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Enhanced electrochemical properties of PbO-rGO nanocomposite prepared by wet chemical method for supercapacitor applications

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Abstract

The supercapacitor is a future energy device because of its higher power density and outstanding cyclic stability with a quick charge and discharge process. Supercapacitors have a lower energy density than regular batteries. The electrochemical characteristic of supercapacitors is strongly depend on the electrode materials. The nanostructured electrode materials continue to be a main focus of supercapacitor research. The considered electrode materials, such as, Lead oxide (PbO) and reduced graphene oxide (rGO) have been widely used in supercapacitors due to their fascinating physicochemical properties. The PbrG was synthesized using the simple and cost-effective ultrasonic-assisted solution method. The prepared PbO and PbrG were examined in XRD, TEM and XPS. The XRD studies confirmed the presence of crystal structure in PbO and PbrG. The TEM images reveal the embellishment of PbO on the rGO sheets. The PbrG showed a higher specific capacitance (448 F/g) compared to PbO NANO (177 F/g) with better cycling stability until 5000 cycles and exhibited excellent conductivity due to the presence of rGO. These properties of PbrG ensures that this electrode material play a beneficial role in the energy storage applications.

Introduction

In recent years the requirement for energy storage has augmented due to the reduction in the natural resources [1], [2], [3], [4], [5], [6], [7], [8], [9], [10]. Energy storage is a powerful tool for bridging the gap between the power supply and consumer demand [11], due to which the attention has been paid to enhance the energy storage kinetics and also to address the global energy crisis [12]. Electrochemical storage is a highly feasible and energy-efficient method of energy storage [13]. Supercapacitors are prominent energy storage devices to overcome the energy demand and in obtaining the clean energy with appealing properties like fast charging, high power density, high cycling stability with a longer lifetime than batteries. The supercapacitor is also called as ultracapacitor, electrochemical capacitor and hybrid capacitor. It can be utilized in different fields of energy storage devices, for example, in the hybrid electric vehicles (HEV), digital communication systems, power and defence equipment, etc. Graphene, carbon nanotubes, metal oxide/sulphides and the conducting polymers have received a considerable attention as supercapacitor materials. The supercapacitors work under two different mechanisms, namely, pseudocapacitors and electrochemical double-layer capacitors (EDLC). The graphene and carbon nanotubes are classified as EDLC. While the metal oxides/sulphides and conducting polymers are classified as pseudocapacitors [14], [15], [16]. During the charge storage process in EDLC-based capacitors, on the surface of electrode material there is a formation of an electric double layer (EDL) due to the adsorption of electrolyte ions. This type of capacitor typically has low energy density [17], [18], [19], [20]. The charges of the pseudocapacitor are stored due to the existence of a faradic redox reaction between the electrode materials and the electrolyte. However, the main disadvantage of this pseudocapacitor is its lower electrical conductivity and poor cyclic stability [21]. In general, the EDLCs keep a higher power density, while pseudo capacitors indicate high energy density and specific capacitance (C_{sp}). Therefore, it gives a prominent impetus to add the EDLCs with the pseudocapacitors to increase both energy densities and power of supercapacitors. The Lead Oxide (PbO) is a semiconductor material and is featured by a typical wide band gap. The PbO has two distinct types of crystalline structures, namely the tetragonal rutile structure (β-PbO) and the orthorhombic structure (α-PbO). Some of the applications of PbO are in nanodevices, nanocoatings, pigments, network modifiers in gas sensors, paints and energy storage. The major drawbacks of PbO are its slow recharge, limited cycle life and specific capacitance, low energy density, low cyclic stability and low electrical conductivity. These drawbacks can be avoided by making the PbO as a composite along with the conducting materials like carbon nanotubes, graphene etc. A very few studies have been done on PbO composites that are related to the supercapacitor applications. In the hybrid supercapacitor, the PbO can act as a positive material. The template method was used for improving the performance of PbO_2 nanowires [22]. The ELD on Ti was applied to synthesize the PbO_2/SnO_2 nanoparticle composite, which was then used as a supercapacitor [23]. The synthesized PbO-decorated SnO_2 nanowires by spin coat process is used for the ethanol gas sensing application [24]. The PbO composite has been shown to improve the PbO-specific capacity, activity and utilization rate. Amra Bratovcic [25] has carried a comprehensive study about the applications of lead oxide nanocomposites like storage batteries, glasses, stabilizers, ceramics and also as a prime material for making anticancer and anti-microbial drugs. Cattley and his group synthesized the lead oxide nanocrystals for application in photovoltaic device [26], [27], [28]. In recent years, in supercapacitors the reduced graphene oxide (rGO) based metal oxide materials are used [29], [30]. For supercapacitors, the graphene material stores more electrical charge due to the synergistic effect with catalyst particles, thus, allowing them for better electrochemical performance. Researchers have started to investigate the use of PbO-carbon nanostructures composite capacitive materials. In the present research work the synthesis of PbrG was done through the simple precipitation method followed by the ultrasonic assisted solution process. The suggested proficiency for synthesis of metal oxide and graphene composites is done in the simple room temperature and this method is cost-effective. This method outputs the high-purity materials, as the impurities, that can be easily removed through washing and filtration processes.

The aim of the present work is to understand the synthesis materials, PbO NANO and PbrG in the supercapacitor applications. The synthesis materials are characterized by different methods to determine the structural, elemental and electrochemical properties [31], [32], [33]. The performance of PbrG is high in comparison to PbO NANO, since, the PbrG showed a particular cyclic stability, with a specific capacitance of 90% after 5000 cycles.

Section snippets

Chemicals and materials

Graphite powder (Alfa Aesar 99.999% USA), sulfuric acid (H_2SO4), sodium nitrate ($NaNO_3$), potassium permanganate ($KMnO_4$), hydrazine hydrate (H_6N_2O), Hydrogen Peroxide (H_2O_2), lead acetate ($Pb(CH_3COO_2).4H_2O$), sodium hydroxide (NaOH) and polyvinylpyrrolidone (PVP) were fetched from the Sigma Aldrich and were used as precursors.…