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Enhanced Supercapacitor Performance through MnO_2-doped Coconut Shell–Derived Activated Carbon Electrodes

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Abstract

Increasing demand for efficient energy storage has intensified research into sustainable supercapacitor electrode materials. Electrochemical double-layer capacitors (EDLCs) offer rapid charge-discharge kinetics and high-power density but remain limited by low energy density and high costs. This study investigates MnO_2 doping optimisation in coconut shell-derived activated carbon to enhance supercapacitor performance while maintaining cost-effectiveness and sustainability. Coconut shells were carbonised in a low-oxygen environment, crushed, washed, and dried at 150°C. Steam activation was performed at 900°C for 2 hours, followed by disk milling. Electrodes were prepared by mixing 0.5 g activated carbon with 0.05 g polyvinylpyrrolidone (PVP) binder in 10 ml isopropanol, with MnO_2 doping at 2%, 4%, 6%, 8%, and 10% (w/w of the activated carbon mass). The mixture was then spray-coated onto titanium current collectors at 150°C and sintered at 200°C for 20 minutes. Finally, the symmetric cells were assembled with filter paper separators and 2.5 M H_2SO_4 electrolyte. Raman spectroscopy revealed D-band (1352 cm^{-1}) and G-band (1603 cm^{-1}) peaks with an I_D/I_G ratio of 1.08, indicating an optimal balance between conductivity and surface reactivity. Electrochemical performance was evaluated through cyclic voltammetry. The 8% MnO_2-doped electrode achieved optimal performance with a specific capacitance of 51.47 F g^{-1} and energy density of 7.15 Wh kg^{-1}, representing an 80% improvement over undoped samples (23.73 F g^{-1}). Other concentrations showed: 2% (33.82 F g^{-1}), 4% (30.68 F g^{-1}), 6% (28.62 F g^{-1}), and 10% (32.66 F g^{-1}). Electrical conductivity improved from 13.87 S m^{-1} for undoped electrodes to 150.88 S m^{-1} at optimal 8% doping. Enhanced performance results from synergistic double-layer capacitance and pseudocapacitive behaviour through MnO_2's multiple oxidation states. At optimal concentration, MnO_2 particles are well dispersed within the carbon matrix, maximising faradaic reactions without blocking pores. Lower concentrations provide insufficient pseudocapacitive contribution, while excessive doping causes agglomeration and reduced electrolyte accessibility. This study demonstrates the successful utilisation of coconut shell waste for sustainable supercapacitor electrodes. The optimal 8% MnO_2 doping significantly enhances electrochemical performance while maintaining cost-effectiveness, contributing to next-generation energy storage solutions.

Keywords: *Supercapacitor, Activated Carbon, Coconut Shell, Mno_2 Doping, Energy Storage*