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ScienceDirect

Solar Energy Materials & Solar Cells ■ (■■■■) ■■■–■■■

Solar Energy Materials and Solar Cells

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Bifacial configurations for CdTe solar cells

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Received 9 February 2007; accepted 14 March 2007

Abstract

We present a different back contact for CdTe solar cell by the application of only a transparent conducting oxide (TCO), typically ITO, as a back electrical contact on all-PVD CdTe/CdS photovoltaic devices that acts as a free-Cu stable back contact and at the same time allows to realize bifacial CdTe solar cells, which can be illuminated from either or both sides. Also devices with thin CdTe layers (from ~2 μm down to 1 μm) have been prepared to improve the conversion efficiency on the back side illumination, which is limited by the collection of carriers far away from the junction and to reduce the amount of material in the CdTe device. Reproducible solar cells exceeding 10% efficiency on the front side illumination and exceeding 3% on the back side illumination are reported.

Keywords: Thin films; CdTe; Bifacial cells

1. Introduction

The CdTe thin film solar cells have now established long-term stable performance [1], high efficiency up to 16.5% under AM1.5 illumination [2] and easy scale-up for large-area production [3]. High efficiency and fast deposition for CdTe by close space sublimation (CSS) allows high throughput and potentially cheap in-line production of solar modules.

In order to improve the efficiency of photovoltaic cells by preparing tandem cells, bifacial configuration thin film devices have been introduced from the early 1980s up to our days [4,5]. For CdTe solar cells inserting a transparent back contact is a particularly challenging task because of both the high electron affinity and high-energy band gap of CdTe [6,7]. Some groups have faced this problem introducing CuTe [8] or ZnTe [9].

We have introduced a different approach to apply a transparent back contact on CdTe solar cells: a thin layer of transparent and conducting ITO [10]. Due to the transparency of the ITO back contact and FTO front contact, solar cells can be illuminated both from the front and rear sides like a bifacial solar cell [10]. Previously a preliminary development of this back contact has been presented, a promising efficiency of about 9% and proved stability for these solar cells has been developed [11].

Our CdTe/CdS fabrication process has been already presented. Briefly all the layers are grown by PVD methods using tin oxide-doped with fluorine (FTO) as front contact and copper–gold layer as back contact [12]. Standard solar cells have a typical efficiency range of 11–12.5% [6,13].

2. Copper-free bifacial cells

ITO back contact has been applied by RF sputtering after a bromine methanol etching: the layer has a sufficient transparency, more than 85%, together with a good

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0927-0248/$ - see front matter
doi:10.1016/j.solmat.2007.03.010

conductivity about 10 Ω/square. As deposited solar cells with pure ITO back contact perform typically very low efficiencies around 2.5% in particular V_{oc} and fill factor are poor, respectively, around 350 mV and 35%.

However, we applied an annealing treatment to the ITO back contacted CdTe cells: different cells have been prepared and after ITO RF-sputtering, annealing in air has been provided at different temperatures from 200 up to 400 °C; best results were given with annealing around 350 °C. The results are that from a starting efficiency of 1–2% after light soaking and annealing, it jumps to 4–5% that can still raise to an upper efficiency above 6% under light soaking. If we analyse the standard Cu/Au contact, we can observe that the efficiency of the solar cells jumps from a poor efficiency up to 10% efficiency after post-deposition annealing treatment

As previously shown [11], the interesting feature of these solar cells is the stability under accelerated lifetime test. We have performed preliminary test also on these devices (solar cells were kept under 1 sun illumination and at 80 °C temperature in open circuit conditions) and they presented an excellent stability and the performance actually improves instead of degrading (see Fig. 1).

The light soaking effect is different in case of as-deposited and annealed devices: in the as deposited device the improvement is very high in the first days (from about 1% efficiency up to above 3% efficiency) and successively tends to stabilize. In the annealed devices, the improvement is lower but still there is a constant increase in an almost 10 years estimated working time.

The defects at the junction between the ITO and the CdTe are more in the as-deposited case and the light soaking fills the recombination centres at the junction while in case of the annealed device the hetero-junction presents a better intermixing and probably the crystallised Te layer helps to inject the carriers across the junction.

3. Copper-containing bifacial cells

In order to compare the ITO-back-contacted cells with the standard copper–gold ones, we have analysed the possibility of inserting copper in the back contact and to study the effects in the performance and in the stability. The basic principle is that a small amount of copper would still leave the back contact transparent and at the same time might not affect the stability of the solar cell.

Prior to the copper deposition, a standard bromine–methanol etching is applied and after copper deposition by physical vapour, the ITO layer is deposited by RF sputtering as previously presented. Several different devices have been made with a standard fabrication process but with different quantities of copper.

