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Silver-tungsten heterostructures nanocomposite for high-performance supercapacitor application

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ABSTRACT

In this study, silver oxide (Ag_2O)-doped tungsten oxides (WO_3) are synthesized via a hydrothermal route and systematically investigated as a potential electrode material for supercapacitor applications. The structural and surface characteristics of the synthesized materials are examined using X-ray diffraction (XRD), UV–Vis spectroscopy, field-emission scanning electron microscopy (FESEM), high-resolution scanning transmission electron microscopy (HRSTEM), and X-ray photoelectron spectroscopy (XPS). Electrochemical performance is evaluated through cyclic voltammetry (CV) and galvanostatic charge–discharge (GCD) measurements. The Ag_2O-doped WO_3 electrode exhibits outstanding electrochemical behavior, delivering a high specific capacitance of 1700 F g^{-1} at a current density of 1 A g^{-1}. In addition, the electrode demonstrates notable cycling stability, retaining 76% of its initial capacitance after 5000 consecutive charge–discharge cycles. To further assess its practical applicability, an asymmetric supercapacitor (ASC) device is assembled using Ag_2O-doped WO_3 as the positive electrode and reduced graphene oxide (rGO) as the negative electrode. The fabricated ASC delivers an energy density of 15.7 Wh kg^{-1} and a power density of 650 W kg^{-1}, indicating its efficient energy-storage capability. Notably, two ASC devices connected in series successfully power a blue light-emitting diode (LED) operating at 2.8 V, demonstrating the practical potential of the developed electrode material.

1 Introduction

The rapid growth in global population, industrialization, and improved living standards has led to a substantial increase in energy demand [1]. Therefore, it is crucial to develop efficient energy storage devices that can meet this growing need. Traditional energy storage solutions often fall short in terms of capacity and longevity. This is where innovative technologies come into play. By investing in research and development of advanced materials and systems, we can create energy storage devices that are not only more efficient but also

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environmentally friendly. Energy storage devices are more important for supplying uninterrupted energy to households and industrial applications. To overcome this, efficient energy storage devices are needed to provide uninterrupted energy to industries and homes [2]. Advanced energy storage technologies, such as fuel cells and batteries, have long been recognized and used as eminent electrochemical energy storage devices, known for their high density and long storage time [3]. Supercapacitors have recently attracted considerable interest as advanced energy storage systems within industrial fields. This popularity is due to their improved characteristics, for example, speedy charging and discharging, high power density, and long cyclic stability [4, 5]. Normally, electrodes with metal oxide-based energy storage devices offer advantages such as increased specific capacity, multiple oxidation states, and fast reaction rates [1]. In recent years, various transition metal oxides such as NiO, CoO, TiO_2, MnO_2, RuO_2, CuO, ZnO, SiO_2, WO_3, and CeO_2 have been studied.[6–10]. They have received more attention due to their inherent properties [11]. Among them, WO_3 is a versatile material that has attracted significant attention for its broad scope of applications, including gas sensing, electrochromic devices, photocatalysis, and energy storage. Its ability to exhibit pseudocapacitive behavior arises from multiple oxidation states, rapid surface redox reactions, and a crystal structure that readily accommodates the intercalation of electrolyte ions. Owing to these unique properties, WO_3 has been extensively explored as an electrode material for supercapacitors, with numerous studies highlighting its promising performance [12]. Numerous approaches have been explored for the preparation of WO_3 nanostructures, such as chemical vaporization CVD [13], Spray pyrolysis approach [14], sol–gel process [15], and hydrothermal method [16], among which the hydrothermal process is commonly employed. WO_3 is a stable n-type semiconductor, and the flower-like WO_3 is synthesized using the hydrothermal method [17]. This unique synthesis method enhances the stability of the n-type semiconductor and contributes to its distinctive flower-like morphology. The hydrothermal process enables precise control over parameters such as temperature and pressure, which are crucial for tailoring the microstructure of WO_3 [18]. Although WO_3 possesses several attractive properties for supercapacitor applications, in practical applications, the material suffers from inadequate electrical conductivity and progressive structural damage during repeated electrochemical cycling. To address these challenges, silver oxide (Ag_2O) has been integrated with WO_3 to form Ag_2O-doped WO_3. The incorporation of Ag_2O significantly improves charge transport by enhancing electrical conductivity [19], introducing more redox-active sites that boost capacitance, and strengthening the structural stability of the electrode. Moreover, the synergistic interaction between WO_3 and Ag_2O creates superior electrochemical characteristics, making it a promising candidate for high-performance energy storage systems. Overall, Ag_2O-doped WO_3 demonstrates strong potential as an electrode material for electrochemical applications. Their unique architecture contributes to enhanced specific capacitance, efficient charge-transfer pathways, and a pronounced synergistic interaction between WO_3 and Ag_2O. Furthermore, the Ag_2O-doped WO_3 combines superior electrochemical stability with adaptable properties, highlighting its potential as an electrode material for energy storage technologies.

2 Experimental details

2.1 Materials

All chemical reagents, such as sodium tungstate dihydrate, oxalic acid, silver nitrate, hydrochloric acid, and ethanol, were purchased from Sigma-Aldrich. All glassware employed in the experiments was thoroughly washed with acid before use. Double-distilled water was used for all dilutions and sample preparations.

2.2 Synthesis of WO_3 and Ag_2O-doped WO_3

The Ag_2O-doped WO_3 was synthesized via a hydrothermal method. For the preparation of Ag_2O-doped WO_3, 0.1 M sodium tungstate dihydrate ($Na_2WO_4{\cdot}2H_2O$), various concentrations of (0.0025, 0.0050, 0.0075, and 0.01 M) silver nitrate ($AgNO_3$), and 1 g of oxalic acid were dissolved in 100 mL of deionized water under continuous stirring at 60 °C. Subsequently, approximately 5 mL of hydrochloric acid was added dropwise until a stable colloidal solution was formed, and the mixture was further stirred for 1 h to ensure homogeneity. The resulting precursor solution was transferred into a Teflon-lined stainless-steel autoclave and subjected to hydrothermal treatment at 150 °C for 24 h. After naturally cooling to room