

Supercapacitor based on activated carbon with addition of copper ferrite

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Abstract: Supercapacitors (SCs) are known for their high power density and fast charging. This study incorporated copper ferrite nanoparticles into activated carbon electrodes using a water-based paint. The modified SC showed a 45.9% increase in capacitance and good capacitance retention after 10,000 cycles (81.93%). The results show that introduction of copper ferrite nanoparticles leads to a significant improvement of supercapacitor performance.

Keywords: Copper ferrite nanoparticles; Capacitor improvement; Supercapacitor

Introduction

Supercapacitors (SC) offer high power density, long service life, and short charging times [1]. The search for energy storage devices with greater energy density and stability has been wide in recent years [2]. One approach is to introduce metal oxides into the electrodes materials, significantly increasing capacitance and improving supercapacitor energy density [3].

The aim of this study was to add copper ferrite nanoparticles obtained by combustion synthesis to activated carbon-based electrodes of supercapacitors and to perform the electrochemical characterization of this device.

Experimental Procedure

A homogeneous solution was prepared by combining activated carbon (AC), Black Pearls and sodium carboxymethylcellulose, and dissolving the mixture in deionized water. For the copper ferrite-based electrodes, 1 wt% of copper ferrite was added to 99 wt% of AC. The resulting slurry was stirred and applied onto etched aluminum foil using an automatic doctor blade technique to achieve a thickness of 300 μm . The resulting carbon-coated films were dried, punched into 16 mm diameter discs, each with an average mass of approximately 8.0 mg, and vacuum-dried at 80 °C for 24 h. The assembly of the supercapacitor cells was performed in a controlled environment inside an Mbraun glovebox under an inert atmosphere. Electrolyte solutions with a concentration of 1.0 M tetraethylammonium tetrafluoroborate in propylene carbonate (TEABF₄-PC) were prepared. A volume of 160 μL of the electrolyte was impregnated into a 25 μm thick polypropylene separator (Celgard), which was placed between the carbon-based electrodes assembled in CR2032-type coin cell.

The ferrite sample was subjected to X-ray diffraction (XRD) in a PANalytical Empyrean diffractometer using Cu K α radiation at 40 kV and 40 mA with a scanning speed of 2 θ and scanning angles of 10° to 60°, with a speed of 0.02°/s and transmission electron

microscopy (TEM) images were obtained in a JEOL JEM-2100 equipment with an accelerating voltage of 200 kV in order to verify the crystallinity of the material. The supercapacitors were subjected to cyclic voltammetry (CV), electrostatic impedance spectroscopy (EIS), galvanostatic charge and discharge (GCD) and cyclability in order to characterize the performance of the devices.

Results and Discussion

X-ray diffraction patterns are shown Figure 1(a) and show the presence of two phases of copper oxide as well as the crystallinity of the material. Figure 1(b) shows the agglomerated oxide nanoparticles, which are directly related to the magnetic characteristic inherent to this material. Figure 1(c) shows an edge of a particle cluster in which the crystallinity of this material is confirmed, as well as the average size of these particles based on the TEM images.

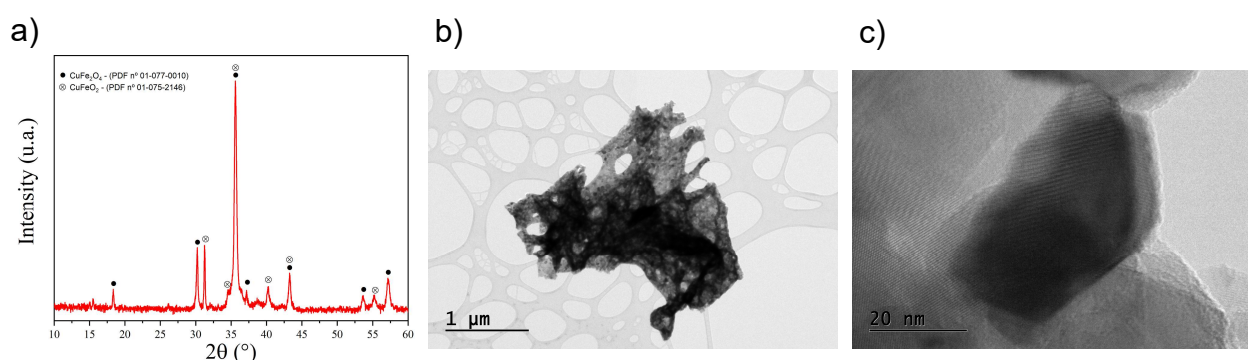


Figure 1: a) XRD of ferrite. b) TEM of particleboard material; c) TEM of grain.

