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Hydrothermal synthesis of cerium titanate nanorods and its application in visible light photocatalysis

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ABSTRACT

Cerium titanate nanorods have been prepared via a hydrothermal process using sodium dodecyl sulfate (SDS) as the surfactant. The cerium titanate nanorods have been analyzed by X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), high-resolution TEM (HRTEM), and ultraviolet–visible (UV–vis) diffuse reflectance spectrum. XRD shows that the nanorods are composed of $CeTi_{21}O_{38}$ phase. Electron microscopy observations indicate that the nanorods have good single crystalline nature. The diameter and length of the nanorods are about 50–200 nm and 1–2 μm, respectively. Cerium titanate nanorods have a band gap of 2.65 eV. The photocatalytic activities of the nanorods have been investigated by degrading methylene blue (MB) under visible light irradiation. MB solution with the concentration of 10 mg L^{-1} can be degraded totally with the irradiation time increasing to 240 min. Cerium titanate nanorods exhibit great potential in photocatalytic degradation of MB under visible light irradiation.

1. Introduction

Great effort has been devoted to photocatalytic technology for the degradation of environmental pollution in recent years. Titanium dioxide based photocatalysts take the advantages of low cost, non-toxicity and high photocatalytic acivity under ultraviolet (UV) light irradiation. However, titanium dioxide with broad bandgap of 3.2 eV for anatase has low separation and migration efficiency of electron–hole pairs and light absorbing with narrow bands restricting large-scale application for the degradation of organic pollutes under UV light irradiation [1]. Therefore, it is important to explore the photocatalysts for the degradation of organic pollutes under visible light irradiation.

Cerium titanate is a kind of important rare-earth titanate and exhibits great potential in the fields of photocatalysts and optical devices. Several cerium titanate phases exist in the Ce–Ti–O system. For example, cerium titanate with Ce_2TiO_5, $Ce_2Ti_2O_7$, $Ce_4Ti_9O_{24}$, $CeTiO_4$, and $CeTi_2O_6$ phases have been prepared by solid phase reaction at high temperature [2,3]. Matsuo et al. [4] reported the synthesis of $CeTiO_4$ by the oxidation of the precursor $Ce_2Ti_2O_7$. $CeTiO_4$ was found to exert a relatively high photocatalytic activity for the degradation of environmental pollutes, such as methylene blue (MB) under visible light irradiation.

Morphology control of the photocatalysts is usually one of the important research directions for the photocatalytic degradation of organic pollutes [5]. The nanostructures of the photocatalysts have an important role in the migration of the electrons and holes. Many new types of nanoscale photocatalysts, such as titanate nanotubes [6], nanofibers [7], and nanosheets [8] have been reported showing smaller band gap and better photocatalytic properties than bulk materials. It has been reported that bulk cerium titanate with $CeTiO_4$ phase has definite photocatalytic degradation ability for MB [4]. The photocatalytic properties are considered to be enhanced by decreasing the size of the cerium titanate, such as cerium titanate nanorods under visible light irradiation.

In the paper, cerium titanate nanorods have been synthesized by a simple hydrothermal process using sodium dodecyl sulfate (SDS) as the surfactant. The structure, morphology, size, and photocatalytic properties of the cerium titanate nanorods have been analyzed by X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), high-resolution TEM (HRTEM), and UV–vis diffuse reflectance spectrum. The growth condition dependence on the formation of the cerium titanate nanorods and possible growth mechanism has also been analyzed. MB is a kind of ionic heterocyclic organic compound and has relatively high molecular weight, high biochemical stability, and high water solubility. However, MB

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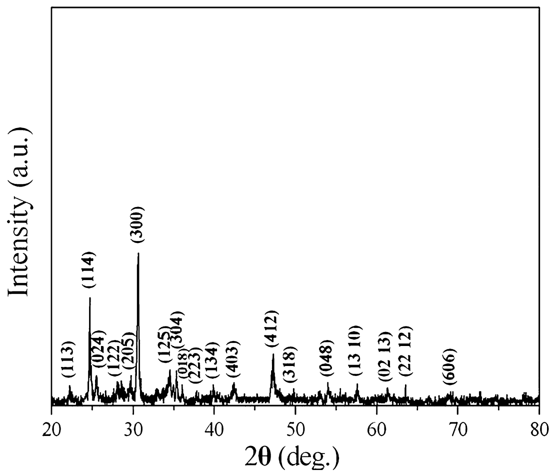

Fig. 1. XRD pattern of the cerium titanate nanorods.

can cause permanent injury to humans and animals on inhalation and ingestion [9]. Therefore, the photocatalytic properties have been evaluated using MB as the target pollutant under visible light irradiation. The cerium titanate nanorods exhibit great potential in the photocatalytic field for the degradation of MB.

2. Experimental

All raw materials are AR grade and used without any further treatment. Cerium acetate (AR grade), titanium butoxide ($C_{16}H_{36}O_4Ti$, AR grade) and sodium dodecyl sulfate (SDS, AR grade) were purchased from Aladdin Reagent Co. Ltd. of PR China. In a typical procedure, 0.75 g cerium acetate, 0.4 g titanium butoxide and SDS with different concentrations were dissolved in 60 mL deionized water, respectively under vigorous stirring. Then, the mixture was placed in a 100 mL autoclave with a Teflon liner. The autoclave was maintained at 80–180 °C for different reaction times. Subsequently the autoclave was cooled naturally in air. The obtained white precipitates were filtered, washed with deionized water for several times and dried at 60 °C in air. Finally, white cerium titanate powders were obtained.

