Flexible, paper-based supercapacitor could improve performance of hybrid electric vehicles

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Flexible, solid-state supercapacitors in two shapes, and one supercapacitor being bent by more than 90 degrees. Image credit: Hu, et al. ©2012 American Institute of Physics

(PhysOrg.com) -- Scientists know that using supercapacitors in conjunction with batteries could greatly increase the fuel economy of hybrid electric vehicles (HEVs) due to the fact that supercapacitors can recover and supply energy much more quickly than batteries. This ability, for example, allows a supercapacitor to recover all of the energy during hard braking, while a battery would allow the energy to be wasted in frictional braking due to its inability to quickly harvest energy.

“Batteries cannot rapidly harvest or supply energy,” Rajesh Rajamani, a mechanical engineering professor at the University of Minnesota, told *PhysOrg.com*. “When a vehicle has to brake quickly, frictional brakes have to be used in addition to electromagnetic brakes, because the electromagnetic brakes cannot charge a battery quickly enough to

decelerate the vehicle as rapidly as the driver wants. Unlike batteries, a supercapacitor can harvest and supply energy very quickly."

However, one of the biggest challenges researchers face in implementing supercapacitors in HEVs is finding a place under the hood to fit the bulky devices. Part of the reason why supercapacitors are bulky is that they often use a hazardous liquid electrolyte that needs to be sealed and housed, and these protective materials add weight and volume to the devices.

To avoid this problem, Rajamani and his colleagues Shan Hu from the University of Minnesota and Xun Yu from the University of North Texas have designed a supercapacitor that is completely solid-state, including a solid-state electrolyte that doesn't require bulky protective materials. The new supercapacitor performs competitively with commercial supercapacitors, yet is thin and flexible enough that it could fit almost anywhere in an HEV, possibly even mounted on the inner surfaces of the vehicle's body. The researchers published their study on the flexible, solid-state supercapacitors in a recent issue of *Applied Physics Letters*.

"HEVs on the market today do not have supercapacitors," Rajamani said. "Several research groups have been working on the use of supercapacitors together with batteries in HEVs to provide better fuel economy and faster vehicle response. Our research provides them a new supercapacitor that is flexible and solid-state and does not require space in the hood or the trunk."

The new solid-state supercapacitor consists of single-walled carbon nanotube-coated cotton paper as electrodes and a solid polymer as electrolyte. For the electrodes, the researchers used the cotton paper that is normally used for cosmetic facial masks, since it's more lightweight and absorbent than printing paper. After cutting the cotton paper to the

desired shape, the researchers repeatedly dipped the paper into a solution of acid-treated nanotubes, which bonded strongly to the paper.

For the electrolyte, the researchers mixed and heated a polymer solution that originally looked like a clear, glue-like gel. But after dipping the finished electrodes into the gel, assembling the electrodes face-to-face and allowing everything to dry, the excess water evaporated and the electrolyte solidified.

“The greatest significance of our work is that it has resulted in a flexible and solid-state supercapacitor,” Rajamani said. “Other researchers have previously used carbon nanotubes in the electrodes for supercaps. However, their supercaps also utilized liquid electrolytes and were therefore neither fully solid-state nor flexible.”

In tests, the supercapacitor could be charged to more than 3 volts, which is beneficial for achieving a high energy density, or allowing more energy to be stored in a given volume. The supercapacitor's other specifications – a specific capacitance of 13.15 F/g and a specific energy of 5.54 Wh/kg – are very similar to the values of commercial supercapacitors. Plus, its flexibility allows it to be bent for easy fitting into small spaces, which could make it useful for portable electronics as well as HEVs.

The new supercapacitor's biggest drawback is its high resistance, which results in a low overall power density and therefore a slow recharge rate. The researchers think the reason for the high resistance is due to the paper-nanotube electrodes, which have a higher resistance than metal electrodes. However, they predict that coating the cotton paper with a higher density nanotube solution can reduce the resistance, and they plan to work on this issue more in the future.

More information: Shan Hu, et al. “Flexible solid-state paper based

carbon nanotube supercapacitor." *Applied Physics Letters* 100, 104103 (2012). DOI: 10.1063/1.3691948