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Waste silicon gets new life in lithium-ion batteries

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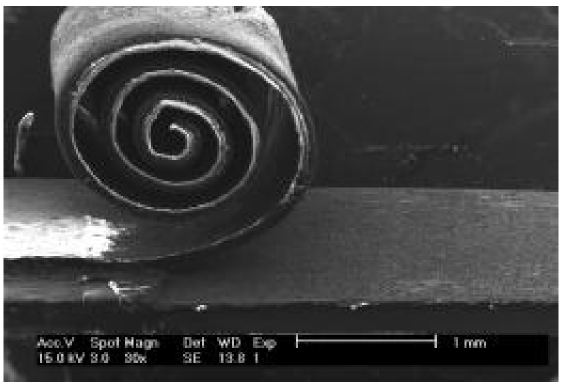


The silicon/copper/polymer composite can be rolled from its silicon substrate and leave a mask in place to begin anew the process of making another anode for a lithium-ion battery. Credit: Alexandru Vlad/Rice University

Researchers at Rice University and the Université catholique de Louvain, Belgium, have developed a way to make flexible components for rechargeable lithium-ion (LI) batteries from discarded silicon.

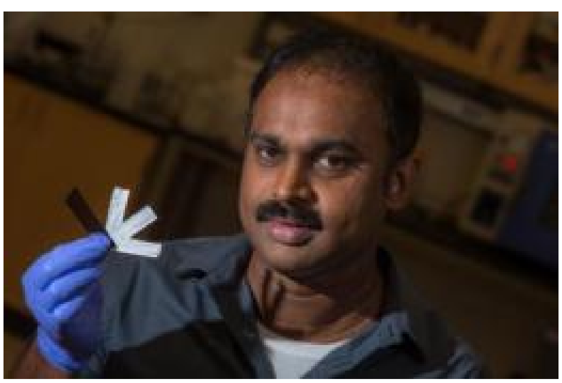
The Rice lab of materials scientist Pulickel Ajayan created forests of nanowires from high-value but hard-to-recycle silicon. Silicon absorbs 10 times more lithium than the carbon commonly used in LI batteries, but because it expands and contracts as it charges and discharges, it breaks down quickly.

The Ajayan lab reports this week in the journal Proceedings of the

National Academy of Science on its technique to make carefully arrayed nanowires encased in electrically conducting copper and ion-conducting polymer electrolyte into an anode. The material gives nanowires the space to grow and shrink as needed, which prolongs their usefulness. The electrolyte also serves as an efficient spacer between the anode and cathode.

Transforming waste into batteries should be a scalable process, said Ajayan, Rice's M. and Mary Greenwood Anderson Professor in Mechanical Engineering and Materials Science and of chemistry. The researchers hope their devices are a step toward a new generation of flexible, efficient, inexpensive batteries that can conform to any shape.

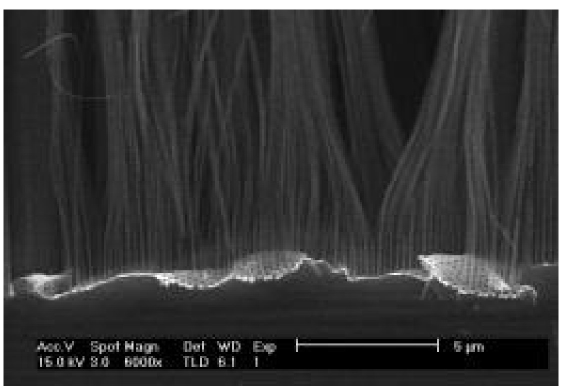
Co-lead authors Arava Leela Mohana Reddy, a Rice research scientist, and Alexandru Vlad, a former research associate at Rice and now a postdoctoral researcher at the Université catholique de Louvain, were able to pull multiple layers of the anode/electrolyte composite from a single discarded wafer. Samples of the material made at Rice look like strips of white tape or bandages.



Rice University research scientist Arava Leela Mohana Reddy holds strips of anode material and a piece of waste silicon (at left). Researchers at Rice and in Belgium found a way to recycle silicon into flexible anodes for lithium-ion batteries. Credit: Jeff Fitlow, Rice University

They used an established process, colloidal nanosphere lithography, to make a silicon corrosion mask by spreading polystyrene beads suspended in liquid onto a silicon wafer. The beads on the wafer self-assembled into a hexagonal grid – and stayed put when shrunken chemically. A thin layer of gold was sprayed on and the polystyrene removed, which left a fine gold mask with evenly spaced holes on top of the wafer. "We could do this on wafers the size of a pizza in no time," Vlad said.

The mask was used in metal-assisted chemical etching, in which the silicon dissolved where it touched the metal. Over time in a chemical bath, the metal catalyst would sink into the silicon and leave millions of evenly spaced nanowires, 50 to 70 microns long, poking through the holes.



As silicon is dissolved in a chemical bath, a gold mask sinks to the bottom, leaving silicon nanowires about 100 nanometers wide poking through the holes. Because silicon holds as much as 10 times the lithium as the anode in a typical lithium-ion battery, researchers at Rice University and in Belgium are researching ways to recycle waste silicon into functional battery components. Credit: Alexandru Vlad/Rice University

The researchers deposited a thin layer of copper on the nanowires to improve their ability to absorb lithium and then infused the array with an electrolyte that not only transported ions to the nanowires but also served as a separator between the anode and a later-applied cathode.

"Etching is not a new process," Reddy said. "But the bottleneck for battery applications had always been taking nanowires off the silicon wafer because pure, free-standing nanowires quickly crumble." The electrolyte engulfs the nanowire array in a flexible matrix and facilitates its easy removal. "We just touch it with the razor blade and it peels right off," he said. The mask is left on the unperturbed wafer to etch a new anode.

When combined with a spray-on current collector on one side and a cathode and current collector on the other, the resulting battery showed promise as it delivered 150 milliamp hours per gram with little decay over 50 charge/discharge cycles. The researchers are working to enhance those qualities and testing the anodes in standard battery configurations.

"The novelty of the approach lies in its inherent simplicity," Reddy said. "We hope the present process will provide a solution for electronics waste management by allowing a new lease on life for silicon chips."

More information: www.pnas.org/cgi/doi/10.1073/pnas.1208638109

Provided by Rice University