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Fabrication of dumbbell-like CdTe/Au nanohybrids

Hongchao Ma, Xiangtao Bai, Liqiang Zheng *

Key Laboratory of Colloid and Interface Chemistry, Shandong University, Ministry of Education, Jinan 250100, China

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ABSTRACT

Dumbbell-like CdTe/Au nanohybrids were synthesized by assembly of CdTe quantum dots with the assistance of $AuCl_4^-$ in aqueous solution. The products were characterized by TEM and SEM techniques. The images reveal that dumbbell-like nanostructures with uniform size were well formed. The dumbbell-like nanostructures were further characterized by HRTEM and EDX spectrum. The results indicate that the as-prepared dumbbell-like nanostructures were composed of CdTe quantum dots and Au nanoparticles. The effect of $HAuCl_4$ concentration on the morphology of the products was also investigated, which shows that the morphology of the products evolved from sheaf-like nanostructures to rod-like nanostructures and finally dumbbell-like nanostructures as the $HAuCl_4$ concentration increased. Based on the above results, a possible mechanism for the formation of dumbbell-like CdTe/Au nanohybrids is proposed.

1. Introduction

Great success has been achieved in the synthesis of single-component nanomaterials with controlled size and morphology [1–3]. However, with the development of the material science and technology, the single-component nanomaterials cannot meet the needs nowadays, thus researchers begin to fabricate nanohybrids with various composition through physical or chemical methods [4,5]. During the past decades, nanohybrids containing semiconductor nanocrystals and other functional nanomaterials have attracted extensive attention due to their unique photoluminescence property and potential application in photoconducting device and biological tag. One useful hybrid nanomaterial based on semiconductor nanocrystals is semiconductor–metal nanohybrid. Banin et al. reported selective growth of Au tips onto CdSe nanorods and tetrapods and found that the synthesized nanohybrids showed modified optical properties [6]. Since then, various kinds of semiconductor–Au nanohybrids such as PbSe/Au [7], TiO_2/Au [8] and InAs/Au [9] were synthesized. These nanostructures changes from two-sided to one-sided growth which were attributed to the electrochemical Ostwald ripening mechanism [10,11]. Kamat et al. prepared Ag@TiO_2 core–shell clusters under UV-Irradiation and found that these nanohybrids were photocatalytically active and useful to promote light induced electron-transfer reactions [12,13]. ZnO nanorods decorated with Ag tips have also been synthesized by Weller et al. [14]. Apart from Au and Ag, magnetic metal such as Co was also used to form nanohybrids with semiconductors. Recently, Maynadié et al. reported the synthesis of CdSe–Co nanohybrids through the growth of Co nanospheres on the preformed CdSe nanorods [15]. These semiconductor–metal nanohybrids have excellent photocatalytic properties due to their tendency of light-induced charge separation in the materials and the catalytic properties of the metal part [16,17]. In this work, we report a facile synthesis of dumbbell-like CdTe/Au nanostructures at room temperature. These dumbbell-like nanostructures are formed by assembly of CdTe quantum dots with the assistance of $AuCl_4^-$. This approach is useful to design and prepare other hybrid nanomaterials.

2. Experimental section

2.1. Synthesis of dumbbell-like CdTe/Au nanohybrids

To synthesize dumbbell-like CdTe/Au nanohybrids, CdTe quantum dots were first prepared and purified according to the literature [18,19]. The purified CdTe quantum dots were then dispersed into deionized water, while the concentration and pH value of the solution were adjusted to 1.0×10^{-3} M and 8.0 respectively. Then, about 5.0 mL 1.0×10^{-3} M CdTe quantum dots aqueous solution was mixed with 2.5 mL 1.0×10^{-2} M $HAuCl_4$ solution. After stirring under ultraviolet lamp for 4 h, brown precipitation was obtained and purified by centrifugation.

2.2. Characterization

The samples were characterized by transmission electron microscope (TEM) (JEOL JEM–100CX II), high resolution transmission electron microscope (HRTEM) (JEM-2100) and scanning electron microscope (SEM) (JEOL JSM-7600F).

* Corresponding author. Tel.: +86 531 88366062; fax: +86 531 88564750.
E-mail address: lqzheng@sdu.edu.cn (L. Zheng).

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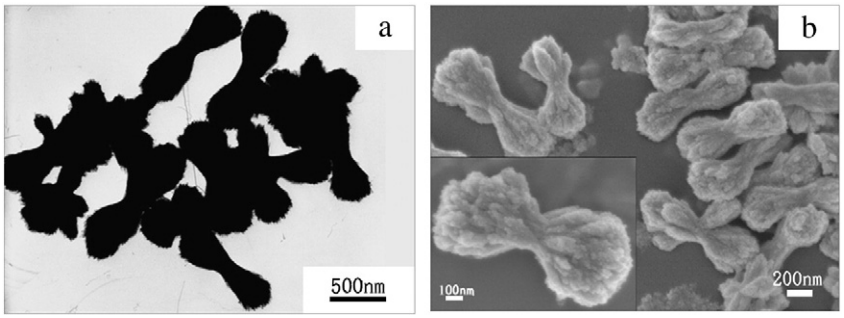

Fig. 1. TEM (a) and SEM (b) images of the dumbbell-like nanostructures.

