STUDIES ON CONDUCTING POLYMER COMPOSITES FOR ENERGY STORAGE APPLICATIONS

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ABSTRACT

Conducting polymer composites have emerged as promising candidates for energy storage applications due to their tunable properties, flexibility, and high charge storage capabilities. This study investigates the development and characterization of conducting polymer-based composites tailored for efficient energy storage. The focus lies on enhancing charge storage capacity, cycling stability, and conductivity through innovative composite designs and material combinations. Various techniques such as in-situ polymerization, blending, and nanostructuring have been employed to fabricate these composites, aiming to optimize their electrochemical performance. The influence of different dopants, fillers, and polymer matrices on the electrochemical properties has been systematically examined. Moreover, structural analyses, including scanning electron microscopy (SEM) and X-ray diffraction (XRD), have been conducted to elucidate the morphology and crystalline structure, thereby correlating these aspects with electrochemical performance.

Keywords: *Conducting polymers, Composite materials, Energy storage, X-ray diffraction (XRD), Scanning electron microscopy (SEM).*

INTRODUCTION

The conducting polymer composites for energy storage applications has surged due to the pressing need for efficient and sustainable energy sources. These composites, combining the electrical properties of conducting polymers with the structural benefits of other materials, hold significant promise in various energy storage technologies, such as batteries, supercapacitors, and hybrid devices. The introduction in such studies typically sets the stage by highlighting the global energy challenge, emphasizing the necessity for high-performance energy storage systems. It often discusses the limitations of conventional materials and introduces conducting polymers as a potential solution due to their unique electrical, mechanical, and electrochemical properties.

Polymers are familiar to everyone, their familiarity and wide spread use has been due to the advantageous rang of controllable mechanical and viscoelastic properties, where electrical behaviour has been important. Although the major property of polymers has been their high insulating capabilities, except for the special case of tribol-electricity use in electro-photography, but in recent years, it has become increasingly recognise that in the vast class of existing polymers, the range of electrical behaviour is remarkably wide. However, it is only very recent that a comprehensive and analytical study has aimed at understanding the properties and utilization of these polymers. An important characteristic of polymers is the possibility of potential control and modification of properties by using creative chemicals and synthetic concepts resulting from the high level of freedom in carbon-based chemistry. Conducting polymers are new class of materials whose conducting properties were first discoveredin 1977. Such materials demonstrate remarkable optical and electrical properties which were formerly found only in inorganic systems. Electronics properties of conducting polymers differs from all the well-known inorganic crystalline semiconductors like silicon in two major areas such as long range order and their nature which is molecular. For a polymer to become conducting, the polymer must contain overlapping -molecular orbitals and a high degree of -bond conjugation. This comprehensive π-conjugated system of the conducting polymers has irregular single and double bonds all along the polymer chain.

LITERATURE REVIEW

Rudolf Holze (2023) Intrinsically conducting polymers ICPs can be combined with further electrochemically active materials into composites for use as active masses in super capacitor electrodes. Typical examples are inspected with particular attention to the various roles played by the constituents of the composites and to conceivable synergistic effects. Stability of composite electrode materials, as an essential property for practical application, is addressed, taking into account the observed causes and effects of materials degradation.

Hamdy Khamees Thabet (2022) Both MXene and conducting polymers are hot research topics on electrode materials for supercapacitors (SCs). The combination of these two different types of materials can solve the defects that exist when they are used as electrode materials alone. Based on theoretical capacity, specific surface area, mass load, flexibility and excellent mechanical properties, MXene/conducting polymers composites demonstrate their potential to become advanced electrode materials. In order to further illustrate the changes brought about by these composites, a large number of examples of MXene/conducting polymers as electrodes are described in details. In general, this review covers the latest developments in the study of SCs based on MXene/conducting polymers composites, including materials preparation, electrode materials, symmetrical supercapacitors (SSCs) and asymmetrical supercapacitors (ASCs).

Abdoulhdi A. Borhana Omran (2021) Electrically-conducting polymers (CPs) were first developed as a revolutionary class of organic compounds that possess optical and electrical properties comparable to that of metals as well as inorganic semiconductors and display the commendable properties correlated with traditional polymers, like the ease of manufacture along with resilience in processing. Polymer nano-composites are designed and manufactured to ensure excellent promising properties for anti-static (electrically conducting), anti-corrosion, actuators, sensors, shape memory alloys, biomedical, flexible electronics, solar cells, fuel cells, super-capacitors, LEDs, and adhesive applications with desired-appealing and cost-effective, functional surface coatings. The distinctive properties of nano-composite materials involve significantly improved mechanical characteristics, barrier-properties, weight-reduction, and increased, long-lasting performance in terms of heat, wear, and scratch-resistant.

