reduce the amount of mesh material used. Instead of forming a robust mesh, it simply forms a handful of connections between a sulfur particle and each of its neighbors. These connections leave most of the particle's surface accessible to the electrolyte and thus able to undergo interactions with lithium. And it allows the particles to shift and expand without causing the mesh that holds them together to break down entirely. A bit of carbon was also added to provide a conductor for electrons to move to the charge collector of the electrode.

To make sure that this was still sufficient to form a coherent material that didn't fall apart before getting into a battery, the researchers had to change the manufacturing process. Normally, the electrode materials are dissolved in water and

then mixed into a slurry. In this case, the researchers mixed the materials together for 48 hours before adding any water. This improved the performance of the material dramatically. Electron microscopy confirmed that the material that resulted lacked the thick mesh of material and was instead held together by multiple individual strands that directly connected individual sulfur particles.

Performance measures

The resulting battery does have a much higher capacity than existing lithium-ion batteries, and the researchers focus on some impressive numbers in their study, showing, for example, that the efficiency of transferring electrons in and out of the electrode remains at 98 percent of its original value after 200 cycles.

But the same graph shows that the battery's overall capacity has dropped by about a quarter after those 200 cycles. And this was done at a relatively low rate of charging, which typically preserves capacity better than a fast charge. This result could be due to the problem we mentioned above: loss of sulfur as it dissolves into the electrolyte. It's hard to tell, however, because the authors largely ignore that issue. Their introduction states that "substantial progress has been made in addressing the highly investigated issue of 'polysulfide shuttle' in Li-S batteries," but they don't include any references to papers showing that progress or mention that they've adopted any of the chemistry that led to it.

In an optimistic view, the loss of capacity is due to the polysulfide shuttle, and the researchers *haven't* done anything to avoid it, but their electrode's chemistry is compatible with techniques to minimize the problem. But it's not clear from this paper whether that sort of optimism is justified.

So why has the paper gotten so much attention? Presumably

because of a press release issued by Monash University, which indicates this technology has been patented, some prototype cells have been built by the German team members, and that Chinese firms have expressed interest in the technology. All of which makes it sound like massive-capacity batteries are on the immediate horizon—the press release even leads by asking the reader to “Imagine having access to a battery, which has the potential to power your phone for five continuous days, or enable an electric vehicle to drive more than 1,000km without needing to ‘refuel.'”

The work seems to represent a good idea that works in practice to a degree. But not a large enough degree that’s especially useful at the moment, unless you’re interested in slow-charging cars that need their batteries replaced every couple of years. There may be methods that can improve the performance further, but the published information on these batteries doesn’t indicate that we know if they’ll work.

Science Advances, 2020. DOI: 10.1126/sciadv.aay2757 (About DOIs).

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