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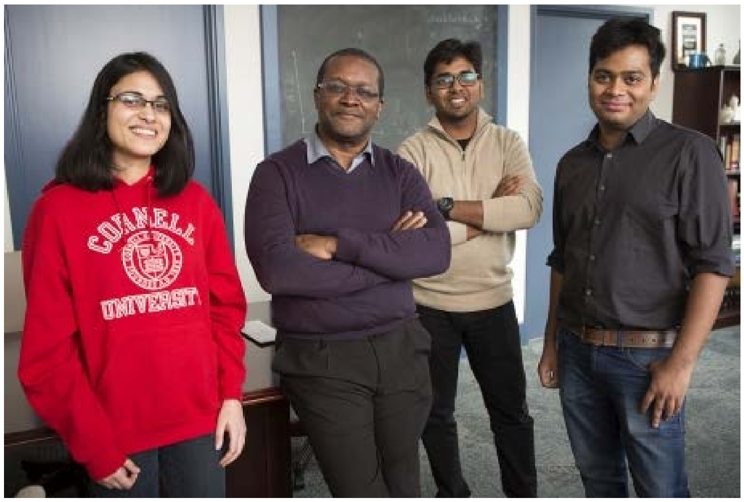
Room-temperature lithium metal battery closer to reality

By Tom Fleischman



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Lynden Archer, second from left, the William C. Hooey Director and James A. Friend Family Distinguished Professor of Engineering and director of the Robert Frederick Smith School of Chemical and Biomolecular Engineering, in a classroom with graduate students Akanksha Agrawal, left, Rahul Mangal and Snehashis Choudhury.

Rechargeable lithium metal batteries have been known for four decades to offer energy storage capabilities far superior to today's workhorse lithium-ion technology that powers our smartphones and laptops. But these batteries are not in common use today because, when recharged, they spontaneously grow treelike bumps called dendrites on the surface of the negative electrode.

Over many hours of operation, these dendrites grow to span the space between the negative and positive electrode, causing short-circuiting and a potential safety hazard.

Current technology focuses on managing these dendrites by putting up a mechanically strong barrier, normally a ceramic separator, between the negative and the positive electrodes to restrict the movement of the dendrite. The relative non-conductivity and brittleness of such barriers, however, means the battery must be operated at high temperature and are prone to failure when the barrier cracks.

But a Cornell team, led by chemical and biomolecular engineering professor Lynden Archer and graduate student Snehashis Choudhury, proposed in a recent study that by designing nanostructured membranes with pore dimensions below a critical value, it is possible to stop growth of dendrites in lithium batteries at room temperature.

"The problem with ceramics is that this brute-force solution compromises conductivity," said Archer, the William C. Hooey Director and James A. Friend Family Distinguished Professor of Engineering and director of the Robert Frederick Smith School of Chemical and Biomolecular Engineering.

"This means that batteries that use ceramics must be operated at very high temperatures – 300 to 400 degrees Celsius [572 to 752 degrees Fahrenheit], in some cases," Archer said. "And the obvious challenge that brings is, how do I put that in my iPhone?"

You don't, of course, but with the technology that the Archer group has put forth, creating a highly efficient lithium metal battery for a cellphone or other device could be reality in the not-too-distant future.

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Archer credits Choudhury with identifying the polymer polyethylene oxide as particularly promising. The idea was to take advantage of "hairy" nanoparticles, created by grafting polyethylene oxide onto silica to form nanoscale organic hybrid materials (NOHMs), materials Archer and his colleagues have been studying for several years, to create nanoporous membranes.

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To screen out dendrites, the nanoparticle-tethered PEO is cross-linked with another polymer, polypropylene oxide, to yield mechanically robust membranes that are easily infiltrated with liquid electrolytes. This produces structures with good conductivity at room temperature while still preventing dendrite growth.

"Instead of a 'wall' to block the dendrites' proliferation, the membranes provided a porous media through which the ions pass, with the pore-gaps being small enough to restrict dendrite penetration," Choudhury said. "With this nanostructured electrolyte, we have created materials with good mechanical strength and good ionic conductivity at room temperature."

Archer's group plotted the performance of its crosslinked nanoparticles against other materials from previously published work and determined "with this membrane design, we are able to suppress dendrite growth more efficiently that anything else in the field. That's a major accomplishment," Archer said.

One of the best things about this discovery, Archer said, is that it's a "drop-in solution," meaning battery technology wouldn't have to be radically altered to incorporate it.

"The membrane can be incorporated with batteries in a variety of form factors, since it's like a paint – and we can paint the surface of electrodes of any shape," Choudhury added.

This solution also opens the door for other applications, Archer said.

"The structures that Snehashis has created can be as effective with batteries based on other metals, such as sodium and aluminum, that are more earth-abundant and less expensive than lithium and also limited by dendrites," Archer said.

The group's paper, "A highly reversible room-temperature lithium metal battery based on crosslinked hairy nanoparticles," was published Dec. 4 in Nature Communications. All four group members, including doctoral students Rahul Mangal and Akanksha Agrawal, contributed to the paper.

The Archer group's work was supported by the National Science Foundation's Division of Materials Research and by a grant from the King Abdullah University of Science and Technology in Saudi Arabia. The research made use of the Cornell High Energy Synchrotron Source, which also is supported by the NSF.