



15% Efficiency CdS/CdTe thin film solar cells using CdS layers doped with metal organic compounds

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Abstract

For improving the photovoltaic performance of CdS/CdTe thin film solar cells, the CdS window layer is one of the most crucial factors. Here we demonstrate the photovoltaic performances of the *low-environmental-load* CdS/CdTe solar cell employing the CdS layer doped with various metal organic (MO) compounds, i.e., $(\text{CH}_3)_2\text{SnCl}_2$, $(\text{C}_6\text{H}_5)_3\text{GeCl}$, $(\text{CH}_3\text{CO}_2)_3\text{In}$, $[(\text{C}_2\text{H}_5)_2\text{NCS}_2]_2\text{Zn}$. Due to the MO doping, the degree of (1 1 1) preferential orientation of CdTe on the CdS layer is improved remarkably, influencing the increases in V_{oc} and F.F. Being almost independent of the kind of the MO compounds, the short circuit current increases due to increasing optical transmittance of the MO-doped CdS layers. As a result, utilizing MO-doped CdS, we have achieved the conversion efficiency of 15.1%.

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1. Introduction

Cadmium telluride is one of the most ideal materials for the photovoltaic application because of the following well-known reasons: the optimum band gap of 1.51 eV for solar spectrum and the direct band gap yielding high optical absorption coefficient. The energy conversion efficiency over 16% has been already realized in the R&D level [1,2]. However, the thickness of the photovoltaic layer, which is usually 5–10 μm , must be reduced from a

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viewpoint of the environmental load related to the Cd compounds. We have developed the *low-environmental-load* CdS/CdTe thin film solar cells with a photovoltaic layer thickness of $< 3 \mu\text{m}$ [3–6]. For the further improvement of the photovoltaic performance, the CdS window layer is one of the most crucial factors [4–6] because it acts as a window layer, as a seed layer for the CdTe growth, and as a sulfur source for the $\text{CdTe}_{1-x}\text{S}_x$ mixed crystal layer lying at CdS/CdTe metallurgical interface [7,8]. We have found that doping of the organic tin compound into CdS is effective for improving the photovoltaic performance, and already achieved a high conversion efficiency of 14.8% [6].

In this paper, we present experimental results the CdS layers doped with various metal organic (MO) compounds, i.e., $(\text{CH}_3)_2\text{SnCl}_2$, $(\text{C}_6\text{H}_5)_3\text{GeCl}$, $(\text{CH}_3\text{CO}_2)_3\text{In}$, $[(\text{C}_2\text{H}_5)_2\text{NCS}_2]_2\text{Zn}$. Structural changes due to MO doping found both in CdS and CdTe are described. Additionally, results on applying the CdS layers doped with the MO compounds the *low-environmental-load* CdS/CdTe solar cells are demonstrated.

2. Experimental

The CdS layer was deposited by metal organic chemical vapor deposition (MOCVD) with a thickness of 80 nm on a glass substrate (Corning glass #1737) coated by indium tin oxide (ITO). The MO compound, $(\text{CH}_3)_2\text{SnCl}_2$, $(\text{C}_6\text{H}_5)_3\text{GeCl}$, $(\text{CH}_3\text{CO}_2)_3\text{In}$ or $[(\text{C}_2\text{H}_5)_2\text{NCS}_2]_2\text{Zn}$, was mixed into the MO CdS source. The doping concentration of the MO compound was changed up to 1 wt%. The CdTe layer was fabricated on the CdS layer by close-spaced sublimation (CSS) with a thickness of 2.5–2.9 μm . The detailed other fabrication procedures of the CdS/CdTe solar cells are described in our previous reports [4]. Elemental analysis was performed by secondary ion microprobe mass spectrometry (SIMS) (CAMECA IMS-6f). The surface micrograph of the CdS layer was taken by field-emission scanning electron microscope (SEM) (JEOL JSM 6340F). X-ray diffraction (XRD) measurements were carried out with a diffractometer (Rigaku RINT 2200) with $\text{Cu-K}\alpha$ radiation. From the XRD peaks, the degree of (1 1 1) preferential orientation of CdTe, $p(1 1 1)$, was derived in accordance with the method of Harris [9], while the (1 0 3) CdS grain size was estimated by the Scherrer's formula [10]. The optical transmittance of the CdS layers was measured by a double-monochromatic spectrometer (Shimadzu UV-3100PC). Illuminated current–voltage (J – V) characteristics were measured under the standard condition (AM1.5, $100 \text{ mW}/\text{cm}^2$). The quantum efficiency (QE) spectrum was taken with a conventional lock-in system. Dark current–voltage (J – V) characteristics were measured with a pico-ammeter (HP 4140B).

3. Results and discussion

Fig. 1 shows the SIMS depth profiles of Sn and Cl in the undoped CdS layer deposited on the ITO-coated glass substrate compared to those of the CdS layer doped with $(\text{CH}_3)_2\text{SnCl}_2$. The doping concentration into the CdS source was 1 wt%. Even in the undoped CdS layer, Sn and Cl are presented with the atomic concentrations of 2×10^{17} and $4 \times 10^{17} \text{ atoms}/\text{cm}^3$, respectively. This is likely to be caused by diffusion from the ITO/glass substrate. Meanwhile, the atomic concentrations of Sn and Cl in the CdS layer doped with $(\text{CH}_3)_2\text{SnCl}_2$ increases to 6×10^{17} and $4.5 \times 10^{18} \text{ atoms}/\text{cm}^3$, respectively. Although the doping is not so efficient, the Sn concentration in the CdS layer actually increases.

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