In Fig. 1, accelerated lifetime stability tests of cells with different amount of copper are shown. Both start with very similar efficiency but the stability trend is opposite. The 3-nm-Cu cell has a degradation that tends to stabilize after 4 years estimated time, on the other hand the <0.5 nm-Cu cell (we believe that at such low quantity of copper, the quartz is not as precise that is the reason why we have put an indicative number of less than 0.5 nm, more investigations on this has to be done) starts from the same efficiency but instead of degrading it improves slightly in the performance. The behaviour of the 3-nm-Cu cell is similar to the one observed for Cu/Au [14] but still the stability is higher. In the back side illumination, the solar cells perform efficiencies in the order of 0.5% with V_{oc} of about 300 mV, J_{sc} of 3–4 mA/cm^2 and fill factor of 45%. The low current in the back side illumination is due to the long

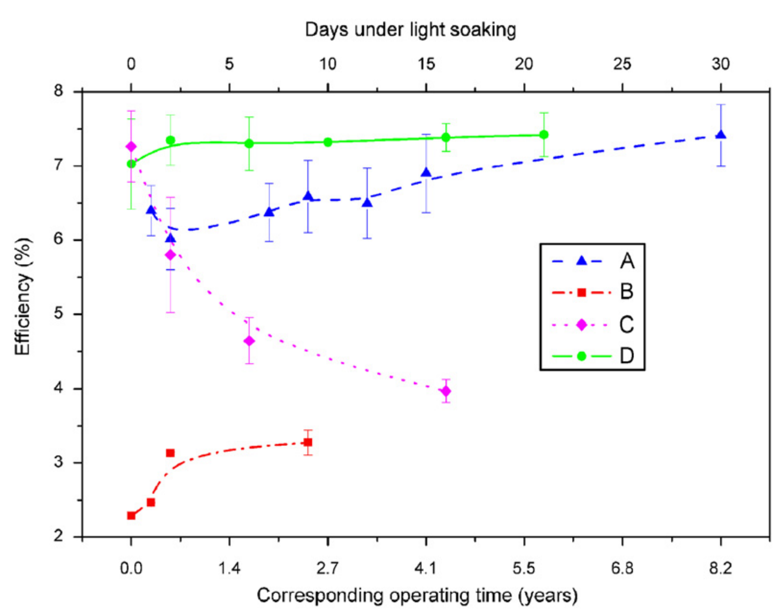

Fig. 1. Accelerated lifetime stability tests of an ITO/CdTe/CdS/FTO solar cell: before (A) and after annealing at 350 °C (B) and of ITO/Cu/CdTe/CdS/FTO solar cells with 3 nm copper deposition (C) and less than 0.5 nm copper deposition (D).

Please cite this article as: A. Romeo, et al., Sol. Energy Mater. Sol. Cells (2007), doi:10.1016/j.solmat.2007.03.010

distance between the hole–electron pair generation and the junction.

However, the <0.5 nm-Cu cell has a very similar behaviour of Sb_2Te_3/Mo cell [13] with a rapid increase at the beginning of the light soaking and a successive stabilization, suggesting that the copper gives instability only if the back contact is not well designed. We believe that if a stable compound with Cu is formed, then the back contact could be very stable: in particular, what could happen is that after the creation of a thin layer of tellurium due to the bromine–methanol etching the copper reacts with the tellurium giving place to copper telluride which is a stable compound. Quantum efficiency measurements, not shown here, have been made and the results have been compared with the one of the standard Cu/Au contacted cell. The latter has a very similar response in the red part near the absorption edge, but has a better response in the 400–550 nm region most probably due to the presence of copper in the bulk of CdTe which passivates the grain boundaries increasing the quantum efficiency [14]. This is an indirect proof that copper is not penetrating in the CdTe layer if the amount is low enough to bind with free Te.

The proof for stability comes also from the annealing test made successively on the light soaked cells, annealing on these devices has been performed for 25 min at 300 °C. The annealed cells did not degrade but instead their efficiency improved in general of about 20%. The increase of the efficiency could be interpreted with the re-crystallization of the Cu_xTe_{1-x} layer, which increases the conductivity of the back contact, but more investigations have to be done.

4. Thin absorber bifacial cells

In order to improve the performance in the back side illumination, we reduced the thickness of CdTe.

The solar cell fabrication process has been adjusted to the different CdTe thickness; in particular the $CdCl_2$ treatment has been processed with only 20% of the standard $CdCl_2$ quantity and by reducing the annealing time.

The first cells were made with about 2.5 μm CdTe thickness and the optimized quantity of copper (less than 0.5 nm).

