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Transition Metal Sulphide-Carbonaceous Material-Conducting Polymer Nanocomposite Electrode Material for Supercapacitors: A Review

Muhammad Asad[1], Muhammad Nadeem[2]

Department of Physical Sciences, UET Taxila, Pakistan

ABSTRACT :

Energy storage solutions are increasingly essential due to the expanding energy crisis. The availability of reasonably priced, eco-friendly energy sources at all times. Supercapacitors (SCs) and batteries are the two significant energy storage mechanisms that should be considered. Although supercapacitors are gaining lot of interest from researchers as an efficient energy storage technology, batteries are impressive in a stable, undeviating discharge at a specific voltage and a higher energy density. Supercapacitors have superior cyclic stability, a high specific capacitance value, fast charging as well as discharging, and higher energy density when compared with other conventional batteries and capacitors.

Supercapacitor performance is significantly affected by the electrodes that are employed in its fabrication. Supercapacitors commonly use, metal sulphide/oxides, carbon nanotubes, activated carbon, graphene and conducting polymers as electrode materials. Higher specific capacitance, high power density, extended cyclic stability, as well as expense have to be corresponded with the particular demands of the application while choosing an electrode material.

A high performance Supercapacitors may find this nanocomposite to be an appealing electrode material due to its outstanding electrical conductivity, exceptional cycle stability, higher power density, and higher specific capacitance.

Introduction :

1.1 Supercapacitor

Rapidly expanding demand of energy storage devices has opened up a new channel for researchers and the scientific community to produce renewable energy resources. It is found that it maintains greater specific capacitance, extraordinary energy and power densities as well as excellent cyclic stability. Its ability to fulfil increasing need of different applications which shows that it is outstanding forms of energy storage systems [1].
Improved specific capacitance, greater power density plus long term cyclic stability below 40°C are maintained by Supercapacitors for reason that of great power performance in addition to energy storage mechanism [2].

1.2 Classifications of Supercapacitors :

1.2.1 Electrostatic Double Layer Capacitor (EDLCs)

Capacitance of EDLCs is a result of static charge separation at the electrolyte and electrode junction. When the electrode is submerged in the electrolyte solution, the double-layer of charges made on intersection of the electrolyte and electrode. At the interface of the electrode and electrolyte, charges continue electrostatically stored. One benefit of EDLCs is that there is no charge transfer in between the electrode and electrolyte. The capacitance is primarily calculated by the area of accessible electrode material and the related surface characteristics. They have reduced energy density but great stability since they are based on non-faradaic reactions [3].
EDLCs are made using electrodes made of carbon-based materials. Carbon is the most exciting material since it can be changed into over ten million distinct chemical compounds. Carbon allotropes with distinct properties include graphene, carbon nanotubes, and activated carbon [4].

1.2.2 Pseudocapacitors

Pseudocapacitors store charges fast because of the electrolyte and electrode's redox activity. Redox charge transfer reactions provide Pseudocapacitive devices their higher energy density since the components are in different states of oxidation. Because of their limited lifespan and low conductivity, Pseudocapacitors are less commonly used in commercial applications [3]. Pseudocapacitors demonstrated better specific capacitance as well as higher energy densities when compared with EDLCs. Numerous conducting polymers, metal oxides, and metal sulphides can be used to develop the Pseudocapacitors electrodes [5].

1.2.3 Hybrid Supercapacitors

EDLCs and pseudo capacitors are used to make hybrid supercapacitors. Both faradaic and non-faradaic developments occur for charge accumulations that lead to improved energy storage. Higher specific capacitance pseudo capacitance characteristics of hybrid supercapacitors are better than EDLCs, but EDLCs also have outstanding cycle stability and high power density [2, 6-9].

1.3 Components of Supercapacitors

Electrodes, separators, electrolyte, and current collector are the vital parts of a Supercapacitors. A separator serves as a membrane to provide electrical separation between two electrodes [3, 7]. Electrolyte and electrodes are essential components of supercapacitors.

1.3.1 Electrode Materials

A wide-ranging potential window and higher specific capacitance can be significantly enhanced by an efficient electrolyte and a suitable electrode material. Considering a variety of their unique physical and chemical properties, various nanocomposites were considered to be the good supercapacitors electrode materials [2, 5].

1.3.2 Separators

Separators in supercapacitors allow ions to flow between the positive and negative electrodes while also physically separating them. Because they ensure ion permeability, reduce internal resistance, and avoid short circuits [10]. The choice and design of separators have a substantial impact on the Supercapacitors efficiency, security, and overall performance [3].

