# Packaging-free design quadruples microbatteries' energy density

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Weighing about as much as two grains of rice but with the energy density of a much larger, heavier battery, the researchers' packing-free design could enable a host of otherwise impossible electronics. Credit: Penn Engineering Today

With wireless-enabled electronics becoming smaller and more ubiquitous, their designers must constantly find ways for batteries to store more power in less space. And because these devices are also increasingly mobile—in the form of wearables, robots and more—those batteries must be lighter while still being able to withstand the bumps and bruises of everyday life. Worse still, energy density gets exponentially harder to improve upon as a battery gets smaller, partially because larger portions of a battery's footprint must be devoted to protective packaging.

With that challenge in mind, new research from the University of Pennsylvania's School of Engineering and Applied Science has shown a new way to build and package microbatteries that maximizes energy density even at the smallest sizes.

The researchers' key developments were a new kind of current collector and cathode that increase the fraction of materials that store energy while simultaneously serving as a protective shell. This reduces the need for non-conductive packaging that normally protects a battery's sensitive internal chemicals.

"We essentially made current collectors that perform double duty," says James Pikul, assistant professor in the Department of Mechanical Engineering and Applied Mechanics in Penn engineering and a leader of the study. "They act as both an electron conductor and as the packaging that prevents water and oxygen from getting into the battery."

That extra space efficiency results in an energy density four times that of current state-of-the-art microbatteries. Light enough to be carried by an insect, the researchers' microbattery design opens the door for smaller flying microrobots, implanted medical devices with longer lifespans and a variety of otherwise impossible devices for the Internet of Things.

The study, published in the journal *Advanced Materials*, was led by

Pikul, Xiujun Yue, a postdoctoral scholar in his lab, Paul Braun, professor in the Department of Materials Science and Engineering at the University of Illinois at Urbana Champaign, and John Cook, Director of R&D at Xerion Advanced Battery Corp.

Batteries store energy in the form of chemical bonds, releasing that energy when those bonds are broken. To function properly, this reaction must occur only when power is needed, but then must react rapidly enough to deliver a useful amount of current.

To address the latter half of these requirements, microbatteries have historically required thin electrodes. This thinness allows more electrons and ions to move quickly through the electrodes, but this comes at the cost of having less energy-storing chemicals and complex designs that are difficult to manufacture.

The researchers developed a new way to make electrodes that allowed them to be thick while also allowing fast ion and electron transport. Conventional cathodes consist of crushed particles compressed together, a process that results in large spaces between electrodes and a random internal configuration that slows ions as they move through the battery.

"Instead, we deposit the cathode directly from a bath of molten salts," Cook says, "which gives us a huge advantage over conventional cathodes because ours have almost no porosity, or air gaps."

"This process also aligns the cathode's 'atomic highways,'" Pikul says, "meaning lithium ions can move via the fastest and most direct routes through the cathode and into the device, improving the microbattery's power density while maintaining a high energy density."

These redesigned components are so efficient at transporting ions that they can be made thick enough to double the amount of energy-storing chemicals without sacrificing the speed necessary to actually power the devices they're connected to. Combined with the new packaging, these microbatteries have the energy and power density of batteries that are a hundred times larger while only weighing as much as two grains of rice.

The researchers will continue to study chemical and physical features that can be tuned to further improve the performance, while also building wearable devices and microrobots that take advantage of these new power sources.

**More information:** Xiujun Yue et al, A Nearly Packaging-Free Design Paradigm for Light, Powerful, and Energy-Dense Primary Microbatteries, *Advanced Materials* (2021). DOI: 10.1002/adma.202101760

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