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Killing two birds with one stone: To eliminate the toxicity and enhance the photocatalytic property of CdS nanobelts by assembling ultrafine TiO_2 nanowires on them

Xin Yu[a], Na Ren[a], Jichuan Qiu[b], Dehui Sun[a], Linlin Li[c,*], Hong Liu[a,b,**]

[a] Institute for Advanced Interdisciplinary Research, University of Jinan, Jinan 250022, PR China
[b] State Key Laboratory of Crystal Materials Shandong University, Jinan 250100, PR China
[c] Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences, Beijing 100083, PR China

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ABSTRACT

Although CdS has been proven to be one of the best photocatalysts in visible light region, its photocorrosion characteristics and toxicity prohibit its practical applications in photocatalytic hydrogen generation and photodegradation of organic pollutants in waste water. In addition, the photocatalytic efficiency of single phase CdS nanostructure is still low due to the recombination of photo-induced carriers. In this paper, a facile modification of CdS nanobelts approach is proposed by assembling TiO_2 nanowire on the surface of CdS nanobelts to form TiO_2 nanowire/CdS nanobelt hybrid nanstructures. This approach can kill two birds with one stone, that is, to eliminate the photocorrosion induced nontoxicity, and enhance photocatalytic properties by inducing UV light active TiO_2 nanowires, and enhance the photo-induced carrier separation ability. The cell cyto-compatibility experiments on TiO_2 nanowire/CdS nanobelt hybrid photocatalyst proved that the toxicity of CdS nanobelts can be totally eliminated. At the same time, photodegradation performance of for CdS/TiO_2 is over 3 times of that for CdS nanobelts and10 times of that for TiO_2. This work gives a new insight in the field of photocatalytic water treatment.

1. Introduction

Recently, the problems of environmental pollution have become increasingly serious, posing a great threat to sustainable development and human health [1–7]. When a photocatalyst absorbs light, it generates electron-hole pairs so that electrons and holes can react with the pollution in water [8–10]. Photocatalysis is bound to play a key role for the search toward water treatment [11–19]. Among the reported photocatalysts, CdS has become one of the most widely used semiconductors due to its ideal band gap energy (2.4 eV) and band positions. It can drive both oxidation and reduction of water under visible light irradiation, which has attracted extensive attention in degradation of organic pollutants, production of H_2 and O_2 from water and photocatalytic conversion of CO_2 [20–23].

Photocatalytic degradation of organic pollutants by using nanostructured CdS offers great potential for the complete elimination of toxic chemicals. However, CdS has two key disadvantages, photocorrosion derived bio-toxicity, and low photocatalytic efficiency caused by photo-induced carrier separation. CdS is hazard to the environment, can cause pollution of water bodies [24–26]. The most challenging aspect of working with these materials in biological systems, is related to toxicity that can result from the decomposition and release of heavy metal ions and/or ligand moieties [27–29]. Therefore, it is absolutely vital to develop a suitable method to solve the above problems.

Recently, CdS has also been combined with other materials such as ZnO, TiO_2, MoS_2 compounds in attempt to improve the photo-efficiency and photo-stability [30–40]. For example, Liu et al. have reported a layer by layer self-assembly approach to synthesize graphene-CdS films with enhanced photocatalytic activity and photostability [41]. Zhang et al. have developed a facile one-pot wet-chemical method to prepare MS_2-CdS (M = W, Mo) nanohybrids with high stability and recyclability [42]. Nevertheless, the problem of high toxicity of CdS is rarely reported and is often overlooked.

Herein, a facile method can realize killing two birds by one stone. By assembling TiO_2 nanowires on CdS nanobelts to form hybrid photocatalysts, photocorrosion can be overcome relying on the UV light blocking effect of TiO_2 nanowire, which has been proved by cell experiment. At the same time, photocatalytic performance of CdS

* Corresponding author.
** Corresponding author at: Institute for Advanced Interdisciplinary Research, University of Jinan, Jinan 250022, PR China.
E-mail addresses: lilinlin@binn.cas.cn (L. Li), hongliu@sdu.edu.cn (H. Liu).

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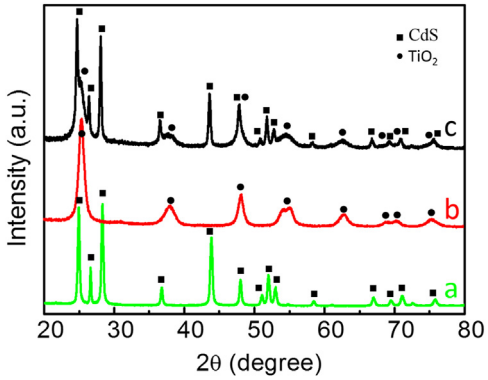

Fig. 1. XRD patterns of curve a: CdS nanobelts, curve b: TiO_2 ultrafine nanowires, and curve c: TiO_2 nanowire/CdS nanobelt hybrid photocatalyst.

nanowirs has been enhanced by the carrier separation effect of TiO_2 nanowire/CdS nanobelt hybrid nanstructures. The reaction constant rate of CdS/TiO_2 is up to 0.0346 min^{-1} under visible light, which is about 3 times greater than that of pure CdS nanobelts and about 10 times that of TiO_2 ultrafine nanowires.

