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Electrospun vanadium pentoxide/carbon nanofiber composites for supercapacitor electrodes

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ABSTRACT

The vanadium pentoxide (V_2O_5)/carbon nanofiber composites (CNFCs) were prepared from polyacrylonitrile/V_2O_5 in N,N-dimethylformamide by a simple electrospinning method, and their electrochemical properties as supercapacitor electrodes were investigated. Different loadings of V_2O_5, the microstructures of the CNFCs (e.g., nanometer-size diameters, high specific surface areas, narrow pore size distributions, and tunable porosities) were changed, and the textural parameters significantly affected the electrochemical properties of the composites. The CNFC capacitors delivered the high specific capacitances of 150.0 F g^{-1} for the CNFCs in an aqueous, with promising energy densities of 18.8 Wh kg^{-1}, over a power density range of 400–20,000 W kg^{-1}. The CNFCs simultaneously exhibited excellent capacity retention.

1. Introduction

In recent years, electrochemical capacitors (ECs) have attracted significant attention for their application in high-power energy storage devices for memory backup and, supplementarily, for hybrid cars [1–3]. Porous carbon is used as electrode material for supercapacitors because of its stable physical and chemical properties, large specific surface area, controlled pore structure, high conductivity, low cost, and availability [4]. The porous structures of carbon electrodes are well known to affect the performance of the resulting capacitors fabricated from this material [5,6] because both the capacitance value distributed along the pore axis and the rate of double-layer buildup are strongly affected by the electrolyte migration resistance in the pores [7]. Consequently, the limitation of electrolyte transport imposed by the pore structure of the carbon electrodes is considered to be one of the key issues that affects the overall performance of ECs. Vanadium pentoxide (V_2O_5) has been used as an electrode material for ECs [8,9] because of its layered structure, high capacity, and ease of preparation. Because V_2O_5 exhibits a modest electronic conductivity, composites of V_2O_5 and carbonaceous materials have been prepared in an attempt to improve electrode performance for EC applications [10–12]. In this work, we attempted to control the pore structure of CNFCs by using different loadings of V_2O_5 to optimize the electrochemical performance of the CNFCs. The morphological and electrochemical characterization of the CNFCs was performed to evaluate their electrochemical utilization in aqueous electrolytes.

2. Experimental

2.1. Materials

Polyacrylonitrile (PAN) and dimethylformamide (DMF) were purchased from Aldrich Chemical Co. (USA) and used as received without further purification. The V_2O_5 with the amorphous nanotubular structure (Fig. 1S) were synthesized according to the previously reported procedure [13].

2.2. Fabrication

Electrospinning solutions were prepared by dispersing a given amount of V_2O_5 (5, 10, and 20 wt% relative to PAN) in a 10 wt% PAN solution in DMF. The blend solution of PAN and V_2O_5 was electrospun into nanofibers using an electrospinning apparatus. Oxidative stabilization was then performed at 280 °C in air to induce thermal stability of the nanofibers. The stabilized nanofibers were then thermally treated at 800 °C in an nitrogen atmosphere. The

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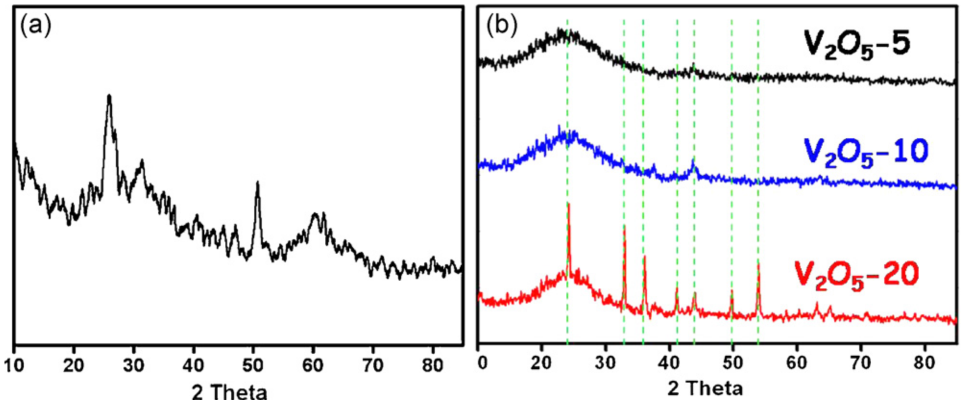

Fig. 1. XRD data of (a) as-prepared V_2O_5 and (b) CNFCs.

carbonized samples were identified as V_2O_5-5, V_2O_5-10, and V_2O_5-20, indicating concentrations of 5, 10, and 20% V_2O_5 relative to PAN, respectively. For the pristine samples, CNF without V_2O_5 were prepared.

