Fundamental mechanics help increase battery storage capacity and lifespan

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Credit: Pexels, Mohamed Abdelghaffar

Batteries are widely used in everyday applications like powering electric vehicles, electronic gadgets and are promising candidates for sustainable energy storage. However, as you've likely noticed with daily charging of batteries, their functionality drops off over time. Eventually, we need to replace these batteries, which is not only expensive but also depletes the rare earth elements used in making them.

A key factor in battery life reduction is the degradation of a battery's structural integrity. To discourage structural degradation, a team of researchers from USC Viterbi School of Engineering are hoping to introduce "stretch" into battery materials so they can be cycled repeatedly without structural fatigue. This research was led by Ananya Renuka-Balakrishna, WiSE Gabilan Assistant Professor of Aerospace and Mechanical Engineering, and USC Viterbi Ph.D candidate, Delin Zhang, as well as Brown University researchers from Professor Brian Sheldon's group. Their work was published in the *Journal of Mechanics and Physics of Solids*.

A typical battery works through a repetitive cycle of inserting and extracting Li-ions from electrodes, Zhang said. This insertion and extraction expands and compresses the electrode lattices. These volume shifts create microcracks, fractures and defects over time.

"These microcracks and fractures in the battery material will lead to structural degradation, which will eventually decrease battery capacity," Zhang said. "Ultimately, the battery will have to be replaced with a new one."

To discourage this, Zhang, who studies intercalation materials—a class of materials used as electrodes in lithium-ion batteries—stretches these intercalation electrodes ahead of time. This change in the initial stress state regulates the phase transformation voltages thus making electrodes more resilient to fracture or amorphization (losing its crystalline properties).

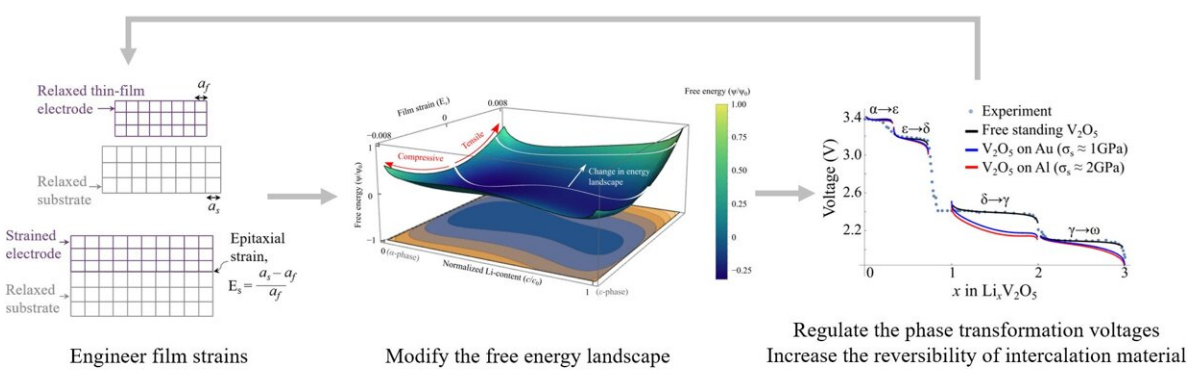
Broader voltage, greater capacity

Phase transformations, when the battery materials shift physical form, result from the cycle of expansion and compression that accompanies daily charging and use. Said Zhang: "These phase transformations can

make the electrodes more susceptible to structural degradation, especially when the process is repeated so frequently."

Reversibility of phases is key in allowing batteries to maintain efficient functionality over time. Said Renuka-Balakrishna: "Reversibility is most enhanced by making sure the material stays in its crystalline form. At certain voltages, when the materials pass from one phase to another, they can become powdery, which is not ideal for efficient operation of the battery."

The researchers thus asked themselves, "Is there a way to keep battery materials in their crystalline form while they cycle back and forth between energy landscapes?" The answer: changing the structure of the materials by introducing an initial stress state.



By stretching the electrodes prior to charging/discharging, the researchers changed the energy landscape across which an electrode goes from the charged to the discharged state. This also allows the battery to operate in a wider voltage range, as shown by the graph on the right. Credit: DELIN ZHANG

Said Zhang: "By stretching the electrodes prior to charging and

discharging, we are changing the energy landscape across which an electrodes goes from the charged to the discharged state. This initial strain allows us to reduce the energy barrier for these transformations and prevent detrimental lattice deformations that lead to material failure. This change in the energy landscape helps prevent microcracks and fractures, protecting the battery's sustainability and energy storage capacity."

An added benefit, Renuka-Balakrishna said, is that by stretching the electrodes, the battery can also operate in a wider voltage window, making it more efficient in its energy storage capacity.

Challenges of modern energy storage

One of the key concerns of the energy storage community, Renuka-Balakrishna said, is moving away from flammable liquid electrolytes typically used in batteries and putting them into solid materials. "This introduces new challenges," she said.

Solid objects, as we all know, can deteriorate over time when repeatedly stressed. Once a crack is introduced, the two sides of a surface will lose contact. In the case of the battery, it creates a simple mechanics problem; without the connection, it's difficult to transport ions across the material, Renuka-Balakrishna said.

Approaches such as that identified by Zhang are an attempt to move forward toward safer, more sustainable batteries while tackling this mechanical challenge. The novelty of this approach is instead of finding a new material to improve battery lifespan, you can improve an existing material's lifespan it by introducing fundamental mechanics concepts to improve their lifespans, the researchers said.

"Mechanics hasn't always been an integral part of developing batteries,"

Renuka-Balakrishna said. "But now engineers can play with this theory/tool Zhang has created and work to engineer the lifespans of battery materials."

Improving the lifespans of batteries would benefit users of electronic devices and electric vehicles enabling longer use of devices and minimizing battery replacement, Zhang said. Given the cost of a lithium-ion battery, it could also save users lots of money over time.

More than that, Zhang said sustainable energy storage is an important part of reducing harmful greenhouse gas emissions and reducing battery waste, and we hope with our work we open a new line of research to enhance material reversibility.

More information: Delin Zhang et al, Film strains enhance the reversible cycling of intercalation electrodes, *Journal of the Mechanics and Physics of Solids* (2021). DOI: 10.1016/j.jmps.2021.104551

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