E-ISSN: 2583-9667
Indexed Journal
Peer Reviewed Journal
https://multiresearchjournal.theviews.in

Received: 08-07-2023
Accepted: 17-08-2023

INTERNATIONAL JOURNAL OF ADVANCE RESEARCH IN MULTIDISCIPLINARY

Volume 1; Issue 1; 2023; Page No. 304-307

Nanocomposite materials based on transition metal oxides and graphene for supercapacitor electrodes

[1]Nadeem Farooq Abbasi and [2]Dr. Arun Sharma

[1]Research Scholar, Arni School of Science, Arni University, Indora, Kathgarh, Kangra, Himachal Pradesh, India
[2]Assistant Professor, Arni School of Science, Arni University, Indora, Kathgarh, Kangra, Himachal Pradesh, India

Corresponding Author: Nadeem Farooq Abbasi

Abstract

Super capacitors are more powerful than batteries and have a greater energy density than regular capacitors. The study of supercapacitors has attracted the attention of researchers because of their unfathomable qualities. Nevertheless, commercially available super capacitors are confined to employing carbon-based materials as electrically active materials, which offer a substantially lower energy density than batteries, due to the inadequate performance of electroactive materials. Thus, it is still essential to build energy devices with high power and energy densities.

The shape, structure, and degree of integration of the electroactive material are important elements to improve the specific capacitance. Many 1D/2D nanostructured materials with unexpected characteristics have been created in the last ten years. Furthermore, it has been claimed that multicomponent nanostructured hybrids inherit the advantages of both nanostructures in addition to benefiting from each one's unique traits. This enhances the electrochemical performance of the electrode as a whole and helps to efficiently utilise electroactive species. Rare-earth materials attracted some attention because of the several transition modes involving the 4f shell of their ions, and lanthanide compound design and production have attracted a lot of interest.

Keywords: Nanocomposite, metal oxides, graphene, electrodes

1. Introduction

Electrochemical energy storage methods are essential to the development of sustainable energy solutions. Numerous new iterations of tiny fuel cells and rechargeable lithium batteries show that it is more effective, adaptable, and modular than other energy storage techniques, which gives it more promise. Electrochemical energy storage has becoming more important as environmental pollution increases because it can lessen our reliance on limited fossil fuel supplies. Similar to ocean thermal, wave, and tidal power, geothermal sources seem to be expensive to produce and have limited geological reach. Because renewable energy drastically lowers carbon emissions, it helps to safeguard the environment. We may prevent growing energy costs and decrease our dependency on fossil fuel, gas, and oil reserves by employing renewable energy sources.

Consumer demand for lightweight, portable electrochemical power sources is being met by emerging technologies including fuel cells, large format lithium-ion batteries, supercapacitors, and electrochemical reactors like ion transport membranes. Their uses include pacemakers, electric cars (EVs), communication devices, and spaceships. Consequently, a new class of electrochemical power sources known as electrochemical supercapacitors has been created during the past ten years as a result of several improvements. Additionally, in order to facilitate the widespread use of plug-in hybrids, hybrid electric vehicles (HEV), etc., greatly improved electrical energy storage (EES) systems are required.

