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A study of vapor $CdCl_2$ treatment by CSS in CdS/CdTe solar cells

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Abstract

We report the effect of $CdCl_2$ vapor treatment on the photovoltaic parameters of CdS/CdTe solar cells. Vapor treatment allows combining $CdCl_2$ exposure time and annealing in one step. In this alternative treatment, the CdS/CdTe substrates were treated with $CdCl_2$ vapor in a close spaced sublimation (CSS) configuration. The substrate temperature and $CdCl_2$ powder source temperature were 400 °C. The treatment was done by varying the treatment time (t) from 15 to 90 min. Such solar cells are examined by measuring their current density versus voltage (J–V) characteristics. The open-circuit voltage (V_{oc}), short circuit current density (J_{sc}) and fill factor (FF) of our best cell, fabricated and normalized to the area of 1 cm^2, were $V_{oc} = 663$ mV, $J_{sc} = 18.5$ mA/cm^2 and FF = 40%, respectively, corresponding to a total area conversion efficiency of $\eta = 5\%$. In cells of minor area (0.1 cm^2) efficiencies of 8% have been obtained.

Keywords: CdS/CdTe solar cells; Intermixing; Vapor $CdCl_2$ treatment

1. Introduction

Thin film CdS/CdTe solar cells have achieved an efficiency of 16.5% in 1-cm^2 device (Wu et al., 2001), and commercial-scale modules with efficiencies of >10% (Cooke, 2008; Meyers, 2006; Ullal and von Roedern, 2007) have been demonstrated. Recently, First Solar has announced 12% in CdTe panels (http://www.firstsolar.com/). One of the critical stages in device fabrication is the treatment of the CdTe film, with $CdCl_2$, a process that is essential in the production of high-efficiency cells. Conventionally, $CdCl_2$ treatment has been carried out as solution treatment. In this, $CdCl_2$ is first dissolved in methanol and then applied on as-deposited CdTe films by coating techniques. In an alternative method, thin layer of $CdCl_2$ is deposited on CdTe films (Compann and Bhat, 1992; Fritsche et al., 2003; Romeo et al., 2007; Schulmeyer et al., 2003; Terheggen et al., 2003). After the $CdCl_2$ application, CdTe film undergoes air or an inert gas atmosphere heat treatment at 400–420 °C for 10–30 min, during which the electrical and structural properties of CdTe films get suitably modified. In general, after heat treatment is done, the sample is washed with hot water to remove the excess of $CdCl_2$. This technique is seemingly easy, but shows many problems. The main ones, for the device, are non-uniformity and degradation due to the processing in a humid environment. It has also been reported that the residue of $CdCl_2$,

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left on film surface after treatment, may not completely be eliminated by washing, because of the formation of oxychlorides, which are insoluble in water (Niles et al., 1998).

There are alternatives techniques, called treatments in chloride vapors. In one of these techniques, CdTe films are heated in the presence of $CdCl_2$ vapors. In a variant of this technique, CdTe films are also heated in the presence of chlorine vapor generated from HCl (Paulson and Dutta, 2000). The use of $CdCl_2$ vapor has been investigated as an alternative viable to the use of solution $CdCl_2$ (Hussain, 2004). Vapor treatment reduces processing time since combining the exposure to $CdCl_2$ and annealing into one step. It improves the experimental reproducibility and the process control and also eliminates the remaining liquid associated with the solution method (Hussain, 2004; Mahathongdy et al., 1998; McCandless et al., 1999; Quadros et al., 2008; Wu et al., 2001; Zhao et al., 2002). Recently, another treatment with a gas has been made; a mix of Ar and difluoro-chloromethane (HCF_2Cl) was used, and also, in this case it is not necessary to heat the sample in air (Mazzamuto et al., 2008; Romeo et al., 2007).

It is well known that the $CdCl_2$ treatment offers several substantial benefits such as increased grain size, grain boundaries passivation and reduced lattice mismatch between the CdS and CdTe layers (Wu et al., 2001). It improves the CdS/CdTe junction behavior by enhancing the inter-diffusion between the semiconductors leading to the formation of an alloyed $CdTe_xS_{1-x}/CdS_yTe_{1-y}$ interface, where x and y are less than or equal to the solubility limits at about 400 °C ($x \sim 0.03$ and $y \sim 0.06$) (Compann et al., 1999). Due to this fact, it improves the structural, morphological and electrical properties of the CdTe solar cells, which eventually result in a significant increase in solar cell conversion efficiency (η) and in all three solar cell parameters: open-circuit voltage (V_{oc}), short circuit current density (J_{sc}) and fill factor (FF) (Loginov, 1996).

