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News

13 AUG 2015 RESEARCH & INNOVATION

Using Graphene to Improve Energy Storage

Mobile phones have become a ubiquitous and essential part of daily life. A modern smartphone can plausibly replace a watch, flashlight, compass, map, calculator, and more. Users can film evidentiary or historically-significant video and summon help in an emergency. Indeed, the prospect of losing mobile contact has become such a source of anxiety that the term “nomophobia” has been coined in the media to describe it, and research has to some extent substantiated the designation. A study commissioned by the United Kingdom Post Office found that 53% of mobile phone users reported feeling a sense of anxiety when they lose their phone, have no network coverage, or run out of battery.

Fortunately for those who experience such unease, researchers like Dr. Eui-Hyeok Yang of the Department of Mechanical Engineering at Stevens Institute of Technology are working to improve upon conventional batteries with a new type of energy storage based on supercapacitors. These electrical components store energy like batteries while offering drastically faster charge and discharge times. Existing supercapacitors are not used in devices like mobile phones because they generally have much lower energy-density than conventional batteries (i.e., they hold a smaller amount of energy than a similarly massed battery). They are currently used in applications where a large amount of power is needed for a relatively short amount of time. If energy-density limitations can be overcome, supercapacitors could be used to supplement or replace batteries in order to create mobile phones or laptops that charge in seconds. Those rapid charge cycles would be a monumental improvement over existing cell phone batteries.

Dr. Yang has outlined his innovation in a recent article, "Out-of-plane growth of CNTs on graphene for supercapacitor applications," which greatly advances efforts to realize the potential of graphene—a one-atom thick sheet of carbon atoms arranged in a honeycomb pattern—as a supercapacitor. The paper was recently selected by the editors of Nanotechnology for inclusion in the exclusive "Highlights 2012" collection. Articles in this collection have been nominated on the basis of a range of criteria including referee endorsement, novelty, scientific impact and broad appeal. Less than 5% of articles from 2012 received this recognition.

“This honor demonstrates the enormous potential of Dr. Yang’s research in the vibrant research field of next-generation batteries and superconductors,” says Dr. Michael Bruno, Dean of the Charles V. Schaefer, Jr. School of Engineering and Science.“This disruptive nanotechnology could have a positive impact on a large proportion of the population as over 90% of American adults have a mobile phone that they charge regularly.”

High surface area and low intrinsic resistance are vital for high-performance superconductors. Morphology-modified carbon nanostructures such as activated carbon (AC), mesoporous carbon (MC) and carbon nanotubes (CNTs) have large surface areas, but suffer from limited performance due to micropores and internal resistance, and therefore exhibit lower capacitance than theoretically predicted. Graphene has recently been identified as a promising material for supercapacitor applications, due to its outstanding theoretical specific surface area (SSA), extraordinary electrical properties in the planar direction (sheet resistance = ∼280 cm−2), high mechanical strength and chemical stability. In addition, graphene exhibits an intrinsic capacitance of up to 21 μF cm−2, which is the theoretical limit of carbon materials. Furthermore, recent successful development of chemical vapor deposition (CVD)-based graphene synthesis techniques facilitates the application of graphene as electrodes in lithium ion batteries and supercapacitors as well as on metal substrates in electronics. However, existing techniques for its fabrication often result in folding and overlapping of sheets, reducing the surface area which is crucial to capacitance capabilities.

In order to overcome the problem of graphene aggregation, Dr. Yang has formulated a new method for fabricating a hybrid nanostructure comprised of carbon nanotubes (CNTs) grown on graphene layers. This method minimizes self-aggregation of graphene sheets while preserving valuable conductive properties. The carbon nanotubes are grown directly out of the graphene sheets to prevent agglomeration while concurrently acting as current pathways which, given the high conductivity of both CNTs and graphene, is anticipated to facilitate electron transport throughout the structure during the charge–discharge process. Dr. Yang investigated the process parameters and growth mechanisms of the hybrid nanostructure to find the optimal range of parameters for carbon growth.

Dr. Yang also characterized the electrochemical performance of the hybrid nanostructure via cyclic voltammetry to demonstrate the potential application of the material as a supercapacitor. The hybrid electrode demonstrated greater capacitance than a graphene-only electrode and maintains exceptionally high capacitance (490.3 μF cm−2) under a fast charging–discharging process (300 mV s−1).

Future work includes a detailed investigation of electrochemical performance of the hybrid nanostructure as a function of available surface area, lifecycle performance and the development of graphene–CNT–graphene 3D multistack as a stepping stone in creating high-performance supercapacitors.

Dr. Yang is currently PI on a number of active grants in the areas of research, education and equipment, from AFOSR and NSF. He directs the Micro Device Laboratory (MDL), a Stevens's multi-user facility. He is also an Associate Editor of several journals including IEEE Sensors.

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