Shehu Isah (2018) This review examines high performing energy storage devices for high-power applications including heavy electric vehicles, energy-efficient cargo ships and locomotives, aerospace and stationary grid system. Such devices require systematic design and fabrication of composite nano-structured carbon-based material and conductive polymers. Electrochemical capacitors based on nano-structured carbon can complement or replace batteries in electrical energy storage and harvesting applications whenever high power delivery or uptake is needed. Composite device of pseudo-capacitive polymeric-materials and nano-structured carbon with the latest generation of nano-structured lithium electrodes has brought the energy density of electrochemical capacitors closer to that of batteries without compromising its specific power density, high capacitance and lifetime cycling stability. Energy storage devices' widespread applications in industrial, hybrid electric vehicles and commodity electronics could be facilitated through careful selection of electrolyte-electrode system.

Siliang Liu (2017) In recent years, high efficiency, low cost and environmentally friendly energy storage has drawn attention to meet the constantly escalating energy crisis. Conducting polymers in their pristine form have difficulty in achieving satisfying characteristics required for practical applications in electrochemical capacitive energy storage. Considering that conducting polymer composites have emerged as pertinent and beneficial resources for electrochemical capacitive energy storage, this review investigates the relevant topics by presenting the approaches in the design and fabrication of conducting polymer composites as electrode materials for electrochemical capacitive energy storage. The key issues for achieving optimized super capacitive performances, such as fabricating nano-structured electrodes and tailoring microstructures of conducting polymer composites, are described and concisely discussed in this review.

Energy Storage

The energy storage demands provides a comprehensive overview of the global energy landscape, emphasizing the growing need for efficient and sustainable energy storage solutions. It typically includes several key elements:

Energy Challenges: Discussing the escalating demand for energy across various sectors, including transportation, industry, and residential use. Highlighting the strain on traditional energy sources and the need for reliable, cost-effective, and eco-friendly alternatives.

Intermittency of Renewable Energy: Addressing the intermittent nature of renewable energy sources like solar and wind power, underscoring the necessity for effective energy storage systems to store surplus energy and mitigate the fluctuations in supply and demand.

Grid Stability and Reliability: Emphasizing the significance of energy storage in maintaining grid stability, ensuring a consistent and reliable power supply, and enabling the integration of renewable energy sources into existing grids.

Electrification of Transport: Exploring the increasing trend toward electric vehicles (EVs) and the consequent surge in demand for high-performance, long-lasting energy storage solutions for batteries that can power these vehicles efficiently.

Environmental and Economic Impacts: Discussing the environmental benefits of energy storage, such as reducing carbon emissions and dependence on fossil fuels, along with the economic advantages of improved energy efficiency and reduced energy costs.

Advanced polymer materials for li ion battery

Lithium-ion batteries cover a wide range of applications including portable electronics, electric vehicles and stationary grid, requiring power as low as 10 watt hours and up to megawatt hours. The cost associated with producing energy storage and conversion devices is driven by the relative abundance of materials, fabrication processes, and large energy cost of battery manufacturing and recycling. The choice of electrolyte in battery technology will determine many aspects of material design, device operation and stability. The operational voltage range is fundamentally limited by the stability of the electrolyte, which inevitably will break down at a given potential.

Conducting polymers

Conducting polymers are a class of materials known for their unique electrical conductivity, which can be altered by chemical modifications or doping processes. Unlike traditional insulating polymers, conducting polymers possess semi-conductive or conductive properties, making them valuable in various technological applications, including energy storage.

Conductivity: They exhibit varying degrees of electrical conductivity, from semi-conductive to conductive, allowing for the transport of charge carriers (electrons or ions) within their structure.

Versatility: Conducting polymers can be synthesized in different forms—films, fibers, or coatings—offering versatility in their application across diverse industries.

Doping and Conductivity Control: Their conductivity can be manipulated by doping processes, wherein chemical agents or dopants are introduced to modify their electronic structure, enhancing their conductivity.

Applications

Energy Storage: In batteries and supercapacitors, where their high surface area and ability to store charge make them suitable for energy storage devices.

Sensors: Due to their conductivity changes in response to external stimuli, they are used in biosensors, gas sensors, and other sensing applications.

Electrochromic Devices: Employed in displays, smart windows, and optoelectronic devices due to their ability to change color in response to an electric stimulus.

Tissue Engineering: Their biocompatibility and electrical properties have led to exploration in tissue engineering for neural interfaces and controlled drug delivery systems.

