

Engineers solve a mystery on the path to smaller, lighter batteries

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A discovery by MIT researchers could finally unlock the door to the design of a new kind of rechargeable lithium battery that is more lightweight, compact, and safe than current versions, and that has been pursued by labs around the world for years.

The key to this potential leap in [battery technology](#) is replacing the [liquid](#)

[electrolyte](#) that sits between the positive and negative electrodes with a much thinner, lighter layer of solid ceramic material, and replacing one of the electrodes with solid lithium metal. This would greatly reduce the overall size and weight of the battery and remove the safety risk associated with liquid electrolytes, which are flammable. But that quest has been beset with one big problem: [dendrites](#).

Dendrites, whose name comes from the Latin for branches, are projections of metal that can build up on the lithium surface and penetrate into the solid [electrolyte](#), eventually crossing from one electrode to the other and shorting out the battery cell. Researchers haven't been able to agree on what gives rise to these metal filaments, nor has there been much progress on how to prevent them and thus make lightweight solid-state batteries a practical option.

The new research, being published today in the journal *Joule* in a paper by MIT Professor Yet-Ming Chiang, graduate student Cole Fincher, and five others at MIT and Brown University, seems to resolve the question of what causes dendrite formation. It also shows how dendrites can be prevented from crossing through the electrolyte.

Chiang says in the group's earlier work, they made a "surprising and unexpected" finding, which was that the hard, solid electrolyte material used for a solid-state battery can be penetrated by lithium, which is a very soft metal, during the process of charging and discharging the battery, as ions of lithium move between the two sides.

This shuttling back and forth of ions causes the volume of the electrodes to change. That inevitably causes stresses in the solid electrolyte, which has to remain fully in contact with both of the electrodes that it is sandwiched between. "To deposit this metal, there has to be an expansion of the volume because you're adding new mass," Chiang says. "So, there's an increase in volume on the side of the cell where the

lithium is being deposited. And if there are even microscopic flaws present, this will generate a pressure on those flaws that can cause cracking."

Those stresses, the team has now shown, cause the cracks that allow dendrites to form. The solution to the problem turns out to be more stress, applied in just the right direction and with the right amount of force.

While previously, some researchers thought that dendrites formed by a purely electrochemical process, rather than a mechanical one, the team's experiments demonstrate that it is mechanical stresses that cause the problem.

The process of dendrite formation normally takes place deep within the opaque materials of the battery cell and cannot be observed directly, so Fincher developed a way of making thin cells using a transparent electrolyte, allowing the whole process to be directly seen and recorded. "You can see what happens when you put a compression on the system, and you can see whether or not the dendrites behave in a way that's commensurate with a corrosion process or a fracture process," he says.

The team demonstrated that they could directly manipulate the growth of dendrites simply by applying and releasing pressure, causing the dendrites to zig and zag in perfect alignment with the direction of the force.

Applying [mechanical stresses](#) to the solid electrolyte doesn't eliminate the formation of dendrites, but it does control the direction of their growth. This means they can be directed to remain parallel to the two electrodes and prevented from ever crossing to the other side, and thus rendered harmless.

In their tests, the researchers used pressure induced by bending the material, which was formed into a beam with a weight at one end. But they say that in practice, there could be many different ways of producing the needed stress. For example, the electrolyte could be made with two layers of material that have different amounts of thermal expansion, so that there is an inherent bending of the material, as is done in some thermostats.

Another approach would be to "dope" the material with atoms that would become embedded in it, distorting it and leaving it in a permanently stressed state. This is the same method used to produce the super-hard glass used in the screens of smart phones and tablets, Chiang explains. And the amount of pressure needed is not extreme: The experiments showed that pressures of 150 to 200 megapascals were sufficient to stop the dendrites from crossing the electrolyte.

The required pressure is "commensurate with stresses that are commonly induced in commercial film growth processes and many other [manufacturing processes](#)," so should not be difficult to implement in practice, Fincher adds.

In fact, a different kind of stress, called stack pressure, is often applied to battery cells, by essentially squishing the material in the direction perpendicular to the battery's plates—somewhat like compressing a sandwich by putting a weight on top of it. It was thought that this might help prevent the layers from separating. But the experiments have now demonstrated that pressure in that direction actually exacerbates [dendrite formation](#). "We showed that this type of stack pressure actually accelerates dendrite-induced failure," Fincher says.

What is needed instead is pressure along the plane of the plates, as if the sandwich were being squeezed from the sides. "What we have shown in this work is that when you apply a compressive force you can force the

dendrites to travel in the direction of the compression," Fincher says, and if that direction is along the plane of the plates, the dendrites "will never get to the other side."

That could finally make it practical to produce batteries using solid electrolyte and metallic lithium electrodes. Not only would these pack more energy into a given volume and weight, but they would eliminate the need for liquid electrolytes, which are flammable materials.

Having demonstrated the [basic principles](#) involved, the team's next step will be to try to apply these to the creation of a functional prototype battery, Chiang says, and then to figure out exactly what manufacturing processes would be needed to produce such batteries in quantity.

Though they have filed for a patent, the researchers don't plan to commercialize the system themselves, he says, as there are already companies working on the development of solid-state batteries. "I would say this is an understanding of failure modes in solid-state batteries that we believe the industry needs to be aware of and try to use in designing better products," he says.

The research team included Christos Athanasiou and Brian Sheldon at Brown University, and Colin Gilgenbach, Michael Wang, and W. Craig Carter at MIT.

More information: Yet-Ming Chiang, Controlling dendrite propagation in solid-state batteries with engineered stress, *Joule* (2022). [DOI: 10.1016/j.joule.2022.10.011](https://doi.org/10.1016/j.joule.2022.10.011). [www.cell.com/joule/fulltext/S2542-4351\(22\)00520-7](https://www.cell.com/joule/fulltext/S2542-4351(22)00520-7)

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