1.3.3 Electrolytes

Supercapacitors demand a suitable electrolyte for successful fabrication. Solid-state electrolytes allow for a safer combination of the two. Organic electrolytes highlight larger energy rates, while aqueous electrolytes value greater power densities [3]. As Supercapacitors technology develops, efforts to identify and create different electrolytes keep contributing to power storage options appropriate for a variety of uses [3].

1.3.4 Current Collectors

The current collector is engineered to optimise charge/discharge rates. Enhancing the Supercapacitor’s overall performance and stability are the physical properties of the current collector [3]. The current collector's structure as well as features influence the Supercapacitor’s capabilities.

1.4 Electrode Materials :

1.4.1 Transition Metal Sulphides

Transition metal sulphides are unique and prominent kind of materials in energy storage devices. Metal sulphides commonly exhibit a greater conductivity with activity, poorer electronegativity, and a smaller band gap than their corresponding oxides. Copper-containing sulphides have recently been highlighted due to their abundant nature, outstanding stability, and inexpensive cost. In addition to the most prominent examples are $CuCo_2S_4$, $CuSbS_2$, Cu_2MoS_4 etc which has strong redox properties and a tremendous ideal capacitance that can be increased by specialised manufacturing techniques, particularly Nano-structuring. Among them Copper Cobalt sulphides ($CuCo_2S_4$) [10] offer an extensive amount of potential, but due to its weak electrical conduction, accumulation, and cyclic instability, they are best used as electrodes for super capacitors in nanocomposite with carbon-based materials.

1.4.2 Activated carbon

Activated carbon has been proven to be a useful material for electrodes due to a number of outstanding characteristics, such as a modified surface area as well as brilliant electric characteristics, as well as offering simple and affordable electrode fabrication. Activation is used to produce activated carbon, which has several pore sizes: micropores, mesopores, and macropores. Despite having a higher surface area and conductivity, activated carbon has a considerably lower specific capacitance than EDLCs theoretical capacitance. As nitrogen, boron, phosphorus, and sulphur are added to activated carbon, its electrochemical characteristics significantly improved [11].

Researchers have unveiled the electrochemical characteristics of activated carbon, which contribute to the retention of specific electrolytes in its Nano porous construction. Activated carbon's specific capacitance was more developed in aqueous electrolytes than in organic electrolytes. Activated carbons are regarded as a promising Supercapacitor electrode material, however its inadequate rate aptitude and energy storage make them less than ideal [11].

1.4.3 Carbon Nanotubes

Carbon Nanotubes are regarded as a suitable as well as preferred nominee for the supercapacitor applications because of their excellent electrical conductivity in an exterior area. Carbon Nanotubes have received substantial interest from scientists in energy storage, as they are regarded as emergent and proficient energy storage solutions due to their flexibility in structural, chemical, electrical, and physical properties [11, 12].
Carbon Nanotubes are classified into two categories based on their structures.

I. Single-walled carbon Nanotubes
II. Multi-walled Carbon Nanotubes

Single-walled carbon Nanotubes exhibit significantly higher electrochemical performance than Multi-walled Carbon Nanotubes. Carbon Nanotubes are not considered to be desirable considering their poor electrochemical performance, high cost, and toxicity. Although composite of Carbon Nanotubes enhances electrochemical performance due to its excellent surface area along with electrical conductivity [6, 12].

1.4.4 Graphene

Carbon atoms in a single sheet make up graphene. It is a two-dimensional material that is good for supercapacitors as an electrode material because of its great electrochemical qualities, good cyclic life, high surface area, and inexpensive. Doping changes the electrochemical characteristics of graphene [12-14]. Thus, a combination of metal sulphide and graphene can improve its cyclic stability as well as electrochemical performance. Similarly, a metal sulphide and carbon-based material nanocomposite contains higher specific capacitance as well as outstanding cyclic stability.

1.4.5 Conducting polymers

Conducting polymers have a charge-storing mechanism similar to that of pseudo capacitors. Commonly used conducting polymers include Polypyrrole, Polyaniline, Polythiophene, and their by-products due to their superior qualities, such as easy polymerization and inexpensive monomer availability. Conducting polymer has superior quick redox reaction characteristics in supercapacitors composed of carbon due to its higher specific energies and improved capacitive behaviour [15].
Although polypyrrole is widely synthesised and considered a promising component for Supercapacitor and battery applications, it has certain drawbacks, such as low mechanical stability and elevated equivalent series resistance during the charging and discharging process [15, 16].

1.5 Suggestion :

Due to the long-term cyclic stability, excellent specific capacitance, as well as better electrical conductivity, the Metal Sulphides-reduce GO-Polypyrrole Nanocomposite may prove to be a viable electrode material for efficient Supercapacitor.

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