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Low-cost $TiO_2/Sb_2(S, Se)_3$ heterojunction thin film solar cell fabricated by sol-gel and chemical bath deposition

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ABSTRACT

Low cost TiO_2/ $Sb_2(S, Se)_3$ heterojunction thin film solar cell are prepared successfully by using sol-gel and chemical bath deposition. At first, TiO_2 thin film is prepared on the ITO-coated glass substrate by a simple sol-gel and dip-coating method. Subsequently, $Sb_2(S, Se)_3$ film is fabricated on TiO_2 by selenizing the Sb_2S_3 film prepared by chemical bath deposition (CBD). The heat-treated process of TiO_2 and $Sb_2(S, Se)_3$ films has been discussed, respectively. After being heat-treated at 550 °C for TiO_2 and 290 °C for $Sb_2(S, Se)_3$ films, the photovoltaic devices are completed with the conductive graphite as electrode. The J-V characteristics of TiO_2/ $Sb_2(S, Se)_3$ solar cell are measured and the open circuit voltage (V_{oc}) of this cell is about 350 mV.

1. Introduction

Thin film solar cell as second generation solar cell has always been cheaper but less efficient than conventional c-Si solar cell. But now, it has significantly improved with the development of copper indium gallium selenide (CIGS) and cadmium telluride (CdTe) solar cell, the lab cell efficiency of which is about 22.6% and 22.1%, respectively [1,2]. However, CIGS and CdTe are not the best and ultimate materials for the thin film solar cell, considering the scarcity and toxicity of Cd, In and Te. Several researchers have done a lot of effort to explore earth-abundant, nontoxic and low-cost absorber material for high-efficiency solar cell, such as CZTS, Sb_2S_3, Sb_2Se_3, Cu_2O, SnS and so on [3–6].

Sb_2Se_3 is a superior absorbing material for novel low-cost and high-efficiency thin film solar cell having the narrow band gap of 1.1–1.3 eV and the theoretical photoelectric conversion efficiency could achieve ≥ 30% [7,8]. It is a typical binary compound with the single phase, avoiding the complexity of phase and defect control as in CZTS. Furthermore, Sb_2Se_3 are abundant and low-toxicity, making it very promising for solar cell application. However, Sb_2Se_3 based solar cells have been rarely reported, until 2012, there are reported Sb_2Se_3 sensitized solar cells [9]. At present, the efficiency of this solar cell is still very low [10]. Jiang Tang group have done several encouraging researches for Sb_2Se_3 solar cell and prepared successfully the CdS/Sb_2Se_3 thin film solar cell with the highest efficiency of 5.6% by using thermal evaporation approach [11–15].

In this paper reported here, we demonstrated a novel and low cost TiO_2/ $Sb_2(S, Se)_3$ heterojunction thin film solar cell prepared by using sol-gel and chemical bath deposition. At first, we prepared TiO_2 thin film on the ITO-coated glass substrate by a simple sol-gel and dip-coating method. Subsequently, $Sb_2(S, Se)_3$ film was fabricated on TiO_2 by selenizing the Sb_2S_3 film obtained by chemical bath deposition (CBD). At last, the electrodes were coated. The major advantages of this paper are that the materials of solar cell is abundant and non-toxicity and the approach of sol-gel and chemical bath deposition is simple and low-cost, because they do not require sophisticated equipment with controlled environments. Meanwhile, the prepare temperature of the TiO_2/ $Sb_2(S, Se)_3$ heterojunction thin film solar cell is relatively low.

2. Experimental

For a typical preparation of TiO_2/ $Sb_2(S, Se)_3$ heterojunction thin film solar cell (see the Schematic illustration in Fig. 1), the TiO_2 sol is synthesized firstly by refluxing the titanium tetrabutoxide monomer ($Ti(O(CH_2)_3CH_3)_4$:Ti(O-*n*-Bu)$_4$) and acetyl acetone ($C_5H_8O_2$:AcAcH) in the isopropyl alcohol (C_3H_8O: IPA) with the molar ratio is 1:1:40 for 2–3 h. After being aged for 48 h, the homogeneous TiO_2 films are prepared on ITO-coated glass substrates by dip-coating and subsequent heat-treatment process.

Secondly, $Sb_2(S, Se)_3$ film is fabricated by CBD method and post selenization. The preparation process is shown in Fig. 2. Antimony

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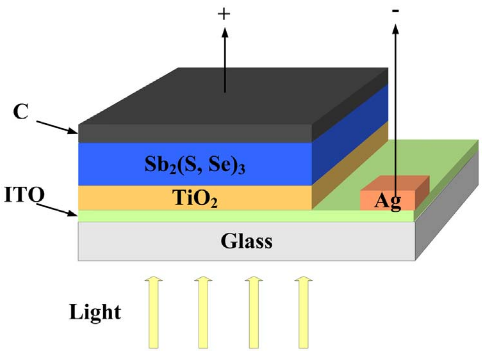

Fig. 1. Schematic illustration of the TiO_2/ $Sb_2(S, Se)_3$ heterojunction thin film solar cell.