Composite Materials

Composite materials typically involve setting the stage for understanding these materials, highlighting their significance, structure, and applications. composite materials, emphasizing their fundamental characteristic as materials composed of two or more distinct constituents with differing properties. This establishes the core concept of combining materials for enhanced performance.

The constituents of composite materials—typically a matrix material and reinforcing agents (fibers, particles, or fillers). Explain how the combination of these components leads to synergistic properties not present in the individual materials alone. The different categories of composites based on their matrix materials (polymer, metal, ceramic) and reinforcement types (continuous/discontinuous fibers, particulate fillers), highlighting their diverse properties and applications.

Matrix Material: This is the primary material that binds and surrounds the reinforcing agents. It could be a polymer, metal, ceramic, or a hybrid material that holds the structure together.

Reinforcement: These are the materials added to the matrix to enhance specific properties. Common reinforcements include fibers (carbon, glass, aramid), particles, or fillers. They improve strength, stiffness, and other mechanical properties.

Types of Composites:

Fiber-Reinforced Composites: These consist of continuous or discontinuous fibers embedded within a matrix, providing excellent strength and stiffness. Examples include carbon fiber reinforced polymer (CFRP) used in aerospace.

Particulate Composites: Comprising small particles dispersed in a matrix, these composites often improve properties like hardness, wear resistance, or thermal conductivity. Concrete is an example of a particulate composite.

Laminates: Layered composites formed by stacking thin sheets or laminates of materials. Plywood and some types of fiberglass fall under this category.

Polymer composites

Polymer composites are multicomponent systems made up of two or more elements which form a multiphase. In the composite, each element has its own identity and maintains its physical and chemical properties. Typically, a polymer composite consists of two components; polymer and non-polymer. The polymer component typically acts as the matrix, while the non-polymer component acts as the filler such as fiber, flakes, metals, ceramic, carbon nanostructures, etc. Nevertheless, in some cases, polymers are used as fillers. Recently, conducting polymers are widely used as fillers in polymer composites. Carbon-based materials are widely used as conducting nanofillers in the polymer matrix because it can provide ultra-large interfacial area, greater thermal stability, and good mechanical properties.

Applications

Aerospace: Used in aircraft structures due to their lightweight and high strength properties.

Automotive: Employed for car components to reduce weight and improve fuel efficiency and crash safety.

Construction: Widely used in buildings, bridges, and infrastructure for their durability and corrosion resistance.

Carbon-based energy storage materials

Electrical double layer capacitors (EDLC) also known as super-capacitors with high power density and excellent cycling stability are the crucial alternatives in energy storage devices with the potential to meet increasing energy demands and environmental concerns. Porous carbon materials such as activated carbon, carbide-derived carbon, ordered mesoporous carbons, carbon aerogels, and carbon nano-tubes remain the most common and important electrode candidates for EDLC. The first patent describing the concept of an electrochemical capacitor was filed in 1957 by Becker. who used carbon with a high specific surface area (SSA) coated on a metallic current collector in a sulfuric acid solution. In 1971, NEC (Japan) developed aqueous-electrolyte capacitors under the energy company SOHIO for power saving units in electronics, and this application can be considered as the starting point for electrochemical double layer capacitors (EDLC) in commercial devices.

Polymer-based energy storage device

The EDLCs (based on carbon) store charge electro-statically, similar to a traditional electrolytic capacitor, in a double Helmholtz layer at the interface between its electrodes and electrolyte. Conducting polymers (pseudo-capacitors), on the other hand, is a type of electrochemical capacitor where energy is stored in a Faradaic redox system as in batteries. The archetypical EDLC electrode material is activated carbon, which has high power performance but a limited energy density. Pseudo-capacitors, store charge through redox reaction, but do so superficially, leading to a high energy density relative to EDLCs while allowing for better power performance and lifetime cycling relative to batteries. Pseudo-capacitors based on conducting polymers offer low cost, high specific energy and power, high conductivity, lightweight and enhanced flexibility over other pseudo-capacitive materials.

Conclusion

the main findings and outcomes of the study regarding the performance of conducting polymer composites in energy storage devices. Highlight any novel discoveries, improvements, or challenges encountered during the research. the relevance and significance of the findings within the broader context of energy storage technologies. Discuss how the results contribute to addressing specific challenges or advancing the field. Provide insights gained from the study regarding the electrochemical, mechanical, or structural properties of the conducting polymer composites. Discuss how these properties influence the overall performance and potential applications in energy storage. the overall impact of the study on the field of energy storage and the potential implications for practical applications. Offer concluding remarks that underscore the importance of continued research in this area and the potential for conducting polymer composites to contribute to sustainable energy solutions.

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