Nanocrystals embedded in nanoporous carbon increase energy-storage capacity

Electrical energy-storage devices inherently face a difficult trade-off between energy and power densities. Although traditional Li-ion batteries store more energy than supercapacitors, they require long charge times and cannot instantaneously deliver it. An ultimate solution, therefore, may lie in a hybrid approach: why not design the anode to act as a battery and the cathode to act as a capacitor? A Georgia Institute of Technology (Georgia Tech) research group recently brought to light this optimized asymmetric solution that takes the advantages of both charge storage mechanisms.

According to group leader Gleb Yushin, his research embedded electrochemically active material nanocrystals into nanoporous carbon particles and demonstrated high performance of these electrodes in batteries. This configuration shows great promise for use in energy-storage devices that require both ultrafast charging times of a few seconds and higher energy densities than what traditional supercapacitors can provide. He says, "The critical aspect of the successful synthesis is to make sure the nanocrystals do not block electrolyte access through interconnected pore channels." While the initial study was focused on intercalation of Li ions into confined nanocrystals, "the approach may be adjusted for use with other metal-ion chemistries (Na, K, Ca, Cs, etc.), thus offering multiple avenues for the formation of high power devices to satisfy the rapidly growing industrial demands," he says. Team member Enbo Zhao adds, "Our work demonstrated a simple, scalable and broadly applicable synthetic methodology to produce nanocomposite powders for drop-in replacement in commercial supercapacitor or battery production lines."

Yushin, along with Georgia Tech team members Zhao and Seth Marder, as well as collaborators from Heilongjiang University (China) and Sila Technologies, highlighted their approach in a recent issue of *ACS Nano* (doi:10.1021/acsnano.6b00479). They focused on lithium titanate ($Li_4Ti_5O_{12}$), or LTO, as the anode material. They grew tiny LTO nanoparticles directly inside porous-activated carbon particles. This method significantly improved the anode's interparticle electrical conductivity and effectively controlled the 0.5–4 nm crystal size of the LTO domains. Yushin and his team members relied on a finely tuned mesoporous-activated carbon and a controlled wet chemistry method to deposit LTO precursors into the pores and thermally synthesize the final spinel phase. This approach exposed most of the anode materials to the electrolyte and maintained a high surface area (over 1300 m^2/g), which allowed rapid charge/discharge electrochemical operation.

The Georgia Tech team used the LTO-carbon composite as a battery anode (for Li-ion intercalation), and standard porous-activated carbon as the supercapacitor cathode (for ion electrosorption) in an asymmetric cell design. The resulting hybrid battery/capacitor stored exceptionally high energies and maintained high rate capabilities and charge/discharge rates even at 350°C (over 100 mAh/g_{LTO}). The device fully recharged in 6 seconds. The resulting energy and power densities, as well as volumetric capacity of the system, easily outpaced those in previous asymmetric capacitor work and demonstrated the viability of LTO in hybrid energy-storage designs.

Yury Gogotsi of Drexel University, who did not participate in this research, says, "Developing new materials for energy storage will lead to better batteries and electrochemical capacitors that power our energy-hungry devices. And it is important to use materials that are scalable, inexpensive, and can be manufactured at a large scale."

These findings demonstrate the critical role of nanoscale materials packaging and the ability to significantly optimize energy-storage nanostructures for higher performance. Although numerous prior studies have described the anode performance of LTO, this work used a scalable and facile approach to demonstrate this material's potential. Future energy-storage designs, especially those in automotive and mass transit systems, will require reliable, efficient, and rapid charge and discharge solutions, and similar hybrid battery/capacitor designs with asymmetric electrodes may become the best approach for this challenge of high energy density and fast power delivery.

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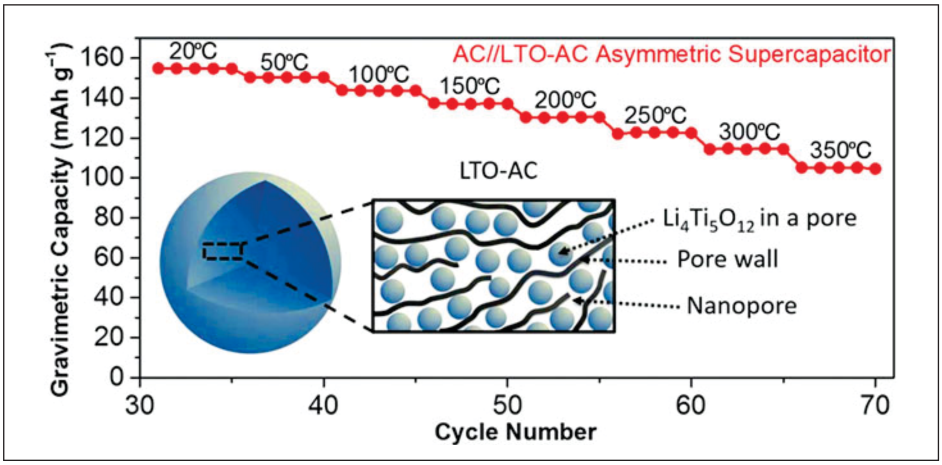

$Li_4Ti_5O_{12}$ (LTO) in porous-activated carbon (AC) yields an asymmetric supercapacitor with improved energy-storage capacity than currently available. Credit: *ACS Nano*.