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August 14, 2007

Power Paper: Energy Storage by the Sheet

By surrounding carbon nanotubes with cellulose, researchers have devised a flexible, paper-thin power source

Could paper be the future of power in electronic gadgetry? Just as plastics unleashed a revolution in the manufacture of everyday materials, a new power source composed of cellulose, carbon nanotubes and a dash of liquid salts could revolutionize the energy behind gadgets from iPhones to pacemakers.

"We have a paper battery, supercapacitor and battery-supercapacitor hybrid device that could be used in a variety of energy storage applications," says biological and chemical engineer Robert Linhardt of Rensselaer Polytechnic Institute (R.P.I.) in Troy, N.Y., who helped lead the team that made the discovery. "These devices are lightweight and flexible and are primarily composed of cellulose paper—an environmentally friendly and biocompatible material."

A collaboration between three labs at R.P.I.—biopolymers, nanotubes and electronics—the power paper works by using cellulose to separate aligned carbon nanotubes functioning as electrodes. The nanotubes are grown and the cellulose is dissolved in an electrolyte—in a regular battery (sulfuric) acid is used, but in this case a room-temperature ionic liquid (otherwise known as a liquid salt)—is poured around it. After drying, a thin sheet of "nanocomposite paper" is left that "can be rolled up, twisted or bent to any curvature," the researchers write in *Proceedings of the National Academy of Sciences USA.*

In addition to all that flexibility, the paper battery can also be cut up or stacked and works at a wide range of temperatures, from –100 degrees Fahrenheit to 350 degrees F (without bursting into flame). And, depending on how the paper is made, it can function as a battery, a supercapacitor (an unusually efficient energy storage device that can deliver a quick burst of power) or both. Separating carbon nanotubes with cellulose to yield black-colored paper gives a commercial-grade supercapacitor, the team reports, whereas separating carbon nanotubes from a layer of laminated lithium delivers a long-lasting battery and two-colored paper: black on one side, gray on the other.

"The nanotubes on which the cellulose is cast contact the paper at the molecular level with an enormous surface area, allowing the device to efficiently store and release power," Linhardt says.

The power paper could also absorb salty bodily fluids, such as sweat or blood, to function as a supercapacitor. "The use of these electrolytes based on bodily fluids suggests the possibility of the device being useful as a dry body implant," Linhardt notes. "We are very interested in the possibility of disposable paper defibrillators as a potential medical application."

So far, the researchers have achieved power densities of 1.5 kilowatts per kilogram in the supercapacitor version and tested it over 100 cycles of discharge and recharge, well short of the million or so typical for current commercial capacitors. They have only made one-inch square versions of the paper, but the unique composite structure already reduces the complexity of creating such devices as well as battery-capacitor hybrids—and it has been used to light up a tiny red light-emitting diode, among other devices.

If the power sheets can be rolled off a printing press, as scientists hope, the future of energy storage may be in paper. "We are realistic enough to recognize that actual scale up of a process can be fraught with unanticipated difficulties," Linhardt says. But "we do not see any insurmountable challenges."