The products were characterized by XRD, SEM, TEM, HRTEM, and UV–vis diffuse reflectance spectrum. XRD pattern was carried out on a Bruker AXS D8 X-ray diffractometer equipped with a graphite monochromatized Cu-Kα radiation (λ = 1.5406 Å). The samples were scanned at a scanning rate of 0.05°/s in 2θ range of 20–80°. SEM observation was performed using JEOL JSM-6490LV SEM with a 15-kV accelerating voltage. TEM and HRTEM samples were prepared by putting several drops of solution with cerium titanate nanorods onto a standard copper grid with a porous carbon film after the nanorods samples were dispersed into distilled water and treated for about 10 min using supersonic wave apparatus. TEM and HRTEM observations were performed using

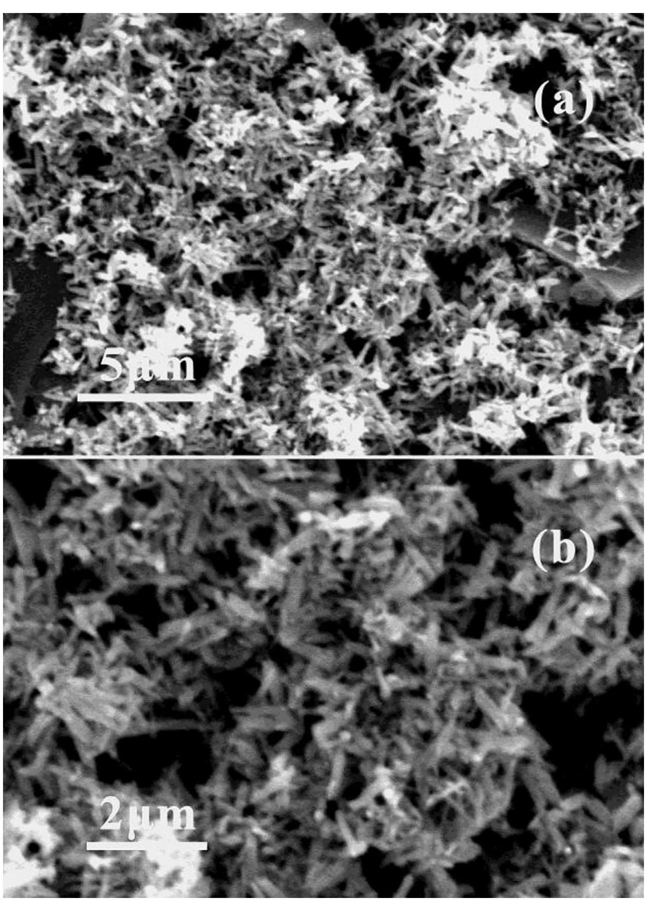

Fig. 2. SEM images of the cerium titanate nanorods with different magnifications.

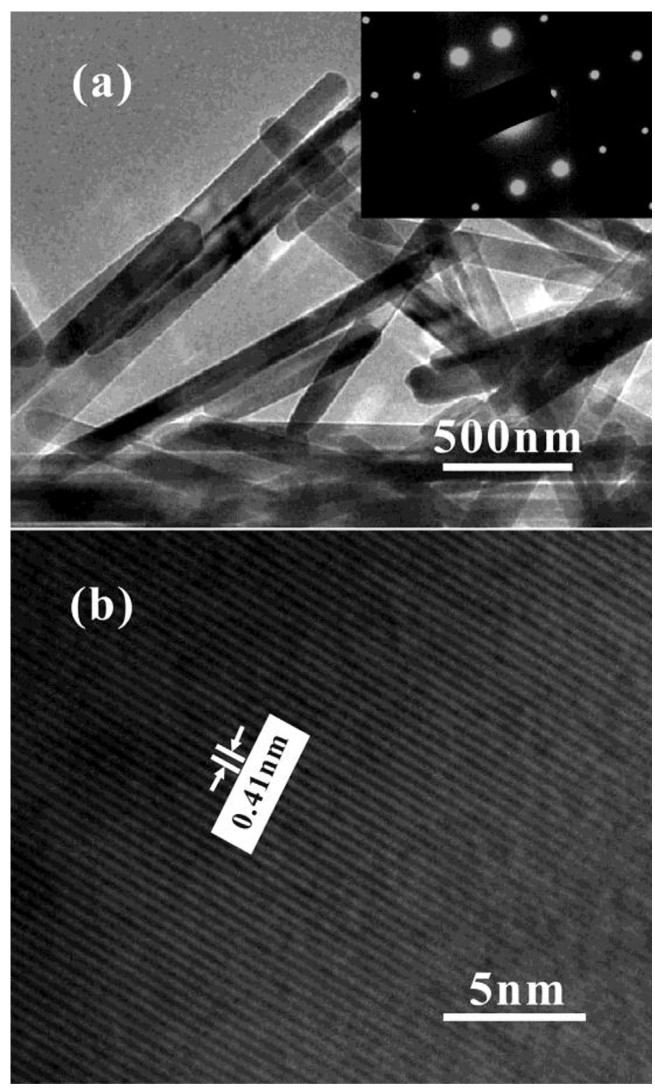

Fig. 3. Transmission electron microscopy images of the cerium titanate nanorods. (a) TEM image, the inset in the upper-right part is the SAED pattern. (b) HRTEM image.