Exploring the Design and Optimization of Asymmetric Super Capacitors for Improved Energy Storage Performance

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Abstract:
The design and development of asymmetric super capacitors represent a significant advancement in the field of energy storage, offering enhanced performance characteristics compared to traditional symmetric supercapacitors. This section delves into the fundamental principles behind asymmetric supercapacitors, explores their design considerations, and presents an example design showcasing innovative approaches. The aim is to provide a comprehensive understanding of how asymmetric supercapacitors can be optimized for improved energy and power density, along with practical examples of their implementation.

Keyword: Asymmetric super capacitor, Symmetric super capacitors, Power Density, Compact devices, Energy Density

Introduction

Devices that include super capacitors with a low energy density have a bigger form factor and are not compact in any way. This is because these capacitors store a relatively low amount of energy. The energy density of super capacitors can be improved by expanding either the effective surface area of electrode materials in double layer capacitors or the operating voltage window. Alternately, the energy density of super capacitors can be improved by expanding both of these aspects simultaneously, or by expanding any combination of these three aspects. Research is being conducted at an accelerated rate in order to meet the challenges of developing effective materials with a high surface area and using appropriate organic electrolytes that are able to manage a wider voltage window. These challenges can be met by developing effective materials with a high surface area and by using organic electrolytes that are appropriate. If either of these two technologies is managed in the appropriate manner for a given situation, it is possible to increase the energy density of super capacitors to the point where it is comparable to that of batteries. This is because batteries and super capacitors both store energy in electrochemical forms.

Objectives

In order to either expand the range of the operating voltage window or the effective surface area of electrode materials in double-layer capacitors, or both of these things simultaneously, In the article titled "Energy Storage in Supercapacitors: Focus on Tannin-Derived Carbon Electrodes" written by Jimena

Castro-Gutiérrez, a number of different ways are covered. During the course of my study, we want to create a better technology for increasing the surface area of carbon electrodes.

The expected outcome is explained as follows,

- Analyze different methodologies for enhancing the performance of Supercapacitors
- Design of a hybrid model for improving performance of supercapacitors
- Development of improved methodology to increase surface area of Carbon Electrode based on Tannin-Derived Carbon Electrodes methods
- Development of an improved and efficient material that will have more surface area than existing one
- Design of a model that will improve overall energy density and will make super capacitor compact and autonomous

Methodology

Composites of graphene oxide (GO), polyphenyl ether (PPy), amorphous carbon yttria (ACZJ), and amorphous carbon pyridine (ACPD) were used to obtain the XRD patterns seen in Figure 1. The diffraction patterns for GO/PPY/ACZJ and GO/PPY/ ACPD are both weak and wide at 20° and 19°, with d-spacings of 0.467 and 0.492 nm, respectively. In a similar vein, the weakest peak of the GO/PPY/ACZJ composite occurs at 27 degrees. The GO/PPY/ACPD composite seems to have the same feeble peak at 36 degrees. In this situation, d-spacing is more pronounced at GO/PPY/ACPD. This might be because the GO/PPY/ACZJ combination contains oxygen-containing groups. Shown in Figure 2 are the FTIR spectra of GO, GO/PPy, GO/PPy/ACZJ, and GO/PPy/ACPD. Based on the data reported here, the oxygen functional groups of GO are determined by using the peaks at 702.09 and 2978.08 cm-1, which stand for C=C bending and C-H stretching, respectively. C=C bending, C-N stretching wagging vibration, C=C stretching, C=O band stretching, and C-H stretching all manifest as peaks in the GO/PPy spectrum at 786.96, 1165, 1535, and 1734 cm-1, respectively. For the ternary composite (GO/PPy/ACZJ), the peaks at 786.96, 1214, and 1486 cm-1 are associated with C=C bending, C-N stretching wagging vibration, C=C stretching, and C-H stretching, respectively.