3. Results and discussion

Fig. 1 shows the typical TEM and SEM images of the products. It can be seen from the TEM image that the products have dumbbell-like morphology. The length of the dumbbells is about 800 nm, the width of the two terminals is about 300 nm while the middle parts come near to 150 nm. The SEM image which reveals that the products are uniform in size and well formed also demonstrates the existence of the typical dumbbell-like nanostructures. The magnified image (the inset part) indicates that the dumbbell-like nanostructure has a rough surface. The formation of this rough surface may be due to the uneven combination of the nanoparticles during the assembly process [20]. The existence of the rough surface is beneficial for the application of the dumbbell-like composite in photoelectric and catalytic fields because it can enhance the light adsorption and enlarge the surface area as well.

The products were further characterized by HRTEM and EDX spectrum. Fig. 2a shows a typical image of the dumbbell-like nanostructure. Fig. 2b is the magnified image of the square part mapped in Fig. 2a. Many small nanoparticles can be seen in the image, which may indicate that the dumbbell-like nanostructures are formed by assembly of small nanoparticles. The inset parts in Fig. 2b show the magnified pictures of part A, B, C and D. Two kinds of crystalline structures can be confirmed in the image. The lattice spacing of part A and D is 0.38 nm, which corresponds to (111) plane of cubic CdTe (PCPDS card no. 65–0880), and that of part B and C is 0.24 nm, which corresponds to (111) plane of cubic Au (PCPDS card no. 65–8601). These results reveal that the formation of the dumbbell-like CdTe/Au nanohybrids may contribute to the assembly of CdTe quantum dots with the assistance of $AuCl_4^-$. The EDX spectroscopy was widely used to detect the exact components and the corresponding proportion of the nanomaterials. Fig. 2c shows the EDX spectrum of the dumbbell-like nanostructure. The elements associated with CdTe/Au such as Cd, Te, Au were both detected, which also demonstrates that the formation of the dumbbell-like nanostructures was contributed to the assembly of the CdTe quantum dots and Au nanoparticles.

In order to further understand the formation mechanism of the dumbbell-like nanostructures, different amount of $HAuCl_4$ solution was added into the CdTe quantum dots aqueous solution under the same conditions. The results indicated that the amount of $HAuCl_4$ played a key role for the formation of the dumbbell-like nanohybrids. As shown in Fig. 3, an apparent shape evolution occurred when 1.0 mL, 1.5 mL, 2.5 mL and 5.0 mL $HAuCl_4$ solution were added into the precursory solution. When 1.0 mL $HAuCl_4$ solution was added, sheaf-like nanostructures were obtained. These sheaf-like nanostructures are composed

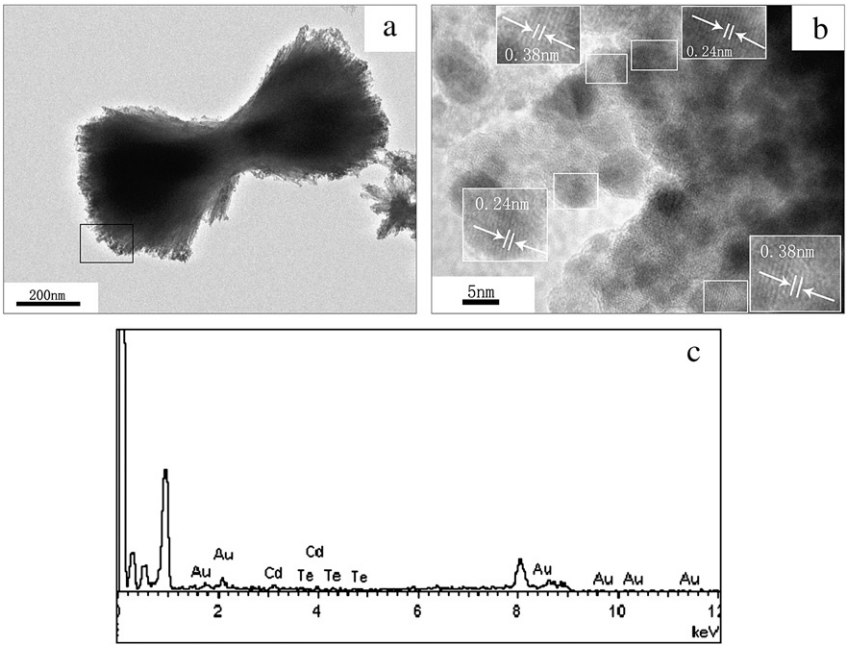

Fig. 2. (a) HRTEM images of a single dumbbell-like nanostructure, (b) the magnified image of the square part in figure (a), (c) EDX spectrum of dumbbell-like nanostructures.