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Dye-sensitized solar cells based on tin dioxide nanoparticles prepared by a facile hydrothermal method

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ABSTRACT

Pure SnO_2 nanoparticles with tetragonal structure were successfully synthesized by using a hydrothermal method and then were employed as a photoanode in dye-sensitized solar cells (DSSCs). A Schiff base ligand was applied to prepare uniform SnO_2 nanoparticles. The morphology and crystalline size of nanoparticles have been characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier transform infrared (FT-IR) spectrum, Electron Dispersive X-ray spectroscopy (EDX) and ultraviolet–visible (UV–vis) spectroscopy. The optical band gap of the SnO_2 nanoparticles was estimated to be 3.8 eV. The photovoltaic properties of SnO_2 electrodes have been investigated and it is shown that using uniform SnO_2 nanoparticles as an active electrode is more beneficial than agglomerated nanoparticles.

1. Introduction

Semiconductor nanomaterials have attracted considerable attention because of their potential scientific and technological applications. SnO_2, an important n-type wide band gap semiconductor (3.6 eV) with high chemical stability and special electrical and optical properties, has been widely used for various applications, such as transistors, catalysts, gas sensors, transparent conducting electrodes, secondary lithium batteries and dye-sensitized solar cells [1–4]. SnO_2 with various nano- and microstructures, such as nanoparticles, nanorods, nanobelts, hollow microspheres, nanoflowers, mesoporous structures [5–8], nanowhiskers [9] and nanowires [10], has been prepared successfully by different methods such as hydrothermal [11,12], carbothermal reduction [13], chemical precipitation [14] microwave [15], thermal decomposition [16], sol–gel [17], and sonochemical routes [18]. Since the properties of nanoscale materials strongly depend on their size and shape, hydrothermal is one of the best chemical methods for synthesis of nanostructures with controlled particle size, phase, homogeneity and morphology.

Dye-sensitized solar cells (DSSCs) based on metal oxide semiconductor photoanodes and redox electrolytes are of great interest for application in solar energy conversion. Several studies have investigated alternative metal oxides such as ZnO, SnO_2, Zn_2SnO_4, and Nb_2O_5 for application in DSSCs. Compared to TiO_2, SnO_2 benefits include certain intrinsic advantages such as higher electron conductivity (100–200 $cm^2\,V^{-1}\,S^{-1}$) and more positive conduction band edge position. The high electron mobility causes faster transportation of photoinjected electrons to a transparent conductive oxide which act as a current collector while the more positive conduction band edge position simplifies electron injection from photo-excited dye molecules, especially in organic sensitizers with low band gap. Furthermore, wider band gap (3.6 eV) in the case of SnO_2 forms less oxidative holes in the valence band under UV radiation and results in minimizing the dye degradation rate and improving the long-term stability of DSSCs. However, in spite of all advantages the performance of

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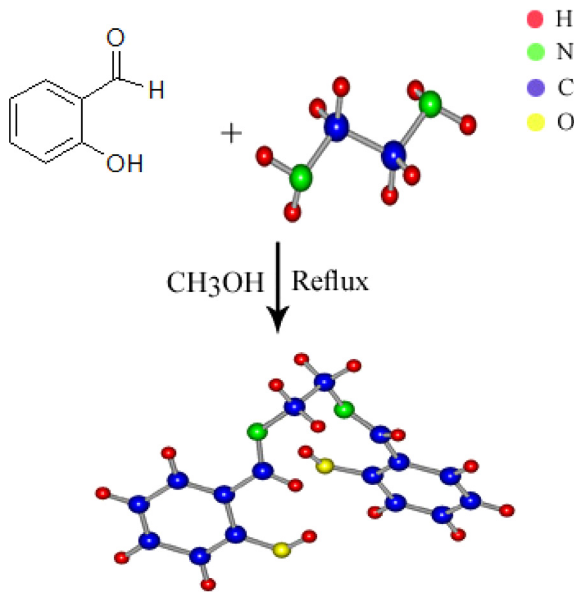
DSSCs based on SnO_2 photoanodes is much less than those consisting of TiO_2 [19–21]. Conventional nanoparticle-based SnO_2 DSSCs show small conversion efficiencies around 1–2% [22–24].

