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Preparation and photovoltaic properties of CdS quantum dot-sensitized solar cell based on zinc tin mixed metal oxides

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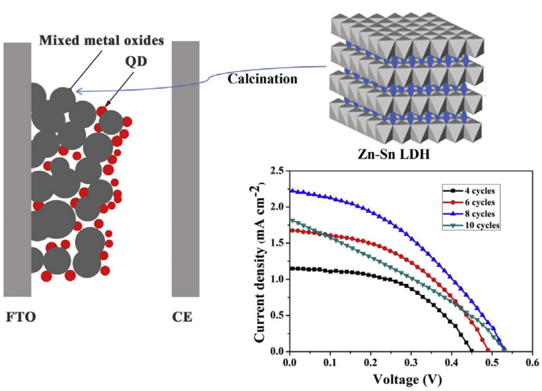
GRAPHICAL ABSTRACT



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ABSTRACT

The present study reports a new type of quantum dot sensitized solar cells (QDSSCs) using the zinc tin mixed metal oxides (MMO) as the anode materials, which were obtained from the layered double hydroxide (LDH) precursor. The successive ionic layer adsorption and reaction (SILAR) method is applied to deposit CdS quantum dots. The effects of sensitizing cycles on the performance of CdS QDSSC are studied. Scanning electron microscopy (SEM), Transmission electron microscope (TEM) and X-ray diffraction (XRD) are used to identify the surface profile and crystal structure of the mixed metal oxides anode. The photovoltaic performance of the QDSSC is studied by the electrochemical method. The new CdS QDSSC exhibits power conversion efficiency (PCE) up to 0.48% when the anode was sensitized for eight cycles.

1. Introduction

Solar energy has been widely considered to be a most promising sustainable energy resource as an effective solution to energy crisis. Therefore, research on the use of the solar energy is of strategic and realistic significance. In recent years, quantum dots sensitized solar cells (QDSSCs) have attracted increasing attention for their low fabrication cost and reasonably high power conversion efficiency [1–3]. Thanks to the intrinsic attractive properties of quantum dots (QDs) such as tunable band gaps [4] and high extinction coefficients [5], a wide variety of QDs have been investigated

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as sensitizers for QDSSCs, such as CdSe [6], PbS [7], SnS [8] and Sb_2S_3 [9]. Among these QDs, cadmium sulfide (CdS) has been paid much attention [10,11] as CdS is an *n*-type semiconductor with a direct band gap of 2.4 eV [12], whose absorption spectrum falls in the visible region at room temperature.

In order to improve the charge separation in metal oxide semiconductor, mixed metal oxides (MMO) have been successfully synthesized [13–15]. Moreover, mixed metal oxides have been investigated as promising materials for catalysis, solar energy conversion and sensors [16–18] for their high surface area and excellent physicochemical property. Meanwhile, dye-sensitized solar cells (DSSCs) based on ZnO/SnO_2 composite photoanodes have achieved good performance [19,20]. A composite of MMO and CdS quantum dots may combine the promising properties of each constitute potentially leading to interesting photoactivity. In this paper, zinc tin layered double hydroxide was obtained by the urea decomposition method and the corresponding MMO was used as the photoanode material in the new type QDSSCs. The CdS QDs were deposited on the surface of the photoanode as the sensitizer by the successive iconic layer adsorption and reaction method (SILAR) [21,22]. The surface morphology, crystal structure, UV–vis absorption properties and the photovoltaic performance of the CdS sensitized photoanodes with different cycles were investigated.

2. Experiment

2.1. Synthesis of zinc tin MMO

The synthesis method of zinc tin MMO was similar to that reported by Zhang et al. [23]. All chemicals were purchased from Sinopharm Group Co., Ltd. and used without further purification. In a typical synthesis, certain amount of $Zn(NO_3)_2{\cdot}6H_2O$, $SnCl_4{\cdot}5H_2O$ (the molar ratio of the Zn^{2+} to Sn^{4+} is 9) and urea were dissolved in deionized water at room temperature in a three-neck flask. The flask was then soaked in an oil bath and heated at 100 °C for 24 h under gentle stirring. The resultant precipitate separated from the solution by suction filtration was washed with deionized water, and then dried at 60 °C for 12 h. The as-prepared LDH was placed in a muffle furnace at 500 °C for 1 h in air. After calcinations, the powders were used to prepare the photoanode. The obtained Zn-Sn MMO was dispersed in an ethylcellulose/terpineol solution and stirred to get the paste.