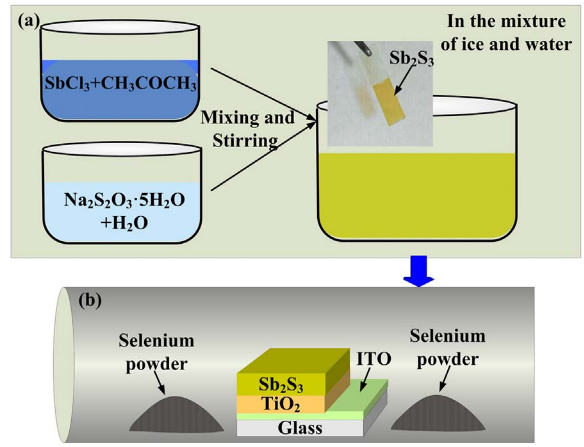

Fig. 2. Preparation process of $Sb_2(S, Se)_3$ by CBD method.

trichloride($SbCl_3$) and sodium thiosulfate ($Na_2S_2O_3{\cdot}5H_2O$) is dissolved in acetone(CH_3COCH_3) and deionized water, respectively. Then the solution in two beakers is mixed and stirred fully till be soluble. The molar ratio of $SbCl_3$ and $Na_2S_2O_3{\cdot}5H_2O$ is set as 4:3 and all processes mentioned above are carried out under ice and water conditions. TiO_2 films on ITO-coated glass are immersed into the mixed solution for about 3 h followed by pulling out and cleaning with distilled water for several times. After that, the golden yellow Sb_2S_3 film is obtained and selenized in an argon pipe furnace to form $Sb_2(S, Se)_3$ film using Se powder source (as seen in Fig. 2(b)). The heat-treatment temperature has been investigated. After depositing the conductive graphite on the $Sb_2(S, Se)_3$ film as the bottom electrode, photovoltaic devices is completed.

The thermal stability, composition and morphology of TiO_2 films are studied by thermogravimetric analyzer (TGA:WRT-3P), differential thermal analyzer (DTA:CRY-3P), respectively. The crystalline phase of TiO_2 and $Sb_2(S, Se)_3$ is tested by X-ray diffraction (D/Max-rA). The profile of TiO_2/ $Sb_2(S, Se)_3$ heterojunction thin film solar cell is characterized by field emission scanning electron microscope (SEM, Hitachi: SU8010) and the IV curves of the cell devices are tested under standard AM1.5 conditions (100 mW/cm^2; 25 °C).

3. Results and discussion

The microstructure change of TiO_2 films can be deduced by TGA, DTA and XRD, as seen in Fig. 3, by which we can determine the following heat-treatment process. From the Fig. 3(a), it can be seen that an

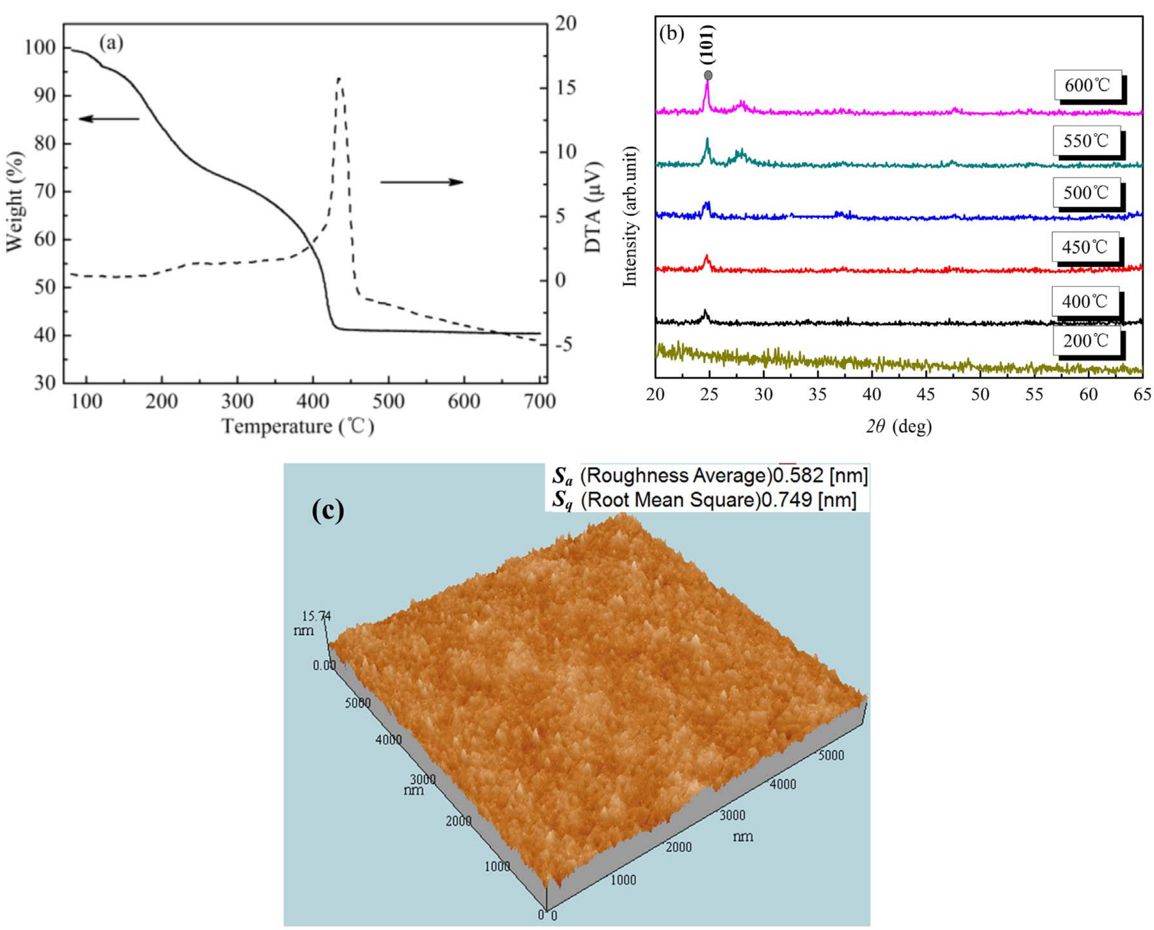

Fig. 3. TGA and DTA curves of the TiO_2 powder gel (a), XRD patterns (b) and AFM image of TiO_2 thin films (c).