In this paper, we report on process optimization of the $CdCl_2$ vapor treatment in the CSS configuration. For our study, we varied the process time from 15 to 90 min.

2. Experimental

The CdS/CdTe cells were prepared in a superstrate configuration; so that light enters the cell through the transparent conductive oxide (TCO)-coated glass substrate.

We used as substrate Corning 7059 glass coated with commercial ITO of one inch square (Delta Technology, USA). The CdS film was prepared by chemical bath deposition (CBD) from an aqueous solution containing cadmium chloride [0.02 M], potassium hydroxide [0.5 M], ammonium nitrate [1.5 M] and thiourea [0.2 M]. The bath temperature was maintained at 75 °C for 30 min, and the thickness of the grown CdS film was about 240 nm. In this work, we do not have any buffer layer on ITO. No special

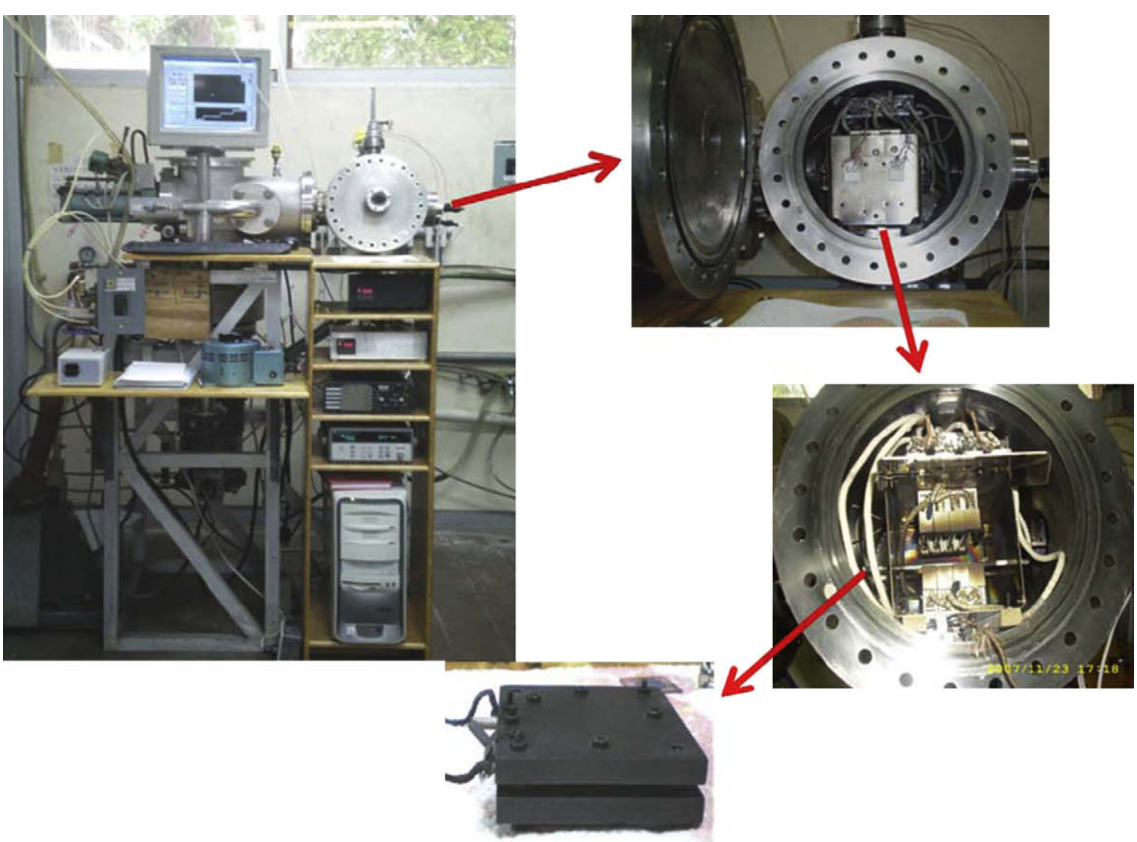

Fig. 1. Close spaced sublimation system.