In this work, SnO_2 nanoparticles were prepared by a facile hydrothermal synthesis technique in the presence of a Schiff base ligand as capping agent. The synthesized tin dioxide was further employed for fabrication of DSSCs.

2. Experimental

The chemical reagents including $SnCl_2 \cdot 2H_2O$ and NaOH, used in our experiments, were purchased from Merck. All the mentioned chemicals were used as received without further purification. Schiff base used as a capping agent in this work was synthesized as shown in Scheme 1.



Scheme 1. Preparation reaction of *N,N′*-bis(salicylaldehyde)ethylenediimine as capping agent.

2.1. Synthesis of Schiff base

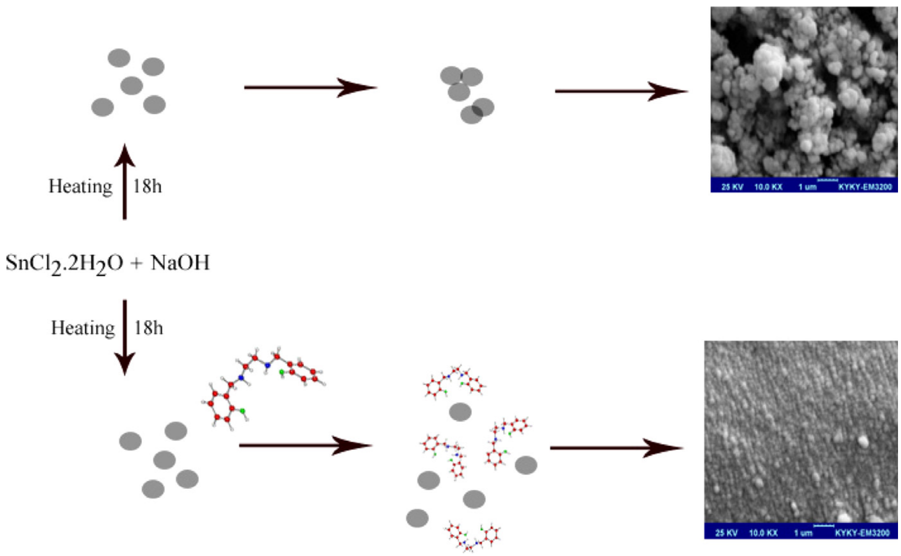
The symmetrical Schiff base ligand *N,N′*-bis(salicylaldehyde)ethylenediimine, $C_{16}H_{16}N_2O_2$ (H_2salen; Scheme 2), was prepared by refluxing 0.06 mol of salicylaldehyde and 0.03 mol of ethylenediamine in 50 ml of ethanol for 3 h and cooling the reaction mixture. The Schiff base was separated as yellow needles and was filtered and washed twice from methanol. The compound was stable at room temperature and was characterized by IR and NMR spectroscopies.

2.2. Synthesis of SnO_2 nanoparticles

$SnCl_2 \cdot 2H_2O$, NaOH and *N,N′*-ethylene-bis(salicylideneimine) were selected as starting materials. At first, 0.3 mol of $SnCl_2 \cdot H_2O$ was dissolved into 50 mL of ethanol. Then 0.5 M of NaOH solution was added into $SnCl_2$ solution under continuous magnetic stirring. The obtained mixture was put into a 100 ml Teflon autoclave, sealed and maintained at different temperatures for 18 h shown in Table 1, and then was cooled down to room temperature. The obtained precipitates were centrifuged and washed with water and ethanol. Finally, the products were dried in vacuum at 80 °C for 1 h.

2.3. Preparation of SnO_2 paste

To prepare SnO_2 paste, 0.78 g of ethylene cellulose was added to absolute ethanol under continuous stirring and then 0.5 g of terpineol was added. Terpineol and ethyl cellulose act as binders in preparation of the SnO_2 paste. Then the obtained SnO_2 was added to 20 mL of aqueous solution of ethanol. Finally, the above two solutions were mixed by stirring and sonicated with ultrasonic horn



Scheme 2. Recommended mechanism for preparation of SnO_2 nanoparticles by using H_2salen.