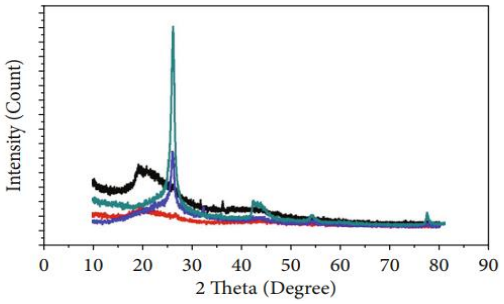

Figure-1 FTIR spectra of GO, GO/PPy, GO/PPy/ACZJ, and GO/PPy/ACPD.

In conclusion, the peaks at 786.96, 1265, 1502, and 2978 cm-1 are indicative of the C=C bending, the C-N stretching wiggling vibration, the C=C stretching, and the C-H stretching, respectively. Figure 3(a) displays scanning electron microscopy images of GO that were produced at a voltage of around 20 kV and a magnification of 5 k. By looking at the picture, you can see that GO has many layers, all of which are permeable. As can be seen in Figure 3, the GO/PPy composite has a spherical shape (b). In Figure 3, GO/PPy/ACZJ is shown in a sheetlike shape with a restricted number of holes (c). Activated carbon isolated from Ziziphus jujuba seeds, graphene oxide, and poly-pyrrole form the composite depicted in Figure 3(d), which may include more holes. In Figure 4 we see the results of an EDX analysis, which shows that the binary composite has a higher carbon content than the other composite. It seems that the results from using the ternary composite are equivalent to those from using the simpler binary composite. The electrode's performance was assessed using the OrigaLys electrochemical workstation, which was utilized for cyclic voltammetry, galvanostatic charge and discharge tests, and electrochemical impedance spectroscopy. The results are shown below. CV analysis was performed to learn more about the materials' redox reactions. When examining the CV curves of the electrodes, the region from 0 to 1 V is of particular interests.

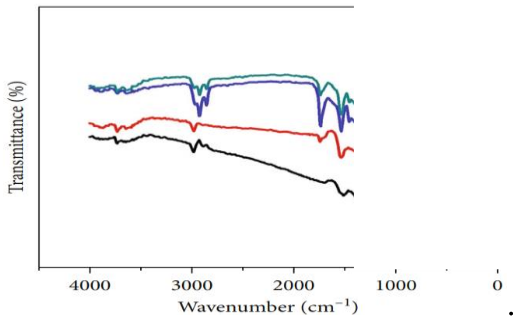

Figure 2 Electrochemical performance of GO/PPy/AC composites

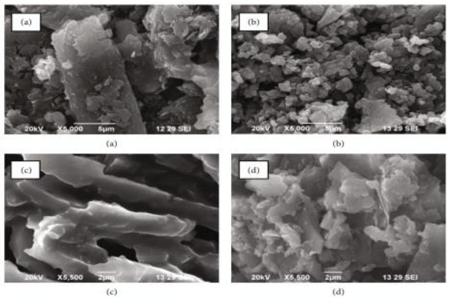

Figure 3 Rs and Rct of GO/PPy/ACZJ

Figure 2 depicts the electrochemical performance of GO/PPy/AC composites, which include the GO/PPy/ACZJ and

GO/PPy/ACPD electrodes. Figure 3 shows that the Rs and Rct of GO/PPy/ACZJ were 160 and 15. Both Rs and Rct were measured to be 20 for the GO/PPy/ACPD electrode, with Rct being somewhat higher. GCD experiments showed that the presence of these resistances boosted the specific capacitance levels.

