

# Facile synthesis of vanadium oxide microspheres for lithium-ion battery cathodes



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## ABSTRACT

A simple and versatile method for preparation of non-solid and solid V<sub>2</sub>O<sub>5</sub> microspheres is developed. Non-solid and solid V<sub>2</sub>O<sub>5</sub> microspheres can be controllably prepared via adjusting the mixed solvent volume ratio and reaction time at low temperature. Solid V<sub>2</sub>O<sub>5</sub> microspheres display higher discharge capacity and better cycling performance than non-solid V<sub>2</sub>O<sub>5</sub> microspheres as a cathode material for lithium-ion batteries, which is ascribed to smaller charge transfer and diffusion resistance.

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## 1. Introduction

Nowadays, there is a remarkable demand for rechargeable batteries with reversible and efficient electrochemical energy storage and conversion in the field of portable electronic consumer devices, electric vehicles, and large-scale electricity storage in smart and intelligent grids [1]. The lithium – ion battery is one of the promising rechargeable batteries for high-power applications in electric vehicles [2].

Vanadium oxides offer the advantages of being cheap, easy to synthesize, plenty of the earth and high-energy density. Therefore, they have attracted much attention in energy conversion and storage. Amongst vanadium oxides, V<sub>2</sub>O<sub>5</sub> is a potential cathode material for lithium-ion batteries, owing to high energy density. However, the cycling stability of V<sub>2</sub>O<sub>5</sub> is not good due to irreversible transformation of Li<sub>x</sub>V<sub>2</sub>O<sub>5</sub> to the  $\gamma$ -phase when more than one lithium ion are intercalated to per V<sub>2</sub>O<sub>5</sub>, which result in the decrease of the amount of cycled lithium, diffusion coefficient of lithium, and dissolution of vanadium cycled at high discharge rates [3]. So far, various measures have been taken to improve the cycling performance of V<sub>2</sub>O<sub>5</sub>, for example, fabricating V<sub>2</sub>O<sub>5</sub> nano-

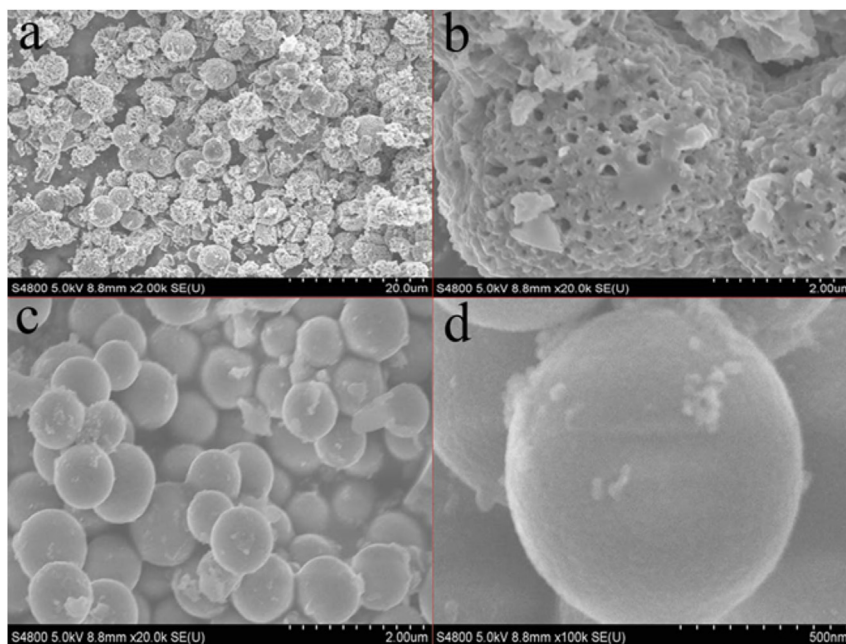
structures [4–7], and coating carbon [8–11] and polymer to the surface of V<sub>2</sub>O<sub>5</sub> [12].

Recently, a particular attention has been paid to prepare V<sub>2</sub>O<sub>5</sub> hollow spheres with different building blocks via various methods with application to lithium-ion batteries [13–16] and photocatalysis [17]. It is reported that the porous V<sub>2</sub>O<sub>5</sub> with interconnected pore networks has shown excellent rate capability as a cathode material for lithium-ion batteries, which is because of the interconnected pore networks facilitating the kinetics of lithium-ion diffusion [18]. Monodisperse and porous V<sub>2</sub>O<sub>5</sub> microspheres also show a greatly improved electrochemical performance, such as highly reversible lithium storage capacity, good cycling stability, and low-temperature behavior [19]. The V<sub>2</sub>O<sub>5</sub> hollow microsphere graphene composite also displayed highly reversible specific capacities, good cycling stabilities and excellent rate capabilities [20].

