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Dimension meditated optic and catalytic performance over vanadium pentoxides

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ABSTRACT

Morphologies and sizes of V_2O_5 had crucial effect on their optic and catalytic performance. Diverse dimensional V_2O_5 were successfully synthesized by the combination of a hydrothermal and post heat treatment method. The as-obtained samples were characterized by X-ray power diffraction, scanning electron microscopy, transmission electron microscopy and Raman spectra. Moreover, the optic properties of diverse dimensional V_2O_5 were examined by Fourier transform imaging spectrometer and UV–vis-spectrophotometer. It showed that the IR transmittance of nanowire (at 1019 cm^{-1} is 85%) and UV absorbance of microflowers (at 480 nm) were high. Furthermore, the catalytic properties of diverse dimensional V_2O_5 on the thermal decomposition of ammonium perchlorate were evaluated and compared by Thermo-Gravimetric Analysis and Differential Scanning Calorimetry. Moreover, the best catalytic performance was obtained with the morphology of nanowire. It showed the thermal decomposition temperatures of AP with nanowire, microflowers and microsphere were reduced to 373 °C, 382 °C and 376 °C (decreased by 52 °C, 43 °C and 49 °C).

1. Introduction

Vanadium-based oxides had received considerable attention over the years due to their abundance in nature, diverse novel properties, chemical structures, and potential applications. Vanadium element which existed in abundant oxidation states (from +2 to +5), consisting of a variety of single-valence and mix-valence oxides including VO_2 [1,2], V_2O_3 [3], V_2O_5 [1,4,5], V_3O_7 [6], V_4O_7 [7], and V_6O_{13} [8]. Vanadium pentoxide (V_2O_5), the most stable condition in the family of vanadium-based oxides, had been at the forefront of both fundamental and applied research due to its potential applications in lithium-ion batteries [9–11], super capacitor electrodes [12,13], infrared detector [14], visible light photochromism [15], catalysis [4] and so on. To our best knowledge, using various methods prepared V_2O_5 structures existed diverse dimensional morphologies including hollow spheres [10], microspheres [11], nanowires [4,5], nanobelts [16], nanosheets [13,17], nanotubes [18], nanofibers [14], nanorods [19], microflowers [9,13] and so on. Among many synthetic methods, the hydrothermal method was the most well-known approach which composed of simple processes such as preparation of solution, heat treatment and collection of reaction products. Moreover, the macroscopic properties of the V_2O_5 nanocrystallines strongly depended on their morphologies and sizes.

As we know, there was no report investigating on FTIR, UV–vis and catalyst properties with diverse dimensional V_2O_5 although many morphologies had long been focus of research. Herein, in our study zero-dimensional (0-D) materials (V_2O_5 microsphere), one-dimensional (1-D) materials (V_2O_5 nanowires), three-dimensional (3-D) materials (V_2O_5 microflowers) were prepared via the simple hydrothermal and post heat treatment method. The as-obtained samples were characterized by XRD, SEM, TEM and Raman spectra. Moreover, the optic properties of diverse dimensional V_2O_5 were examined by FT-IR and UV–vis. Furthermore, the catalytic properties of diverse dimensional V_2O_5 on the thermal decomposition of ammonium perchlorate (AP) were evaluated and compared by TGA and DSC. It was the first report about synthesis, analysis and comparison of optic and catalytic performance with diverse dimensional V_2O_5 morphologies. Compared with diverse dimensional V_2O_5 morphologies, the IR transmittance of nanowire (at 1019 cm^{-1}) and UV absorbance of microflowers (at 480 nm) were

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high. As for catalytic properties, nanowires presented excellent behavior concerning the thermal decomposition performance of AP. The optic and catalytic properties of these diverse dimensional morphologies indicated the close relationship between the microstructure and macro-properties.

2. Experimental

Synthesis of V_2O_5 nanowire: 3.3 mmol of bulk V_2O_5 (0.6 g) was dissolved in 20 mL of deionized (DI) water, followed by magnetic stirring for 30 min. Subsequently, 15 mL of H_2O_2 (30 wt%) was added into the solution, which was under ultrasonic for 10 min at room temperature. When the mixture turned into brown liquid, the vanadium precursor was transferred into a 50 mL Teflon lined stainless steel autoclave and kept in an electric oven at 180 °C for 10 h.

Synthesis of V_2O_5 microflowers: 3 mL of DI water and 20 mL of ethylene glycol (EG) were dispersed with magnetic stirring for 10 min, followed by the addition of bulk V_2O_5 (0.18 g). After ultrasonic for 20 min, 0.5 mmol acetylacetone vanadium (IV) oxide bis (2,4-pentanedionate) ($VO(acac)_2$, 0.13 g, ≥99.0%, Alfa Aesar) was added into the mixture with magnetic stirring for 20 min. Then the mixture was transferred into a 50 mL Teflon lined stainless steel autoclave and kept in an electric oven at 200 °C for 12 h.