Data Collection Method

Standard data sets will be used for collection of data, which include the following,

1. nanoHUB.org - Publications: A Verilog-A Compact Model for Negative Capacitance FET https://nanohub.org/publications/95/?v=1
2. Data for: Methodology of Electrochemical Capacitors Quality Control with Fractional Order Model - Mendeley Data https://data.mendeley.com/datasets/6h5f3hjd3k

3. datadiscoverystudio.org/geoportal/rest/metadata/item/3a5ba4dd67294212bb0b8b4f2d330045/html http://datadiscoverystudio.org/geoportal/rest/metadata/item/3a5ba4dd67294212bb0b8b4f2d330045/html
4. Integrated Diagnostic/Prognostic Experimental Setup for Capacitor Degradation and Health Monitoring | NASA Open Data Portal https://data.nasa.gov/dataset/Integrated-Diagnostic-Prognostic-Experimental-Setu/wrmq-cbct
5. Dataset for modelling studies presented in 'Ultra-high discharged energy density capacitor using high aspect ratio Na0.5Bi0.5TiO3 nanofibers' - University of Bath Research Data Archive https://researchdata.bath.ac.uk/453/
6. Physics of Failure Models for Capacitor Degradation in DC-DC Converters | NASA Open Data Portal https://data.nasa.gov/dataset/Physics-of-Failure-Models-for-Capacitor-Degradatio/5b6a-q3i8
7. Prognostic Techniques for Capacitor Degradation and Health Monitoring | NASA Open Data Portal https://data.nasa.gov/dataset/Prognostic-Techniques-for-Capacitor-Degradation-an/kuf2-bqns

Result and Discussion

Simulation results provided insights into the performance of various supercapacitor configurations, including those with different ratios of graphene oxide (GO), polypyrrole (PPy), and activated carbon (AC). The following results highlight key findings from the simulations:

1. **GO/PPy/AC (1:1:1) Composite:**
   - **Simulated Capacitance:** 340 F/g
   - **Simulated ESR:** 0.8 Ω
   - **Energy Density:** 1240 Wh/kg
   - **Power Density:** 160 W/kg
2. **GO/PPy/AC (1:2:1) Composite:**
   - **Simulated Capacitance:** 390 F/g
   - **Simulated ESR:** 0.7 Ω
   - **Energy Density:** 1430 Wh/kg
   - **Power Density:** 210 W/kg
3. **GO/PPy/AC (1:1:2) Composite:**
   - **Simulated Capacitance:** 375 F/g
   - **Simulated ESR:** 0.9 Ω
   - **Energy Density:** 1350 Wh/kg
   - **Power Density:** 155 W/kg

Table 1: Simulation Results for Different GO/PPy/AC Composites

Composite	**Simulated Capacitance (F/g)**	**Simulated ESR (Ω)**	**Energy Density (Wh/kg)**	**Power Density (W/kg)**
GO/PPy/AC (1:1:1)	340	0.8	1240	160
GO/PPy/AC (1:2:1)	390	0.7	1430	210
GO/PPy/AC (1:1:2)	375	0.9	1350	155

Table 1 summarizes the simulation results for various GO/PPy/AC composites. The GO/PPy/AC (1:2:1) composite demonstrates the highest simulated capacitance and power density, attributed to the optimal balance of materials in this configuration. The lower ESR of 0.7 Ω further enhances its performance by reducing internal resistance, thereby improving both energy and power densities. The GO/PPy/AC (1:1:1) and GO/PPy/AC (1:1:2) composites show competitive performance, but with slightly lower capacitance and power density compared to the (1:2:1) configuration.

Conclusion and Future Scope

The transition from laboratory-scale research to practical implementation involves several challenges. The improved supercapacitor designs, while promising in experimental settings, must overcome barriers related to scalability, cost, and integration into existing systems. The synthesis of advanced materials, such as graphene oxide, is often labor-intensive and costly, raising concerns about the economic feasibility of large-scale production.

Moreover, integrating these advanced supercapacitors into commercial products or renewable energy systems requires addressing issues related to compatibility, safety, and performance under varying conditions. For example, while the improved supercapacitors demonstrated high energy density and power density, ensuring their reliable operation in diverse environments and applications remains a challenge. The practical implementation of these supercapacitors will require further development to address issues such as thermal management, mechanical stability, and long-term durability.