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Short communication

Polymer-pyrolysis assisted synthesis of vanadium trioxide and carbon nanocomposites as high performance anode materials for lithium-ion batteries

Yucheng Dong [a,b,*], Ruguang Ma [c], Mingjun Hu [b], Hua Cheng [b], Jong-Min Lee [c], Yang Yang Li [b], Juan Antonio Zapien [a,b,*]

[a] *Center of Super-Diamond and Advanced Films (COSDAF), City University of Hong Kong, Hong Kong, China*
[b] *Department of Physics and Materials Science, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon, Hong Kong, China*
[c] *School of Chemical and Biomedical Engineering, Nanyang Technological University, Singapore 637459, Singapore*

HIGHLIGHTS

- Vanadium trioxide and carbon nanocomposites were synthesized by a simple polymer-pyrolysis assisted method.
- The metal complex atomistically distributed throughout the viscous polymer structure.
- The as-prepared vanadium trioxide and carbon nanocomposites electrode possesses superior battery performance.

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ABSTRACT

We present a simple polymer-pyrolysis assisted method to prepare vanadium trioxide and carbon nanocomposites as an advanced anode material for lithium-ion batteries. The as-prepared material deliver a superior battery performance with highly retained capacity of ~780 mAh g^{-1} over 100 cycles at a current density of 200 mA g^{-1}, showing excellent cyclic stability, and good rate capability. The improved electrochemical performance of vanadium trioxide and carbon nanocomposites electrode makes it promising as a suitable anode material for practical battery applications.

1. Introduction

In the past decade, rechargeable lithium-ion batteries (LIBs) have been extensively used as power sources for electronic devices [1]. Afterward, an increasing attention was diverted to explore suitable power supplies for electrical/hybrid vehicles thus greatly increasing market demand for materials with high specific capacity, durable cyclic stability, good rate capability and cost-effective to replace the commercially successful graphitic anode (372 mAh g^{-1}). As a result, intense research aims to explore new electrode materials with enhanced electrochemical performance for LIBs. Transition-metal oxides, such as Fe_3O_4, Co_3O_4 and MoO_3, have been widely investigated as potential anode materials for LIBs due to their high theoretical capacity [2–4]. Among them, vanadium trioxide (V_2O_3) has been identified as a viable candidate for LIBs because of its high theoretical capacity (1070 mAh g^{-1}), low toxicity and natural abundance [5]. However, progress on the application of V_2O_3 as anode material in LIBs lags behind other transition-metal oxides due to its perceived disadvantage resulting from its poor conductivity [6]. Therefore, to improve the conductivity of V_2O_3, conductive carbon has to be incorporated into the system, which also serves as cushion layer to accommodate the volume change during the cycle processes.

Herein, we report a polymer-pyrolysis assisted route to prepare vanadium trioxide and carbon nanocomposites (V_2O_3/C NCs). Compared with carbon free V_2O_3 nanoparticles (C-free V_2O_3 NPs)

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* Corresponding authors. Center of Super-Diamond and Advanced Films (COSDAF), City University of Hong Kong, Hong Kong, China.
E-mail addresses: yc-d@hotmail.com (Y. Dong), apjazs@cityu.edu.hk (J.A. Zapien).

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electrode prepared under the same experimental conditions, the as-prepared V_2O_3/C NCs electrode possesses much better electrochemical performance, such as high specific capacity, excellent cyclic stability, and good rate capability.

2. Experimental

The V_2O_3/C NCs were synthesized by a simple polymer-pyrolysis assisted method as follows. First, 0.81 g oxalic acid ($H_2C_2O_4$) and 0.54 g commercial vanadium pentoxide (V_2O_5) were dissolved in 5 mL distilled water under stirring at room temperature until the color of the solution changed from yellow to blue [7]. Then, 0.25 g glucose ($C_6H_{12}O_6$) and 0.45 g polyethylene oxide (PEO, Relative molecular mass: 500000) were successively added to the above solution under active stirring at 60 °C until a homogeneous viscous liquid was obtained. The general idea is to distribute the metal complex atomistically throughout the viscous polymer structure so that the precursor solution generates in situ a polar mesoporous carbonaceous material during the evaporation process [8]. Next, the resulting viscous liquid was dried at 80 °C for 24 h to complete dehydration and form a well-distributed polyacrylate. Finally, the obtained copolymeric product was annealed at 600 °C for 3 h under argon atmosphere.