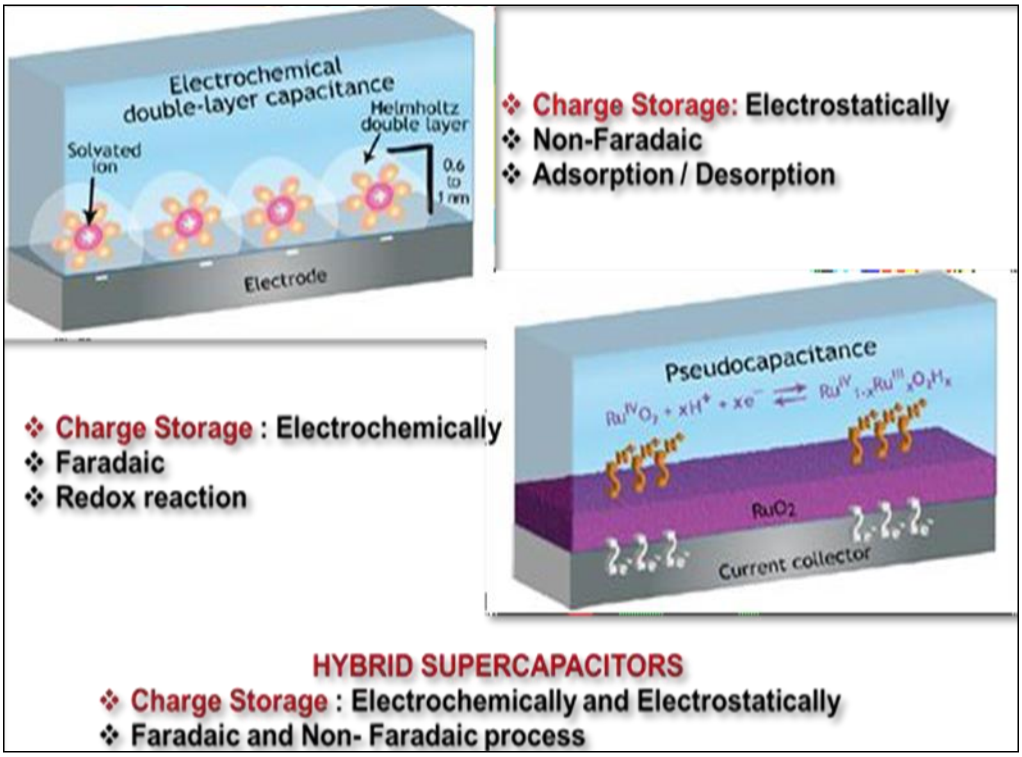

Fig 1: Principle of operation of the supercapacitor

With this technology, cars powered by fuel cells and hybrid electrics need a significant initial energy boost. Many electrical and technical applications that need for a quick, high-energy discharge also need supercapacitors. Among the names for capacitors that store energy within the electrochemical double-layer at the electrode/electrolyte interface are double-layer capacitors, supercapacitors, ultracapacitors, power capacitors, gold capacitors, and power cache. The basic idea behind charge storage in these kinds of capacitors is described by the electrochemical double-layer capacitor. Because of the usual extra contributions to the capacitance beyond double layer effects, these capacitors are known as electrochemical capacitors (EC). The first patents were filed in 1957 after Becker's description of a high-surface-area carbon capacitor.

Supercapacitors are electrochemical energy storage devices, just as batteries. A separator is used to keep the two electrodes apart. Electrical transmission between the electrodes is stopped by the separator saturated with electrolyte. For best results, low-thickness separators need to have high electric resistance and be ion-permeable for quick ionic charge transfer. The electrodes are different for asymmetric SC and the same kind for symmetric SC. In comparison to batteries, solid-state batteries (SCs) offer a greater capacity, lower internal resistance, and a faster rate of energy storage and conveyance due to their unique storage mechanism and charge separation at the electrode/electrolyte interface surface [4-5]. Extended cycle life, excellent power density, a broader working temperature range (-40 °C to 70 °C), reduced weight, and a lower price are some of the appealing features of supercapacitors.

Supercapacitors are governed by the same basic principles as regular capacitors. The distance [D] between the electrodes is lowered, nevertheless, since they combine electrodes with noticeably bigger surface areas [A] and noticeably thinner dielectrics. Supercapacitors preserve the low ESR feature of traditional capacitors, allowing them to achieve similar power densities. Supercapacitors also have a variety of benefits over fuel cells and electrochemical batteries, such as a longer cycle life, a better power density, and a quicker charging time.

Energy storage technologies are critical for the development of sustainable energy systems. Supercapacitors, known for their high power density and long cycle life, have gained significant attention as potential candidates for energy storage devices. The performance of supercapacitors largely depends on the electrode materials used. Transition metal oxides (TMOs), such as manganese oxide (MnO_2), cobalt oxide (Co_3O_4), and nickel oxide (NiO), have shown promise due to their high specific capacitance. However, their low electrical conductivity and poor cycle stability are major drawbacks. Combining TMOs with graphene, a material known for its excellent electrical conductivity, high surface area, and mechanical strength, can overcome these limitations.

2. Materials and Methods

2.1 Synthesis of TMO/Graphene Nanocomposites

Li-ion batteries are secondary batteries that include dissolved Li+ ions in carbon and a lithium anode. Lithium is released by the chemicals that make up the cathode material. Rechargeable batteries with a high energy density and minimal self-discharge are commonly utilised in portable gadgets. Compared to lead-acid or nickel-cadmium batteries of the same size and weight, lithium-ion batteries have three times the energy while NiMH batteries have double the energy. It is half the size and weight of a NiMH battery for the same amount of energy. Because of these characteristics, the Li-ion battery has played a key role in the electronic revolution, enabling the creation of powerful portable computers and multipurpose mobile phones.

