

The Back Contact in CdTe/CdS Thin Film Solar Cells

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Summary

A barrier-free back contact in CdTe/CdS solar cells is fundamental for obtaining high-efficiency devices. Generally, the back contact is made by depositing a few nanometres of copper onto an etched CdTe surface, where a thin layer of tellurium is formed. In this way, a Cu_xTe film is obtained forming an ohmic contact with CdTe. However, if x exceeds 0.4 the contact is not stable and the solar cell degrades. Several attempts were made to make a barrier-free contact by using low-resistivity p-type materials such as: Sb_2Te_3 , As_2Te_3 , Bi_2Te_3 , MoO_x and ZnTe but the results were not definitive. Still some copper seems to be needed. We used As_2Te_3 , Bi_2Te_3 and ZnTe as buffers covered by ~ 10 nm of copper deposited at 520 K substrate temperature. This kind of contact works very well but only if the final contact is made of a thin layer of platinum covered by a thicker layer of molybdenum. Platinum exhibits a high work function (5.8 eV) and it is thus suitable to make an ohmic contact to the p-type high-conductivity buffer layers. **Keywords:** CdTe, Back Contact

1. Introduction

The CdTe/CdS solar cell has reached an efficiency of 22.1% [1] which, together with CuInGaSe₂ (CIGS), is the highest efficiency obtained for thin film solar cells. This efficiency is comparable with that of the best crystalline silicon solar cells. However, there is something which has not been completely clarified. That is, how to make an ohmic and stable contact to CdTe? Is it necessary to use copper? If yes, how to limit the copper diffusion into CdTe? It is known that, if copper reaches the junction, it can cause short-circuits or it can dope CdS, which becomes insulating. Several attempts have been made in order to avoid the use of copper in the back contact. For example, Lin et al. [2] and Drayton et al. [3] used MoO_3 thermally evaporated onto the CdTe surface as back contact. They find that this kind of contact works well on CdTe made both by closed-space sublimation (CSS) or R.F. sputtering. However, this contact works well if MoO_3 exhibits the right stoichiometry, which is not so simple to be obtained. Another promising material to be used as a Cu-free back contact is iron pyrite [4] but the obtained results are not definitive. In the past, we reported the preparation of a copper-free back-contact to CdTe by using a low resistivity p-type material such as Sb_2Te_3 [5] covered by molybdenum. Despite a high efficiency ($\sim 15\%$) was obtained, we found out that a roll-over is present in the J-V characteristics which is an indication that some barrier still exists at the back-contact. More recently, we used other buffers such as As_2Te_3 and Bi_2Te_3 covered by 5 – 10 nm of copper and we have demonstrated that an annealing at 520 K in air frees tellurium which combines with copper that, diffusing through the buffer, forms a thin layer of Cu_xTe on the CdTe surface [6-7]. If the Cu-diffusion is controlled in order that the x in the Cu_xTe is less than 0.4, then the contact is quite stable over time. It seems that a Cu_xTe (with $x \leq 0.4$) film is necessary to form a good contact with CdTe. In theory, the most suitable contact should be ZnTe since it is p-type, it does not exhibit any lattice mismatch with CdTe and its valence band is aligned to that of CdTe. However, ZnTe thin films generally exhibit high resistivity. We found out that, if ZnTe thin films are grown by radio frequency (R.F.) magnetron sputtering at 300 K substrate temperature and then annealed at 520 K for 20 minutes, their resistivity is lowered from $10^5 \Omega \text{ cm}$ to $2 \Omega \text{ cm}$. In these conditions, ZnTe is suitable to be used as a back contact for CdTe. In any case, in order to make a good contact, a few nanometers of copper (~ 10 nm) on top of ZnTe are necessary in order to form, through Cu-diffusion, a Cu_xTe layer in the CdTe surface. Finally, the last contact on the buffer layer must be a metal which must form an ohmic contact with the buffer layer. We found out that, in order to avoid any roll-over and to have always a fill factor (F.F.) greater than 0.7, we had to use a few nanometers of platinum covered by molybdenum, that is, only platinum which exhibits a work function of 5.8 eV makes an ohmic contact with ZnTe. The same results are obtained if As_2Te_3 or Bi_2Te_3 are used as buffer layers.

2. Experimental

As shown in figure 1, CdTe/CdS solar cells are made up of 4 main layers. As a substrate, a 1 inch square soda lime glass is used. The front contact is prepared by depositing in sequence on the glass 500 nm of indium tin oxide (ITO) and 150 nm of pure ZnO at a substrate temperature of ~ 670 K. ITO is prepared by direct current (D.C.) pulsed magnetron sputtering in an atmosphere of Ar + 2% of O_2 , while ZnO is prepared by R.F. magnetron sputtering from a target of pure Zn in an atmosphere of Ar + 10% of O_2 . In both cases O_2 has to be minimized in order to avoid any excess of oxygen in the films. CdS is also prepared by R.F. magnetron

sputtering in an atmosphere of Ar + 6% Trifluorometane (CHF_3). This gas contains F, which is freed in the sputtering discharge and, being electronegative, bombards the substrate during the growth of the CdS film. In this way, any excess of Cd or S are removed from CdS during its growth and the film results stoichiometric with a forbidden gap a little higher than that of the film grown without CHF_3 [8]. CdTe is prepared by CSS at a substrate temperature of 773 K. Typical thickness of CdS is 100 nm while CdTe thickness is 6 μm . Before making the back-contact CdTe is treated for 20 – 30 minutes at 690 K in an atmosphere containing 2×10^3 Pa of Freon R22, whose formula is CHClF_3 , and 5×10^4 Pa of argon.