Phases of the products were characterized by micro-area X-ray diffraction (XRD, Philips X'Pert MRD). Raman spectroscopy (Renishaw 2000, Raman microscope with 633 nm argon ion laser) was employed to verify chemical bonding characteristics of V_2O_3 and carbon. The morphological characteristics of V_2O_3/C NCs were investigated by scanning electron microscopy (SEM, Philips, XL 30FEG). The electrochemical measurements were performed using coin cells (2032) with lithium foil as counter electrode. The working electrodes were prepared by mixing the active material (V_2O_3/C NCs), acetylene carbon black and polyvinylidene fluoride (PVDF) with a weight ratio of 80:10:10 dissolved in 1-methyl-2-pyrrolidinone (NMP) to form a slurry which was uniformly coated on copper foil and dried at 100 °C for 8 h in a vacuum oven. Celgard 2032 (Celgard, Inc., USA) served as the separator and a solution of 1 M $LiPF_6$ in ethylene carbonate/dimethyl carbonate (EC:DEC = 1:1, v/v) as the electrolyte.

Cyclic voltammograms (CV) were obtained on a CHI-660C electrochemical workstation, on which electrochemical impedance spectroscopy (EIS) measurements were also conducted in a frequency range from 10 mHz to 100 kHz with a potentiostatic signal amplitude of 5 mV. Galvanostatic discharge/charge cycling measurement was performed on an Arbin Instruments (BT 2000, College Station, Texas, USA) battery test system at various C rates ($1C = 1000\ mA\ g^{-1}$) between 5 mV and 3 V versus Li^+/Li at room temperature. Note that the mass of carbon was included when calculating the capacity of V_2O_3/C NCs.

3. Results and discussion

Fig. 1(a) shows the morphology of the V_2O_3/C NCs. The voids can be observed between particles, which were produced by CO and CO_2 release when the precursor decomposed during annealing process [7]. It has been suggested that the voids enable rapid electrolyte transport and consequently more efficient ion diffusion and better energy storage [9]. The crystalline structure of the V_2O_3/

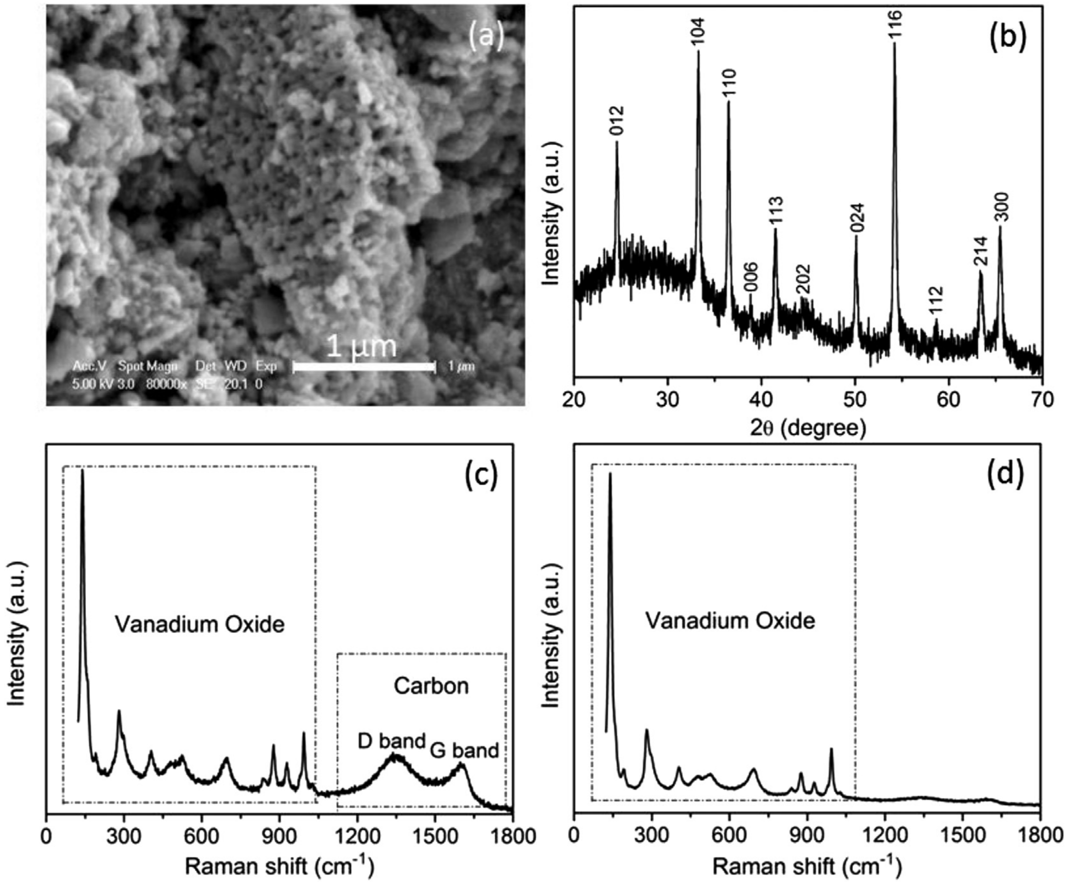

Fig. 1. (a) SEM image and (b) XRD pattern of V_2O_3/C NCs; Raman spectra of (c) C-free V_2O_3 NPs and (d) V_2O_3/C NCs.