Figure 2 shows the electrochemical characterization of the SC without ferrite compared to the device with addition of ferrite. Using the CV technique, Figure 2 (a-b), and GCD, Figure 2 (g-h), the difference between the energy stores is visible, this is due to the contribution of Faradaic reactions from the oxides, which contributes to the gain in capacitance. Both devices proved to be resistant as the charging scan rate increased, Figure 2 (e-f). Regarding the EIS technique, in Figure 2 (c-d), it can be seen that both have a slope that proves the presence of the electric double layer inherent to supercapacitors. However, the addition of ferrite caused a change in the shape of the graph, Figure 2-d, related to the access of the electrolyte ions to the electrode surface, is due to the redox reactions of the system, as well as the increase in the catalytic activity resulting from the magnetism of the material.

Based on the electrochemical tests performed, the data were tabulated and the capacitance, energy density, power density of the supercapacitors were calculated and the results are presented in Table 1.

Table 1 – Supercapacitor electrochemical performance results.

	Capacitance (F)	Energy density (kW·kg ⁻¹)	Power density (kWh·kg ⁻¹)
Without ferrite	17,18	21,50	94,01
With ferrite	25,08	31,25	41,83

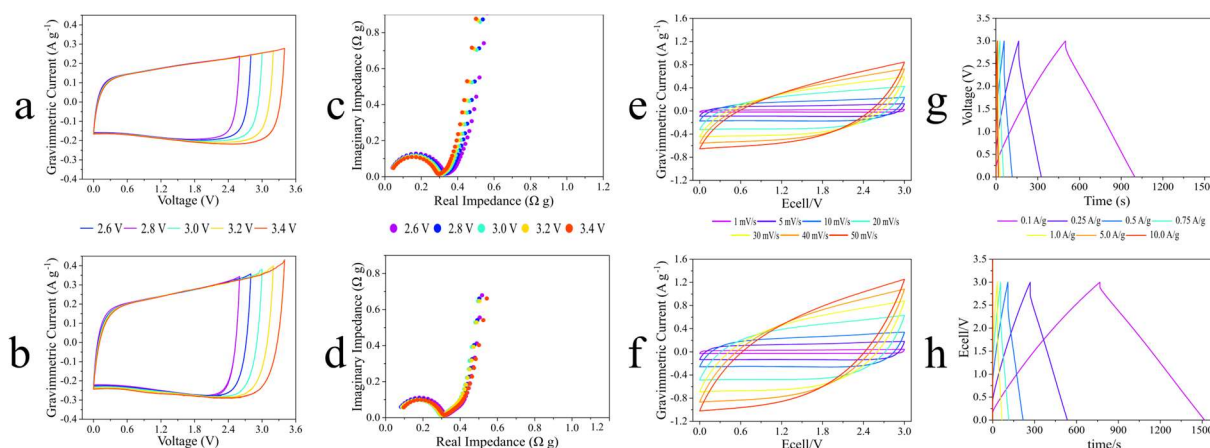


Figure 2: Electrochemical characterization of the SCs: (a–b) CV at a scan rate of $10 \text{ mV} \cdot \text{s}^{-1}$ under different voltages. (c–d) EIS at various applied voltages. (e–f) VC at different scan rates. (g–h) GCD at different current densities. Top figures refer to SCs without ferrite, bottom figures to SCs with ferrite.

From the results presented, a considerable decrease in power density can be noted, but this can be justified by the experimental error in the assembly of the supercapacitors as well as an increase in resistivity caused by the addition of the oxide, since it is an inherent characteristic of the material.

Conclusions

The introduction of ferrite led to a capacitance to 25.08 F, a 45.9 % improvement compared to 17.18 F in the reference EDLC. On the other hand, ferrite addition led to a slightly lower capacitance retention: 81.93% after 10,000 cycles versus 92.6% in a device without ferrite. These findings highlight copper ferrites' potential to enhance SC performance while emphasizing the need to investigate mechanisms causing capacitance retention loss. Future studies should optimize material composition and synthesis to mitigate performance degradation while maximizing benefits. This will be key to advancing metal oxide-based EDLCs for high-performance energy storage.

Acknowledgments

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