How can we design electronic devices that don't overheat?

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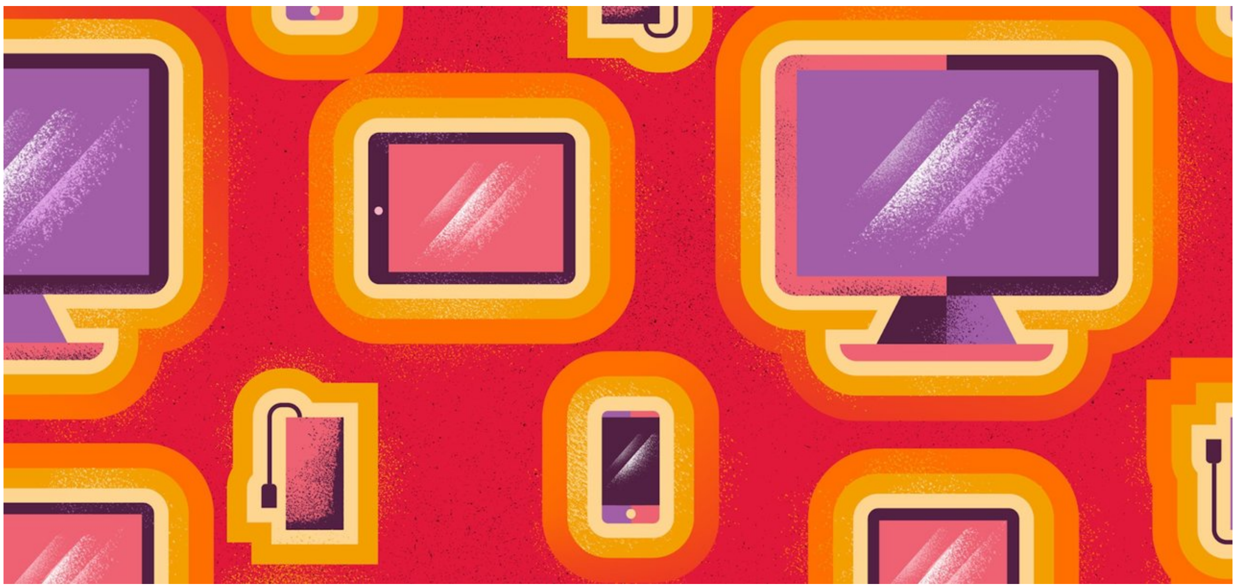

Credit: Stanford University

You've felt the heat before—the smartphone that warms while running a navigation app or the laptop that gets too hot for your lap.

The heat produced by electronic devices does more than annoy users. Heat-induced voids and cracking can cause chips and circuits to fail.

Now a Stanford-led engineering team has developed a way to not only manage heat, but help route it away from delicate devices. Writing in

Nature Communications, the researchers describe a thermal transistor—a nanoscale switch that can conduct heat away from electronic components and insulate them against its damaging effects.

"Developing a practical thermal transistor could be a game changer in how we design electronics," said senior author Kenneth Goodson, a professor of mechanical engineering.

Researchers have been trying to develop heat switches for years. Previous thermal transistors proved too big, too slow and not sensitive enough for practical use. The challenge has been finding a nanoscale technology that could toggle on and off repeatedly, have a large hot-to-cool switching contrast and no moving parts.

Aided by electrical engineer Eric Pop and materials scientist Yi Cui, Goodson's team overcame these obstacles by starting with a thin layer of molybdenum disulfide, a semiconducting crystal that is made up of layered sheets of atoms. Just 10 nanometers thick and effective at room temperatures, this material could be integrated into today's electronics, a critical factor to making the technology practical.

In order to make this heat-conducting semiconductor into a transistor-like switch, the researchers bathed the material in a liquid with lots of lithium ions. When a small electrical current is applied to the system, the lithium atoms begin to infuse into the layers of the crystal, changing its heat-conducting characteristics. As the lithium concentration increases, the thermal transistor switches off. Working with Davide Donadio's group at the University of California, Davis, the researchers discovered that this happens because the lithium ions push apart the atoms of the crystal. This makes it harder for the heat to get through.

Aditya Sood, a postdoctoral scholar with Goodson and Pop and co-first author on the paper, likened the thermal transistor to the thermostat in a car. When the car is cold, the thermostat is off, preventing coolant from flowing, and the engine retains heat. As the engine warms, the thermostat opens and coolant begins to move to keep the engine at an optimal temperature. The researchers envision that thermal transistors connected to computer chips would switch on and off to help limit the heat damage in sensitive electronic devices.

Besides enabling dynamic heat control, the team's results provide new insights into what causes lithium ion batteries to fail. As the porous materials in a battery are infused with lithium, they impede the flow of heat and can cause temperatures to shoot up. Thinking about this process is crucial to designing safer batteries.

In a more distant future the researchers imagine that thermal transistors could be arranged in circuits to compute using heat logic, much as semiconductor transistors compute using electricity. But while excited by the potential to control heat at the nanoscale, the researchers say this technology is comparable to where the first electronic transistors were some 70 years ago, when even the inventors couldn't fully envision what they had made possible.

"For the first time, however, a practical nanoscale thermal transistor is within reach," Goodson says.

More information: Aditya Sood et al. An electrochemical thermal transistor, *Nature Communications* (2018). DOI: 10.1038/s41467-018-06760-7

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