Supercapacitors have been used in place of or in addition to batteries in energy storage and/or load-leveling applications, such as long-term continuous circuits, plug-in hybrid electric cars, wind farms, and portable electronic gadgets. Supercapacitors offer a high power density, but because of their expensive cost and poor energy density in comparison to batteries, their market penetration is restricted. A supercapacitor is just a high energy density electrochemical capacitor. Usually, it consists of an insulator separating the two conductors (anode and cathode). Conventional symmetric supercapacitors based on activated carbon are inherently poor energy density devices. A solution may be to create an asymmetric supercapacitor with a transition metal oxide anode and carbon cathode. However, kinetic concerns about extremely thin electrode sheets limited the development of such supercapacitors in the early stages.

The TMO/graphene nanocomposites were synthesized using a hydrothermal method. In a typical synthesis, the TMO precursor was mixed with graphene oxide (GO) in an aqueous solution. The mixture was then subjected to hydrothermal treatment at 180 °C for 12 hours. The resulting product was washed, dried, and annealed to obtain the TMO/graphene nanocomposite.

2.2 Characterization

The synthesized nanocomposites were characterized using various techniques:

- **X-ray Diffraction (XRD):** To determine the crystalline structure.
- **Scanning Electron Microscopy (SEM):** To analyze the morphology.
- **Transmission Electron Microscopy (TEM):** To observe the nanoscale structure.
- **Raman Spectroscopy:** To confirm the presence of graphene.
- **Brunauer-Emmett-Teller (BET) Analysis:** To measure the surface area.

2.3 Electrochemical measurements

The electrochemical performance of the TMO/graphene nanocomposites was evaluated using a three-electrode system in 1 M KOH electrolyte. The working electrode was prepared by coating the nanocomposite on a nickel foam substrate. Cyclic voltammetry (CV), galvanostatic charge-discharge (GCD), and electrochemical impedance spectroscopy (EIS) were performed to assess the capacitive behavior, specific capacitance, rate capability, and cycling stability.

The word nanotechnology is a compound word made up of the phrases technology and the Greek number prefix Nano, which signifies one billionth. Given that a nanometer is one billionth of a metre (10 9 m), nanotechnology, also known as nanoscaled technology, is generally understood to be at a size smaller than 0:1 _m, or 100 nm. The study of events, properties, and reactions of materials at the atomic, molecular, and macromolecular dimensions-typically between 1 and 100 nm in size-is known as nano scale science, or nano science. The characteristics of matter change significantly from those at a larger particle scale at this scale, especially below 5 nm (i.e., quantum-scale effects play a significant role).

It is projected that there will be significant breakthroughs in metrology, biology and biotechnology, medicine and medical technology, information and communication technology, and a host of industrial uses. Among the many industries where nanoscience and nanoengineering have important applications are pharmaceuticals, cosmetics, processed foods, chemical engineering, high-performance materials, electronics, precision mechanics, optics, energy generation, and environmental sciences. More than 2,500 patent applications have been filed at important patent offices including the European Patent Office, and more than 50,000 papers on nanotechnology have been published yearly around the world in recent years [3]. The field of nanotechnology is expanding and vibrant. Critical human challenges including energy security, climate change, and deadly illnesses can be helped by nanotechnology.

3. Results and Discussion

3.1 Structural and Morphological Analysis

XRD patterns confirmed the successful synthesis of TMOs and their composites with graphene. SEM and TEM images revealed the uniform distribution of TMO nanoparticles on the graphene sheets, indicating strong interaction between the components. The BET surface area analysis showed an increased surface area for the composites compared to pure TMOs, contributing to enhanced electrochemical performance.

3.2 Electrochemical Performance

CV curves demonstrated the pseudocapacitive behavior of the TMO/graphene nanocomposites, with larger integrated areas compared to pure TMOs, indicating higher capacitance. GCD tests showed that the specific capacitance of the composites was significantly higher than that of pure TMOs. For instance, MnO_2/graphene composite exhibited a specific capacitance of 350 F/g at a current density of 1 A/g, compared to 200 F/g for pure MnO_2. The composites also showed excellent rate capability, retaining 80% of their capacitance at 10 A/g. EIS measurements revealed lower charge transfer resistance for the composites, attributed to the enhanced electrical conductivity provided by graphene. Additionally, the composites exhibited superior cycling stability, retaining over 90% of their initial capacitance after 5000 cycles.