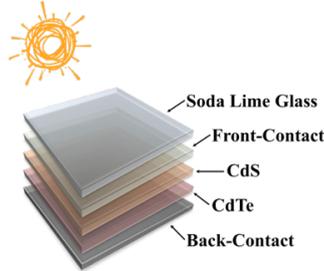


Fig. 1: Outline of CdTe/CdS solar cell.

For the back-contact we experimented four buffer layers namely: Sb_2Te_3 , As_2Te_3 , Bi_2Te_3 and ZnTe . Those buffer layers are generally covered by 10 nm of copper and the external layer is made by depositing in sequence 10 nm of platinum and 200 nm of molybdenum (as shown in figure 2).

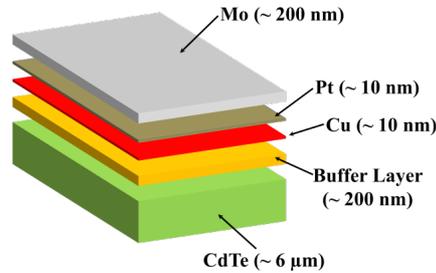


Fig. 2: Scheme of back-contact structure.

Sb_2Te_3 , As_2Te_3 , Bi_2Te_3 all exhibit a low resistivity on the order of $10^{-2} - 10^{-3} \Omega \text{ cm}$ but ZnTe exhibits a high resistivity. The lowest resistivity observed on ZnTe is about $10^5 \Omega \text{ cm}$, when it is deposited by R.F. sputtering with the substrate kept at room temperature. But, it is enough a 20 minutes annealing made at 520 K in vacuum to lower the resistivity to $2 \Omega \text{ cm}$. At higher annealing temperatures the resistivity tends to increase again. The results obtained with As_2Te_3 , Bi_2Te_3 and ZnTe are very similar while the efficiency obtained with Sb_2Te_3 is a little smaller. Efficiency for these cells is on the order of 15 - 16% with a fill factor of 0.7 - 0.72. Figure 3 shows the J-V characteristics of the solar cell with a buffer layer of ZnTe and the external contact made with or without platinum. While the short-circuit current density (J_{sc}), open-circuit voltage (V_{oc}) and F.F. are almost the same, a roll-over appears in the J-V characteristic when platinum is not used. From these results it comes out that in order to get CdS/CdTe solar cells with high efficiency without any roll-over:

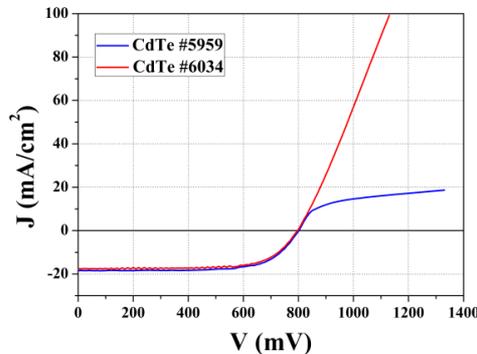


Fig. 3: Sample CdTe #5959: external contact is made without platinum. Sample CdTe #6034: external contact is made with platinum.

1 - Copper is necessary in order that a Cu_xTe layer is formed on top of CdTe. 2 - The diffusion of copper has to be controlled in order to form a Cu_xTe layer with $x \leq 0.4$. 3 - A buffer layer is needed in order to control the Cu-diffusion. 4 - A contact with a high work function, such as platinum (with a work function of 5.8 eV) is needed in order to make an ohmic contact to the buffer layer.

3. Stability tests

Accelerated lifetime tests have been done on solar cells with different buffer layers. Typically, the tests are made by keeping the devices in a box in which the temperature is controlled at 350 K. During the tests the solar cells are exposed to one sun light for about 1200 hours. Almost no efficiency degradation is observed on solar cells with ZnTe buffer layers. There is an initial increase in the efficiency which then stabilizes at values close to the initial value. For the other buffer layers the efficiency decrease from 5% to 10% after 1200 hours of light soaking at 350 K.

4. Conclusion

Here we described a way to make a non-rectifying back-contact to CdS/CdTe solar cells. We found out that the back-contact can contain copper whose diffusion must be controlled by a buffer layer. Finally, we would like to put in evidence that, in order to avoid any roll-over in the J-V characteristic, the contact on the buffer layer has to be made with a high work function metal such as platinum.

5. References

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