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Design of Doped Graphene Quantum Dot Composites for Next-Generation Energy Storage Devices

Invited Talk

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Abstract

The development of cost-effective, high-performance electrode materials is crucial for advancing supercapacitor (SC) technology toward next-generation energy storage applications. This presentation highlights two complementary graphene quantum dot (GQD)–based strategies that leverage heteroatom and rare-earth doping, along with polymer composite engineering, to significantly enhance electrochemical performance.

In the first approach, sulfur- and nitrogen-co-doped graphene quantum dots (SN-GQDs) were synthesized using a rapid and facile microwave-assisted hydrothermal method under mild conditions. The dual heteroatom doping introduced abundant electrochemically active sites and improved electrical conductivity, resulting in an outstanding specific capacitance of 1040 F g^{-1} at 0.5 A g^{-1}. When incorporated into a polyaniline (PANI) matrix, the SN-GQDs/PANI composite exhibited superior device performance, delivering a high energy density of 44.25 Wh kg^{-1} at a power density of 1.227 kW kg^{-1} in a symmetric supercapacitor configuration.

In the second approach, neodymium-doped graphene quantum dots (Nd-GQDs) were synthesized via a microwave-assisted hydrothermal process that enables rapid heating, efficient energy transfer, and reduced reaction time. Nd doping effectively modulated the electronic structure of GQDs, leading to enhanced charge storage behavior and electrochemical activity. Nd-GQDs demonstrated a high specific capacitance of 618 F g^{-1} at a scan rate of 5 mV s^{-1}. Further, Nd-GQDs were integrated with PANI to form composite electrodes. Among various compositions, the symmetric supercapacitor fabricated with 20 mL Nd-GQDs in the PANI matrix exhibited an excellent specific capacitance of 354 F g^{-1} at 1 A g^{-1}, along with a high energy density of 49.15 Wh kg^{-1} and a power density of 2000 W kg^{-1}.

Overall, these studies demonstrate that both heteroatom-doped and rare-earth-doped GQDs, particularly when combined with conducting polymers, offer a powerful and scalable route for designing high-performance supercapacitor electrodes with enhanced capacitance, energy density, and power density.

Keywords: Graphene quantum dots, supercapacitors, heteroatom doping, rare-earth doping, energy storage

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