2.2. Fabrication of CdS sensitized Zn-Sn MMO anodes

Fluorine-doped tin oxide (FTO) was used as the electrode and Pt electrode (Jinge-solar Energy, Wuhan) was used as the counter electrode. The Zn-Sn MMO paste was coated on the FTO glass substrate (0.5 cm $*$ 0.5 cm) by a doctor-blade and then sintered in a muffle furnace at 500 °C for 30 min to remove the organic material.

The CdS QDs were deposited on the photoanode by the successive ionic layer adsorption and reaction (SILAR) method. First, the Zn-Sn MMO film was immersed in 0.1 M $Cd(NO_3)_2$ ethanol solution for 1 min, followed by rinsing with ethanol and drying in air. Subsequently, the as-prepared film was immersed into 0.1 M Na_2S ethanol/water(1:1 v/v) for 1 min, then rinsed by ethanol and dried in air. The two steps were defined as one SILAR cycle. The amount of deposited CdS could be controlled by increasing the number of SILAR cycles. Samples went through n SILAR cycles, herein referred to as CdS(n).

The prepared electrodes were assembled into quantum dot-sensitized solar cells to investigate their photoelectric properties. The electrode was assembled with the counter electrode by hot melting the adhesive polymer film at 120 °C. An electrolyte solution containing 0.5 M lithium iodide, 0.05 M iodine, and 0.4 M 4-tert-butylpyridine in acetonitrile was injected into the gap between the two electrodes by capillarity.

2.3. Characterization

The Zn-Sn MMO films coated with CdS were characterized by transmission electron microscope (TEM JEM-2100F, JEOL, Japan), scanning electron microscopy (SEM S-4800, Hitachi, Japan), X-ray diffraction (XRD, Cu Kα radiation, Bruker D8, Germany). The UV–vis absorption spectra of the Zn-Sn MMO films and Zn-Sn MMO/CdS electrodes were collected by a UV–vis spectrophotometer (TU-1901, Persee, China). The photovoltaic performance was characterized by a computer-controlled digital source meter (Keithley 2400) under simulated AM 1.5 sunlight with an output power of 100 mW cm^{-2} using a Solar Simulator (Sofn Instruments Co., Ltd China) as the light source. Electrochemical impedance spectroscopy (EIS) measurements were analyzed in the dark using a CHI660E electrochemical workstation (CH Instrument Inc., China). The impedance spectra obtained were fitted by use of Zsimpwin software.

3. Results and discussion

3.1. Microstructure and optical performance of CdS/Zn-Sn MMO

XRD pattern of Zn-Sn LDH is shown in Fig. 1(a). The XRD pattern shows the basal peaks of planes (003), (006) and (009) and

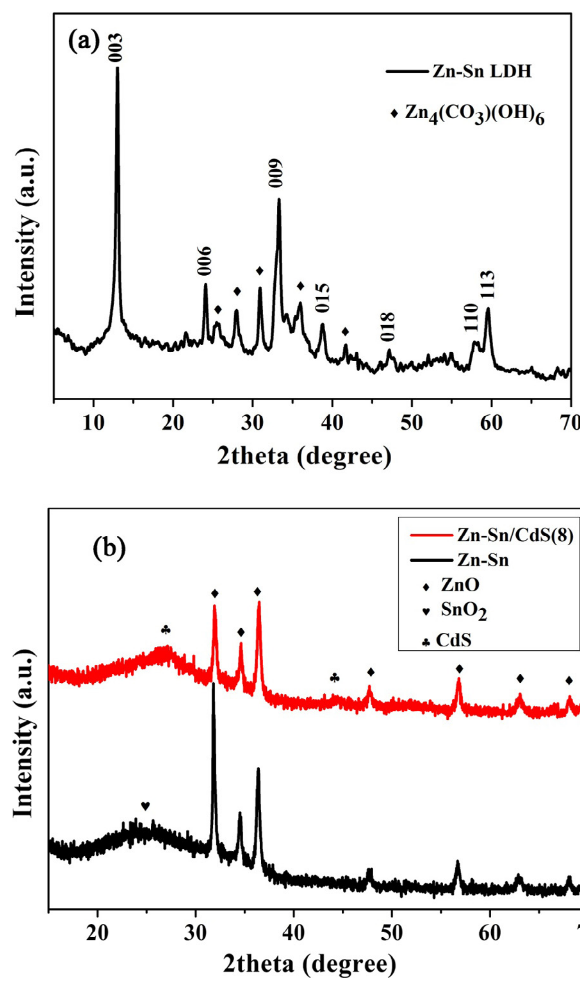

Fig. 1. XRD patterns of (a) Zn-Sn LDH precursor (Zn:Sn = 9:1) and (b) Zn-Sn MMO and Zn-Sn MMO/CdS(8).