CuIn$_{1-x}$Ga$_x$S$_2$ thin film solar cells with Zn$_x$Cd$_{1-x}$S as heterojunction partner

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ABSTRACT

Copper indium gallium sulfide, CuIn$_{1-x}$Ga$_x$S$_2$ (CIGS2) solar cells prepared with chemical bath deposited heterojunction partner zinc-cadmium sulfide (Zn$_x$Cd$_{1-x}$S) layer has exhibited better blue photon response and in turn, higher currents. This can be attributed to its higher bandgap than that of CdS. The open circuit voltages for CIGS2/Zn$_x$Cd$_{1-x}$S were also higher than those of the CIGS2/CdS devices, indicating improved junction properties. A cross-over effect was indicated by J-V curves at different temperatures showing the need for further optimization.

INTRODUCTION

CdS heterojunction partner layer has shown higher photovoltaic conversion efficiencies with copper-indium-gallium diselenide (CuIn$_{1-x}$Ga$_x$Se$_2$) absorber layer while efficiencies are lower with CIGS2, which is a chalcopyrite based material with a wider band gap of ~1.5 eV. CIGS2/CdS devices have shown a cliff of approximately 0.45 (±0.15) eV in the conduction band [1]. A favorable band alignment is necessary in order to achieve higher open circuit voltages. A possible solution is to use a larger bandgap alternative heterojunction partner, such as Zn(O,S) compounds which can also provide optimal conduction band offset [2-3] with CIGS2 absorber layer. Earlier studies at the FSEC PV Materials Laboratory have demonstrated that the efficiencies of CIGS2 devices are limited by low short circuit current values. Higher efficiencies can be obtained for these devices, if heterojunction partner with a higher bandgap as compared to CdS (2.4 eV) is used for a better blue-photon gain. Using Zn$_x$Cd$_{1-x}$S as heterojunction partner can be advantageous because of its higher band gap [4], control over the lattice parameter [5] and control over the conduction band offset to some extent by varying the ratio of cadmium to zinc.

EXPERIMENTAL TECHNIQUE

Sodalime glass/Mo/CIGS2/heterojunction partner/ ZnO/Cr/Ag contact fingers solar cells of area ~0.44 cm$^2$ were fabricated at FSEC. The absorber layer was prepared by sulfurization of metallic precursors deposited by DC magnetron sputtering in Cu rich regime i.e. Cu/(In+Ga)>1. Cu$_2$S phase that segregates at the surface was etched away using dilute KCN solution prior to the deposition of heterojunction partner by chemical bath deposition (CBD). i:ZnO/Al:ZnO transparent and conducting window bilayer was deposited by RF magnetron sputtering. Finally, front contact fingers of Cr/Ag were deposited by thermal evaporation through a metallic mask.

Zn$_x$Cd$_{1-x}$S depositions were carried out in an aqueous solution of ZnSO$_4$ and CdSO$_4$, NH$_4$OH, and SC(NH)$_2$ in a chemical bath. The bath parameters were similar to those used elsewhere [6]. Each chemical bath deposition was carried out for 15 minutes. All the devices were completed using two layers of Zn$_x$Cd$_{1-x}$S grown by chemical bath deposition.

RESULTS AND DISCUSSION

The external quantum efficiency measurement carried out at NREL showed gain in blue photon region for Glass/Mo/CIGS2/Zn$_x$Cd$_{1-x}$S/i-ZnO/ZnO:Al as compared to Glass/Mo/CIGS2/CdS/i-ZnO/ZnO:Al because of the transmission of low wavelength photons through the higher bandgap Zn$_x$Cd$_{1-x}$S heterojunction partner layer (Figure 1). As expected this has resulted in higher values of short-circuit current density, J$_{SC}$.
Figure 2 shows the current-voltage characteristics of the highest efficiency cell fabricated with Zn$_x$Cd$_{1-x}$S (1657CZ) and Figure 3 shows the current-voltage characteristics of the highest efficiency cell fabricated with CdS (1657C) as heterojunction partners for a 1.7 µm thick CIGS2 absorber as measured at NREL. CIGS2/Zn$_x$Cd$_{1-x}$S device has shown higher open circuit voltage, $V_{oc}$ indicating improved junction properties. However, the fill factor of CIGS2/ Zn$_x$Cd$_{1-x}$S cell was lower than that of CIGS2/CdS cell. This can be attributed to the higher resistivity of Zn$_x$Cd$_{1-x}$S film as compared to that of CdS layer. The efficiency measured for Zn$_x$Cd$_{1-x}$S as heterojunction partners at NREL was 7.95% and for CdS it was 8.74%. The fill factor can be increased further by suitably doping the Zn$_x$Cd$_{1-x}$S layer to enhance its conductivity.

Current –voltage measurements under dark and illuminated conditions were carried out on Zn$_x$Cd$_{1-x}$S devices at different temperatures. As can be seen from Figure 4 the dark and light J-V curves fail to superimpose indicating the crossover effect. The crossover is observed even after current and voltage values are corrected for series and shunt resistances. Thus it can be concluded that the crossover effect is not due to series and shunt resistances but is inherent to the diode itself. The crossover effect indicates that a conduction band offset is still present and needs further optimization.

Light-beam-induced-current (LBIC) measurements were carried out on CIGS2 solar cell fabricated with Zn$_x$Cd$_{1-x}$S as heterojunction partner. Uniformity variation of 3% can be observed from the LBIC image for CIGS2/ Zn$_x$Cd$_{1-x}$S device shown in Figure 5. Limited uniformity variations indicate good quality cell.

The Capacitance-Voltage measurement of Zn$_x$Cd$_{1-x}$S device (#1657CZ) was carried. The slope of the
linear extrapolation of plot shown in Figure 6 gives an average carrier density of $1.6 \times 10^{17}$ cm$^{-3}$.

![Graph](image)

Fig.6: C-V curve for Zn$_x$Cd$_{1-x}$S device (#1657CZ).

**CONCLUSIONS**

Efficiencies comparable to CIGS2/CdS devices have been obtained with CIGS2/Zn$_x$Cd$_{1-x}$S devices. Higher values of short-circuit current density, $J_{sc}$ and open-circuit voltage, $V_{oc}$ have been obtained for CIGS2/Zn$_x$Cd$_{1-x}$S devices. Lower fill factor, FF and efficiencies of the CIGS2/Zn$_x$Cd$_{1-x}$S can be attributed to high resistivity of Zn$_x$Cd$_{1-x}$S films. J-V curves at different temperatures have indicated that there is conduction band offset in these cells. Therefore, further optimization would result in better devices.

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**REFERENCES**