2. Results and discussions

The phase purity and crystal structure of the obtained samples were examined by X-ray diffraction (XRD) spectra. Fig. 1 curve a depicts the XRD pattern of CdS nanobelts, with the diffraction peaks matching this of hexagonal wurtzite CdS (JCPDS card, no. 41–1049) [43,44]. For TiO_2 nanowires (Fig. 1 curve b), the detected peak positions are consistent with standard anatase TiO_2 (JCPDS card, no. 73–1764) [45–47]. For TiO_2 nanowire/CdS nanobelt hybrid photocatalysts (Fig. 1 curve c), all the diffraction peaks can be indexed to either CdS or TiO_2. The broad and weak diffraction peaks of the TiO_2 nanowire/CdS nanobelt hybrid photocatalysts indicate that the crystallinities are slightly reduced in comparison with single phase TiO_2 and CdS. This result may be attributed to lattice distortion induced by interfacial strain because of the different lattice parameters between CdS and TiO_2. The defects may affect photocatalysis by effective capture of the photoexcited electrons, and thus inhibit the recombination of the photoexcited electrons and holes [48].

Fig. 2a and b show typical SEM images of the CdS nanobelts. The CdS exhibit the 1D morphology with ca. 35 nm wide, 5–10 nm in thickness and lengths range up to several micrometers. The shape and dimension of the TiO_2 ultrafine nanowires grown at the surface of the CdS nanobelts (Fig. 2c) are identical to those of the individually synthesized TiO_2 ultrafine nanowires. These ultrafine nanowires cover the whole surface of the CdS nanobelt, forming a kell-shell TiO_2 nanowire/CdS nanobelt hybrid photocatalysts, as shown in Fig. 1d. Interestingly, the small size and homogeneous distribution of the TiO_2 nanowires will increase the effective surface area available for the photocatalytic reaction. Furthermore, this photocatalyst is designed so that the UV light is absorbed by the TiO_2 at the shell, whereas visible light can reach the CdS core, thus leading to an efficient use of the white light spectrum.

In order to further visualize the morphology and microstructure of the as-prepared TiO_2 nanowire/CdS nanobelt hybrid photocatalysts, transmission electron microscopy (TEM) has been employed to investigate blank CdS nanobelts and the TiO_2 nanowire/CdS nanobelt

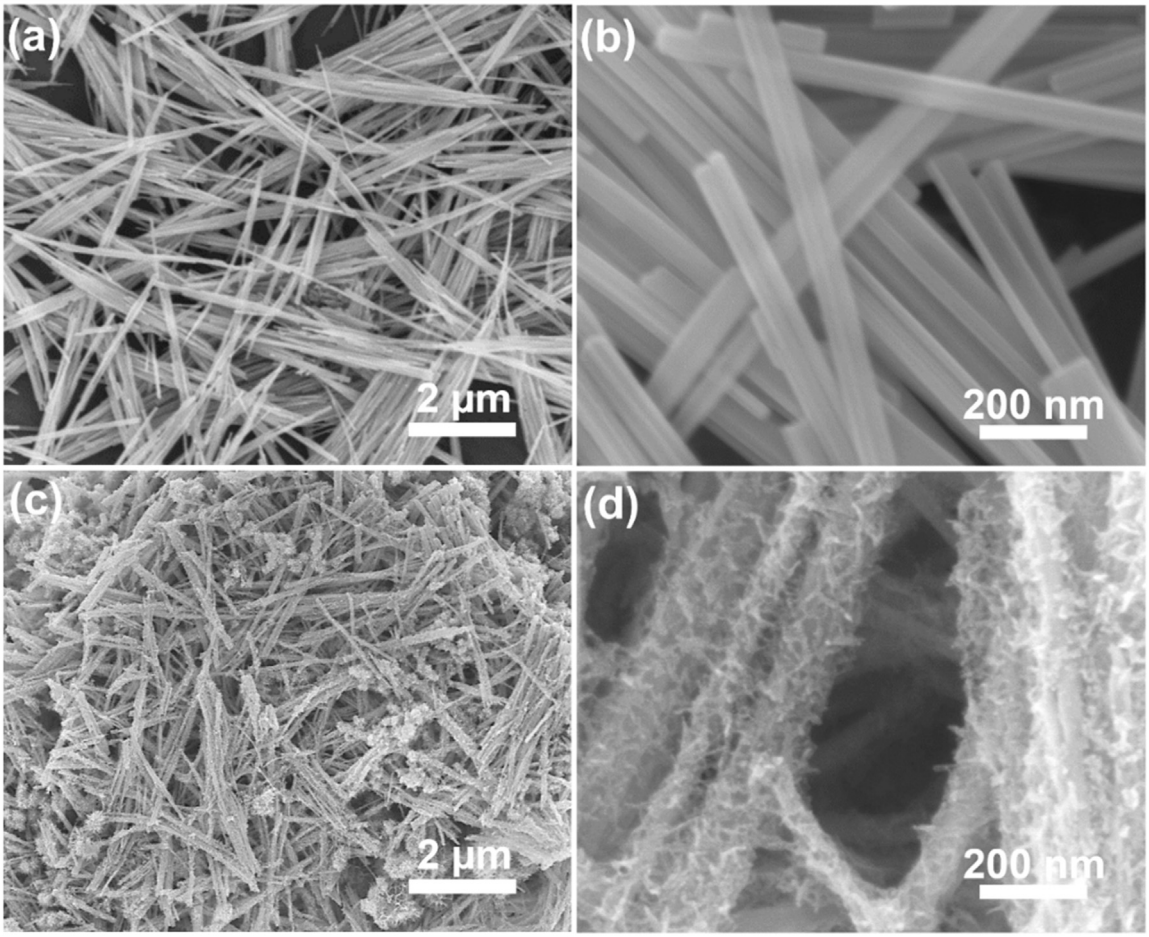

Fig. 2. SEM images of (a, b) CdS nanobelts, (c, d) TiO_2 nanowire/CdS nanobelt hybrid photocatalyst.