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Nano-scale Morphology Control of Graphene, Conducting Polymer, and Carbon Nanotube Electrodes for High Performance Energy Storage

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Abstract:

Supercapacitors are promising energy storage devices due to their higher power density and long cycle life time (> millions) compared with conventional batteries, and greater energy density than dielectric capacitors. In order to meet the demands of a wide range of electrical and electronic technologies, such as hybrid electric vehicles, backup power sources and portable electronic equipment, supercapacitors with higher energy density and power density are required. In the past decade a great deal of effort has been devoted to improve the energy and power densities of supercapacitors that are far beyond state-of-art supercapacitors comprised of activated carbon powders. For supercapacitors, the energy density (E) is related to the cell capacitance (C) and operation voltage (V), i.e.,

$$E = \frac{1}{2}CV^2 \tag{1}$$

And the maximum power density P is determined by

$$P = \frac{V^2}{4*ESR} \tag{2}$$

where ESR is the equivalent series resistance of the supercapacitor cell. Equations (1) and (2) indicate that the most effective way to increase the power and energy densities is to raise V due to the square dependence of these properties on V. In general, the operation voltage of supercapacitors is limited by the electrochemical window of the electrolyte which is determined by both the electrolyte and the electrode materials. One promising approach to increase the operation voltage and hence the energy and power densities is to assemble asymmetric supercapacitors that make full use of the electrochemical windows of the two electrodes to increase the maximum cell operation voltage in the devices. Moreover, developing new electrode materials with large C and small ESR are also critical in improving both E and P of supercapacitors. Here, an asymmetric supercapacitor, exploiting nm-scale conformal coating of conducting polymer (CP) on aligned carbon nanotubes as the anode, and an ultra-high density activated microwave exfoliated graphite oxide (a-graphene) as the cathode, has been developed. The asymmetric configuration of the supercapacitor allows both electrodes to be separately tailored, increasing device capacitance and the electrochemical window, and thereby operating voltage. The conformal CP coating on the nanowires enhances charge storage of the anode while the aligned nanowire morphology provides direct non-tortuous fast ion transport pathways. The a-graphene cathode is fabricated from a self-assembly process shows high specific gravimetric and volumetric capacitance, providing an ideal cathode. As a result of complementary tailoring of the asymmetric electrodes, the device exhibits a wide 4V electrochemical window, and the highest power and energy densities reported thus far for carbon-based supercapacitors, 149 kW L^{-1} and 113 Wh L^{-1} in volumetric performance and 233 kW kg^{-1} and 177 Wh kg^{-1} in gravimetric performance, respectively.