Synthesis of V_2O_5 microsphere: 0.7 mmol of $VO(acac)_2$ (0.19 g) and 0.25 mmol of PVP (0.25 g, Mr = 10000, Tianjin Bodi Chemical Ltd.) were dispersed in 30 mL of EG to obtain a suspension solution with magnetic stirring for 10 min. After ultrasonic for 1 h the suspension solution turned clear, which indicated the formation of vanadium precursor. Then the mixture was sealed in a steel autoclave and kept in an electrical oven at 180 °C for 10 h.

When all the reactions were finished, the precipitates were filtered off, washed with anhydrous alcohol and DI water for three times and one time, respectively, followed by dried in vacuum at 60 °C for 24 h. Then they were annealed in air at 350 °C for 2 h.

The structure of the samples was examined by X-ray diffraction (XRD, D8/ADVANCE diffractometer, Cu Kαλ = 1.5418 Å) and Raman spectra (HR800, laser power: 1 mW, excitation wavelength: 633 nm). The morphology was observed using a field emission scanning electron microscope (SEM, S-4800, Hitachi) and transmission electron microscope (TEM, JEM-2100F). The properties of infrared and visible light were examined by Fourier transform imaging spectrometer (FTIR, Nicolet iS50, Thermo SCIENTIFIC) and UV–vis-spectrophotometer (UV–vis, UV3600, Shimadzu). To test the catalytic effect of V_2O_5 with diverse dimensional morphologies on the thermal decomposition of AP, the mixture of AP and V_2O_5 was carefully ground for 10 min and was detected by a Differential Scanning Calorimeter (DSC) and Thermo Gravimetric Analysis (TGA, N33-TG 209F3) using a STA 449C thermal analyzer with a heating rate of 10 °C/min in N_2 atmosphere over the temperature range of 30–500 °C. The mass percentage of V_2O_5 samples to AP in the mixture was 4%.

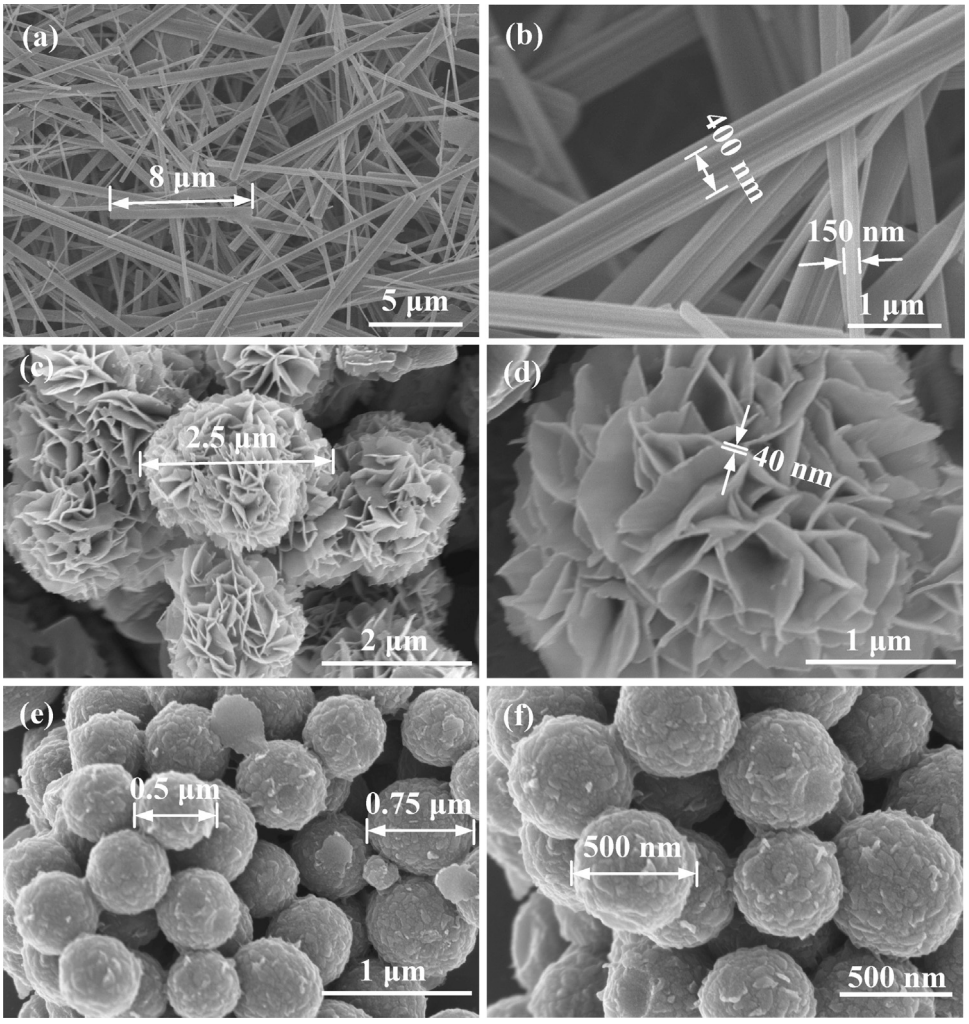

Fig 1. SEM images of as-synthesized V_2O_5 with diverse dimensional morphologies: nanowire (a, b), microflowers (c, d) and microsphere (e, f).