2.3. Characterization

The crystalline structure of V_2O_5 was characterized by XRD (D-Max-2400 diffractometer), equipped with graphite monochromatized CuKα radiation ($\lambda = 0.15418$ nm). The chemical state of the pore surface was examined by XPS using a VG Scientific ESCALAB250 spectrometer equipped with a monochromatized AlK X-ray source (15 mA, 14 kV). The surface morphology of the nano-structured materials was determined by FE-SEM (Hitachi, S-4700) and TEM (Phillips, TECHNAI-F20). The porosity was investigated from the nitrogen adsorption isotherm at 77K (ASAP 2020, Micromeritics, USA). The specific surface area, the mesopore size distribution, and the micropore size distribution of the samples were evaluated using the Brunauer–Emmett–Teller (BET) method and the Barrett–Joyner–Halenda (BJH). The bulk electrical conductivity of the CNFCs was measured using a four-point probe method at room temperature. The electrical conductivity, σ, was measured by 4-point method and calculated using the equation: $\sigma = L/(wtR)$, where R is the electrical resistance in Ω, w is the sample width in cm, t is the sample thickness in cm, and L is the distance between the electrodes in cm.

2.4. Cell fabrication and measurement

The electrodes of the supercapacitor cells were fabricated with two symmetric CNFC electrodes (1.5 cm × 1.5 cm) using Ni foil as the current collector. All samples used as electrodes were cut into pieces of the web and directly used for the electrode; without adding any polymer binder, such as poly(vinylidene fluoride), or conducting agent, such as super-p, because they were fabricated as a web that enables adequate contact between the sample and the current collector. Two electrolytic solutions were studied: a 6 M KOH aqueous solution. Cyclic voltammetry (CV) of the unit cell

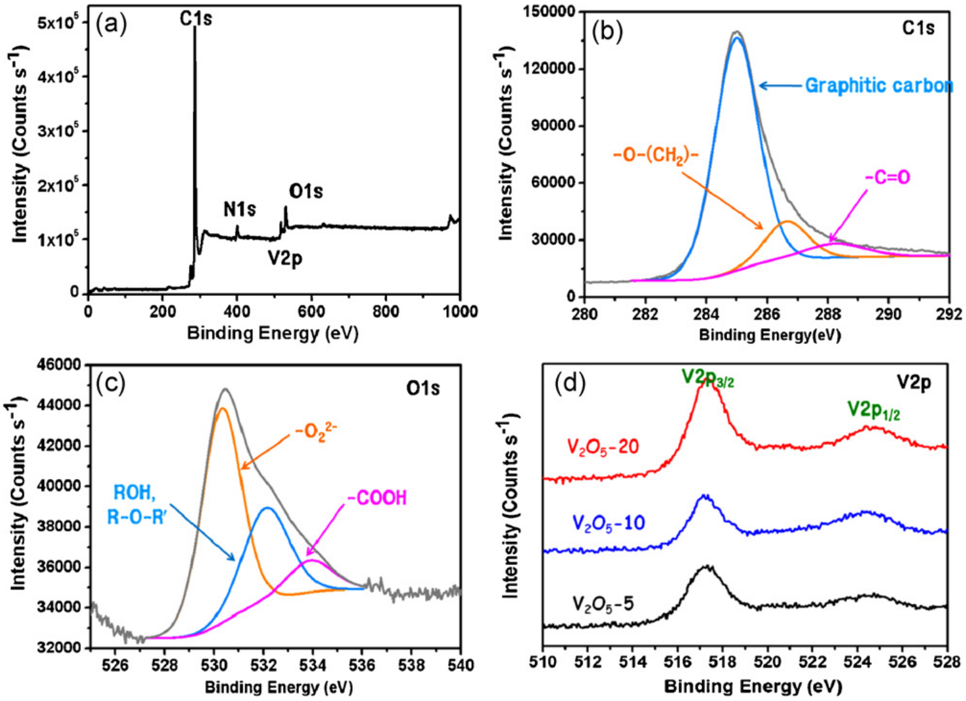

Fig. 2. (a) Wide-scan XPS. High-resolution scan for (b) C(1s), (c) O(1s) core levels of the V_2O_5-20, and (d) V(2p) XPS of the CNFCs.