4. Conclusion

Pure ZnO nanocrystals have been produced chemically and medically by the precipitation process. An X-ray diffraction analysis reveals that the structure of the generated ZnO nanocrystals is hexagonal. SEM analysis has shown that ZnO nanoflakes are formed biologically, whereas nanorods are created chemically. For the zinc oxide nanoparticles, the average particle sizes of the nanorods and nanoflakes were 31 and 34 nm, respectively, amply illustrating the polydispersion. ZnO nanorods at a concentration of 1:0.1 molar show superior photocatalytic activity for the degradation of MB dye when compared to other concentrations and biologically generated ZnO nanoflakes. After four hours of exposure, the nanorods' dye degradation efficiency is 76%. The production of nanorods during chemical synthesis is the reason for the higher photocatalytic activity compared to nanoflakes. increased

catalytic activity
The integration of transition metal oxides with graphene results in nanocomposites with enhanced electrochemical performance, making them suitable for high-performance supercapacitor electrodes. The synergistic effect between TMOs and graphene leads to high specific capacitance, excellent rate capability, and long cycle life. Future work will focus on optimizing the synthesis parameters and exploring other transition metals to further improve the performance of these nanocomposites.

5. References

1. Nikalje AP. Nanotechnology and its applications in medicine. Medchem. 2017;5:081-089.
2. Kolodziejczak-Radzimska A, Jesionowski T. Zinc oxide – From synthesis to application: A review. Materials. 2014;7(4):2833-2881.
3. Rena AV, Kanny K, Abitha VK, Thomas S. Methods of synthesis of nanoparticles and fabrications of nanocomposites. In: Synthesis of Inorganic Nano Materials. 2018. pp. 121-139.
4. Pedroza AM, Mosqueda R, Vante NA, Rodriguez-Vazaquez FR. Sequential treatment via Trametes versicolor and UV/TiO2/RuSeY to reduce contaminants in wastewater resulting from the bleaching process during paper production. Chemosphere. 2007;67(4):793-801.
5. Meyer BK, Alves H, Hofmann DM, Kriegseis W, Forster D, Bertram F, *et al*. Bound exciton and donor–acceptor pair recombinations in ZnO. Physica Status Solidi (b). 2004;241:231-260.
6. Bauer G, Boschloo G, Mukhtar E, Hagfeldt A. Electron injection and recombination in Ru(dcbpy)2(NCS)2 sensitized nanostructured ZnO. J Phys Chem B. 2001;105:5585–5588.
7. Karunakaran C, Vinayagamoorthy P. Magnetically recoverable Fe3O4-implanted Ag-loaded ZnO nanoflakes for bacteria inactivation and photocatalytic degradation of organic pollutants. New J Chem. 2016;40(2):1845-1852.
8. Drexler K. Engines of creation: The coming era of nanotechnology. Doubleday; 1986. ISBN: 0-385-19973-2.
9. Bahnemann D, Ye J, Puma GL, Schneider J, Dionysiou DD. Photocatalysis: Fundamentals and Perspectives. Royal Society of Chemistry; 2016. ISBN: 9781782622338.
10. Zhang D, Zeng F. Visible light – activated cadmium doped ZnO nanostructured photocatalyst for the treatment of methylene blue dye. J Mater Sci. 2012;47:2155-2161.
11. Davar F, Majedi A, Mizaei A. Green synthesis of ZnO nanoparticles and its application in the degradation of some dyes. J Am Ceram Soc. 2015;98(6):1739-1746.
12. Mansoori GA, Rohani Bastami T, Ahmadpor A, Eshaghi Z. Environmental application of nanotechnology. Ann Rev Nano Res. 2008;2:439-493.
13. Silva GA. Introduction to nanotechnology and its applications to medicine. Surg. Neurol. 2004;61(3):216-220.
14. Guanalansangeetha, Rajeswari S, Venkatesh R. Green synthesis of zinc oxide nanoparticles by Aloe barbadensis Miller leaf extract: Structure and optical properties. Mater Res Bull. 2011;46:2560-2566.
15. Park HH, Woo K, Ahn J. Core-shell bimetallic nanoparticles robustly fixed on the outermost surface of magnetic silica microspheres. Sci Rep. 2013;3:1497.

Creative Commons (CC) License
This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY 4.0) license. This license permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.