The solar cells started with a very good performance from the beginning (9.5%) and increased after light soaking to reach an efficiency exceeding 10% as shown in Fig. 2. The back side illumination performance improved considerably compared to the standard cell. As shown in Fig. 2, after 3 days light soaking we have 2.1%. Accelerated lifetime stability test have been provided: the cells are practically stable having a strong increase at the beginning and a successive short degradation afterwards.

A further reduction of the CdTe thickness could open up different possibilities: a further increase in the back side illumination performance, application for tandem configuration cells and a mirror on top could be applied in order to absorb all the light with a very low amount of material used. One micron CdTe thick solar cells have been prepared using a reduced $CdCl_2$ treatment, 30 nm thick $CdCl_2$ and 15 min annealing in air at standard annealing temperatures, copper insertion has been reduced to less than 0.3 nm. As expected, the current density is reduced and the overall efficiency drops to 7–8%, however, the performance in the back side illumination improves up to more than 3% (see Fig. 3). The maximum efficiency is obtained after some days under light soaking and then there is a slight degradation, similar to the behaviour shown in Fig. 1 for the thicker cell.

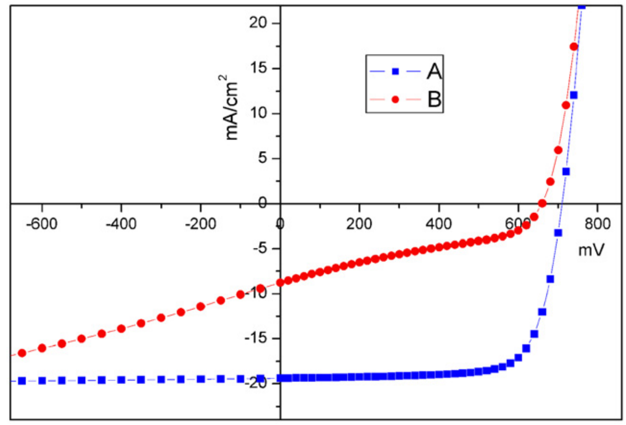

Fig. 2. Front (A) ($V_{oc} = 710$ mV, $J_{sc} = 19.4$ mA/cmA^2, FF = 74.6%, $\eta = 10.3\%$) and back (B) illuminated ($V_{oc} = 659$ mV, $J_{sc} = 8.8$ mA/cmA^2, FF = 36%, $\eta = 2.1\%$) CdTe solar cell with 2.5-μm-thick absorber.

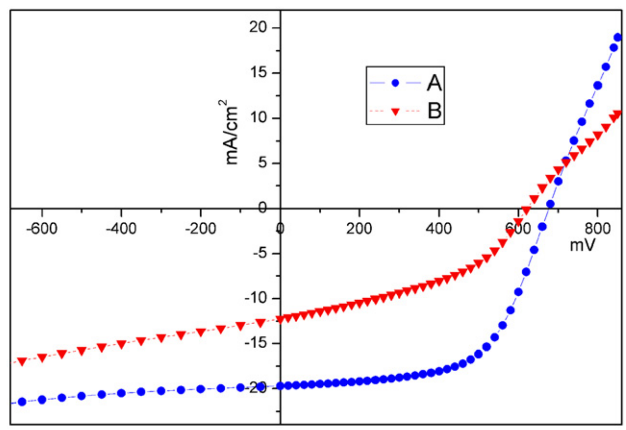

Fig. 3. Front (A) ($V_{oc} = 676$ mV, $J_{sc} = 19.7$ mA/cm^2, FF = 60.5%, $\eta = 8\%$) and back (B) illuminated ($V_{oc} = 622$ mV, $J_{sc} = 12.2$ mA/cm^2, FF = 43%, $\eta = 3.2\%$) CdTe solar cell with 1-μm-thick absorber.

5. Conclusions

Application of a different back contact, based on TCO, on p-CdTe opens a variety of new applications of CdTe solar cells. They can work as bifacial cells, illuminating the back and the front surfaces simultaneously or they can be used in tandem solar cells. The controlled insertion of a very limited amount of copper into the ITO back contact permits to have reproducible devices with high efficiencies still keeping the bifacial configuration.

Please cite this article as: A. Romeo, et al., Sol. Energy Mater. Sol. Cells (2007), doi:10.1016/j.solmat.2007.03.010

Thin CdTe layer solar cells have been realized with efficiencies exceeding 10%. The reduced thickness of CdTe allows to have a better performance (efficiencies exceeding 3.5%) on the back side illumination and reduces the amount of CdTe material increasing the transparency.

Solar cell layers need further optimisation and transport properties need investigation to improve the efficiency of bifacial cells. However, TCO back contact on CdTe provides superior cell stability, simplified processing and a potential for low-cost production.

Acknowledgements

The Italian Ministry of Research and the Swiss National Foundation (Project SCOPES IB 7420-111038) are thankfully acknowledged.

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