However, the above-mentioned hollow and porous V<sub>2</sub>O<sub>5</sub> microspheres were prepared at high temperature above 300 °C. It is important to find a simple method to prepare V<sub>2</sub>O<sub>5</sub> microspheres with adjustable porosity at low temperature. It is well known that the hydrothermal method is a facile way to obtain nanostructured materials with good electric and optic properties [21–23]. Herein, we report a simple and versatile soft template route for preparation of non-solid and solid V<sub>2</sub>O<sub>5</sub> microspheres at low temperature. Non-solid and solid V<sub>2</sub>O<sub>5</sub> microspheres can be controllably prepared via adjusting the volume ratio of surfactant to solvent as well as

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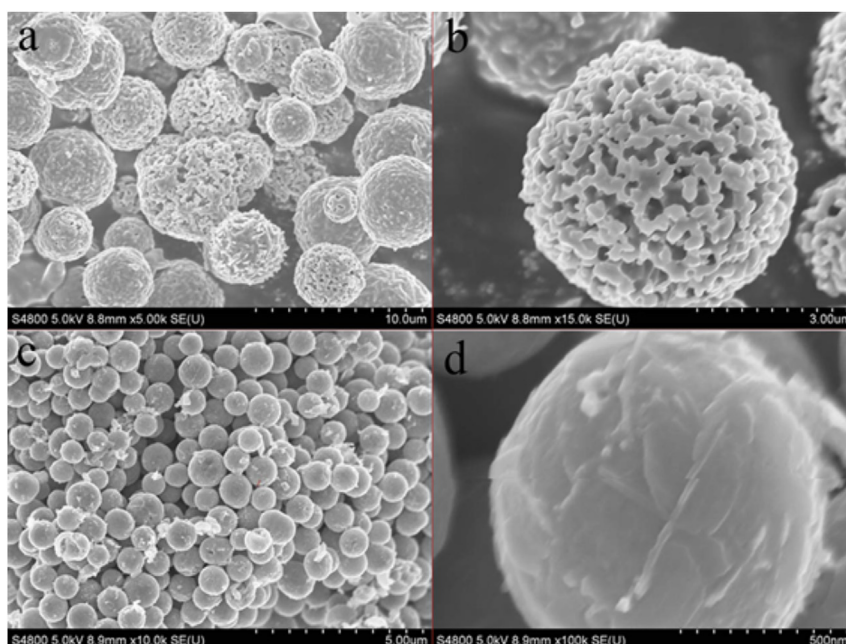
**Fig. 1.** SEM images of samples prepared without calcinations at different volume ratio of PEG 400 to EG (a, b) 1, (c, d) 2.

reaction time. A possible mechanism for the formation of non-solid and solid microspheres is proposed. Their electrochemical performances were evaluated as cathode materials for lithium-ion batteries. This simple two-step route would be of significance to design hollow and solid metal oxide microspheres with advanced functions.

## 2. Experimental

All chemicals (analytical grade reagents) were commercially available and used without further purification. Solid  $V_2O_5$

microspheres were prepared according to the following procedure. 1.25 mmol oxalic acid was dissolved in the mixture of 20 ml polyethylene glycol 400 (PEG 400, HO(CH<sub>2</sub>CH<sub>2</sub>O)<sub>400</sub>H) and 10 ml ethylene glycol, and then 6 mmol ammonium vanadate (NH<sub>4</sub>VO<sub>3</sub>) was added into the solution under stirring at room temperature. After that, the mixture solution was transferred into a 50-ml Teflon-lined stainless autoclave, sealed, kept at the 200 °C for 24 h and cooled to room temperature. The precursor was filtered, washed with absolute ethanol, and dried at 70 °C for 12 h. The dried precursors were heated at 200 °C for 5 days. When 15 ml polyethylene glycol 400 and 15 ml ethylene glycol were used and the autoclave was kept at 200 °C for 1 h, porous precursors were obtained. Non-



**Fig. 2.** SEM images of the calcined samples prepared at different volume ratio of PEG 400 to EG (a, b) 1, (c, d) 2.

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