X-rays uncover a hidden defect in Elon Musk Tesla Motors batteries that will cause deadly lithium-ion battery fires and explosions

SLAC National Accelerator Laboratory

X-rays uncover a hidden property that leads to failure in a lithium-ion battery material

The lithium-ion batteries commonly used to power electric buses and cordless tools and vacuum cleaners are ofter made up of billions of nanoparticles of lithium iron phosphate, the battery material investigated in this paper. The material … more

Over the past three decades, lithium-ion batteries, rechargeable batteries that m lithium ions back and forth to charge and discharge, have enabled smaller devic juice up faster and last longer.

Now, X-ray experiments at the Department of Energy's SLAC National Accelerat Laboratory and Lawrence Berkeley National Laboratory have revealed that the p lithium ions take through a common battery material are more complex than prev thought. The results correct more than two decades worth of assumptions about material and will help improve battery design, potentially leading to a new gener lithium-ion batteries.

An international team of researchers, led by William Chueh, a faculty scientist at Stanford Institute for Materials & Energy Sciences and a Stanford materials scie professor, published these findings today in *Nature Materials*.

"Before, it was kind of like a black box," said Martin Bazant, a professor at the Massachusetts Institute of Technology and another leader of the study. "You cou that the material worked pretty well and certain additives seemed to help, but yo tell exactly where the lithium ions go in every step of the process. You could only develop a theory and work backwards from measurements. With new instrumen measurement techniques, we're starting to have a more rigorous scientific unde of how these things actually work."

The 'popcorn effect'

Anyone who has ridden in an electric bus, worked with a power tool or used a co vacuum has likely reaped the benefits of the battery material they studied, lithiur phosphate. It can also be used for the start-stop feature in cars with internal com engines and storage for wind and solar power in electrical grids. Better understa this material and others like it could lead to faster-charging, longer-lasting and m durable batteries. But until recently, researchers could only guess at the mechar allow it to work.

When lithium-ion batteries charge and discharge, the lithium ions flow from a liqu solution into a solid reservoir. But once in the solid, the lithium can rearrange its

sometimes causing the material to split into two distinct phases, much as oil and
separate when mixed together. This causes what Chueh refers to as a "popcorn
The ions clump together into hot spots that end up shortening the battery lifetim

In this study, researchers used two X-ray techniques to explore the inner workin
lithium-ion batteries. At SLAC's Stanford Synchrotron Radiation Lightsource (SS
bounced X-rays off a sample of lithium iron phosphate to reveal its atomic and e
structure, giving them a sense of how the lithium ions were moving about in the
At Berkeley Lab's Advanced Light Source (ALS), they used X-ray microscopy to
the process, allowing them to map how the concentration of lithium changes ove

Swimming upstream

Previously, researchers thought that lithium iron phosphate was a one-dimensio
conductor, meaning lithium ions are only able to travel in one direction through t
the material, like salmon swimming upstream.

But while sifting through their data, the researchers noticed that lithium was mov
completely different direction on the surface of the material than one would expe
on previous models. It was as if someone had tossed a leaf onto the surface of t
and discovered that the water was flowing in a completely different direction tha
swimming salmon.

X-rays uncover a hidden property that leads to failure in a lithium-ion battery material

When lithium ions flow into the battery's solid electrode -- illustrated here in hexagonal slices -- the lithium c
itself, causing the ions to clump together into hot spots that end up shortening the battery lifetime. Credit: S
University/3Dgraphic

They worked with Saiful Islam, a chemistry professor at the University of Bath, U
develop computer models and simulations of the system. Those revealed that lit
moved in two additional directions on the surface of the material, making lithium
phosphate a three-dimensional conductor.

"As it turns out, these extra pathways are problematic for the material, promotin
popcorn-like behavior that leads to its failure," Chueh said. "If lithium can be ma
move more slowly on the surface, it will make the battery much more uniform. T
key to developing higher performance and longer lasting batteries."

A new frontier in battery engineering

Even though lithium iron phosphate has been around for the past two decades,
to study it at the nanoscale and during battery operation wasn't possible until jus
of years ago.

"This explains how such a crucial property of the material has gone unnoticed fo
said Yiyang Li, who led the experimental work as a graduate student and postd
fellow at Stanford and SLAC. "With new technologies, there are always new and
interesting properties to be discovered about materials that make you think abou
little differently."

This work is one of the first papers to come out of a collaboration between Baza
and several other scientists as part of a Toyota Research Institute-funded resear
that utilizes theory and machine learning to design and interpret advanced exper

These most recent findings, Bazant said, create a more complex story that theor
engineers are going to have to consider in future work.

"It further builds the argument that engineering the surfaces of lithium-ion batteri
really the new frontier," he said. "We have already discovered and developed so
best bulk materials. And we've seen that lithium-ion batteries are still progressing
pretty remarkable pace: They keep getting better and better. This research is en
steady advancement of a tried technology that actually works. We're building on
important bit of knowledge that can be added to the toolkit of battery engineers a
to develop better materials."

Spanning different scales

To follow up on this study, the researchers will continue to combine modeling, si
and experiments to try to understand fundamental questions about battery perfo
many different length and time scales with facilities such as SLAC's Linac Coher
Source, or LCLS, where researchers will be able to probe single ionic hops that
timescales as fast as one trillionth of a second.

"One of the roadblocks to developing lithium-ion battery technologies is the huge
length and time scales involved," Chueh said. "Key processes can happen in a s
second or over many years. The path forward requires mapping these processe
lengths that go from meters all the way down to the motion of atoms. At SLAC, w
studying battery materialsat all of these scales. Combining that with modeling ar
experiment is really what made this understanding possible."

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