Progress in Taking the CdS Layer out of Thin-Film Polycrystalline Solar Cells

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ABSTRACT

Several investigators have attempted to eliminate the CdS window layer commonly used in CdTe, $CuIn_xGa_{1-x}Se_2$, and related solar cells, or to reduce its thickness to very nearly zero. The motivation has been to increase photocurrent, and in some cases, to eliminate the use of cadmium. There has been considerable progress with non-CdS cells, but to varying degrees, there have been associated issues with reduced voltage and other cell properties. This paper compares and quantifies the differences between CdS and non-CdS cells seen in selected studies.

1. Introduction

CdS is used in most $CuIn_xGa_{1-x}Se_2$ (CIGS)- and CdTe-based thin-film solar cell fabrication. Cells with a CdS layer in general have respectable efficiency, including relatively large open circuit voltage (V_{oc}). A shortcoming of such devices is that CdS, with a band-gap energy (E_g) ~ 2.4 eV, has a high absorption coefficient for photons with wavelengths less than ~ 520 nm. Carriers generated in the CdS are generally lost and do not contribute to the overall current, because of a high defect concentration both in the CdS and at the window-absorber interface. Consequently, the presence of a CdS layer in a device limits the short-circuit current density (J_{sc}). To avoid such losses, numerous attempts to eliminate or reduce the CdS have been made. In this paper, we evaluate some of these efforts using current density vs. voltage (JV) and quantum efficiency (QE) characteristics of the devices made by collaborating laboratories.

2. CIGS-Based Devices

2.1. ZnS/CIGS. One material that has been successfully substituted for CdS is ZnS. ZnS has E_g ~ 3.8 eV, and hence should be transparent at wavelengths above ~ 330 nm. Consequently, short-wavelength current losses in ZnS/CIGS should be small.

Fig. 1 compares the JV and QE of the CIGS-based record solar cell (efficiency 18.8 %) made at the National Renewable Energy Laboratory (NREL) [1], which has a CdS layer, with an 18.1 % cell made at Aoyama Gakuin University (AGU). The latter has ZnS [2] instead of CdS. As can be seen from the QE graph, the loss in the short-wavelength spectral response is significant in the CdS/CIGS cell, but much less in the ZnS/CIGS cell. The difference in J_{sc} is 3.1 mA/cm^2. Also shown in the QE graph is that the band gap of the NREL absorber is less than that of the AGU absorber: 1.12 eV vs. 1.19 eV.

The similar appearance of the JV curves is misleading, because the band-gap difference of the two cells, the superior current of the ZnS cell, and the superior voltage of the CdS cell relative to the band gap, very nearly cancel each other. Physically, the low ZnS absorption increases photocurrent, but the ZnS/CIGS junction results in greater recombination current and hence lower voltage relative to the band gap [3]. The near trade-off in efficiency, however, is clear progress compared to previous attempts.

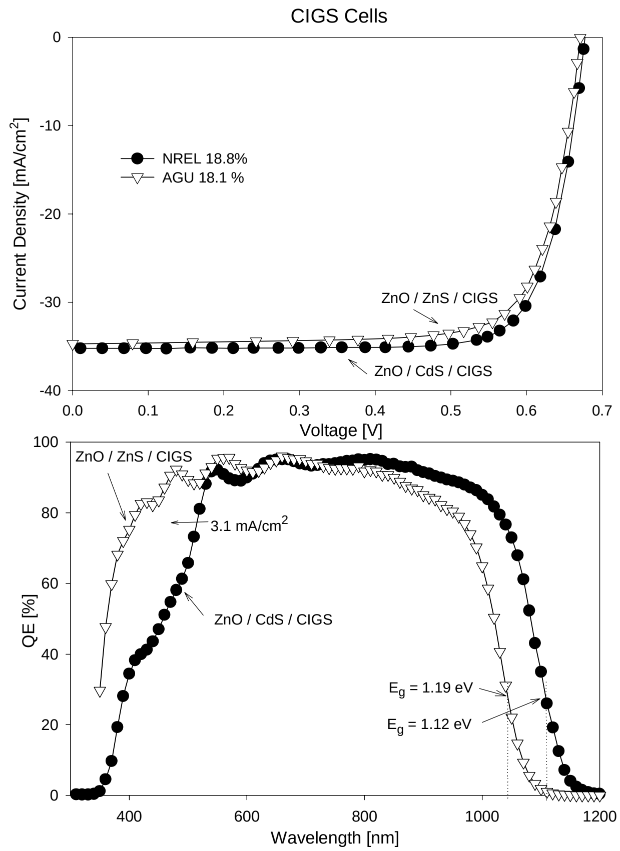

Fig. 1. JV and QE characteristics of high efficiency CIGS-based solar cells.

2.2. Cd-Enriched CIGS Surface. Another possible alternative to CdS, as shown by colleagues at NREL, is to dope the CIGS surface with Cd without adding a potentially absorbing layer [4,5]. Two types of devices were prepared at NREL: one with a CdS/CIGS diode structure and one CIGS film dipped into a partial electrolyte of Cd (Cd PE process). ZnO was used as a transparent conductive oxide (TCO) for both types of cells.

Fig. 2 compares the JV and internal QE characteristics of two of these cells. As seen in the internal QE graph, replacing the CdS layer with the Cd PE treatment of the CIGS film leads to an improvement in the "blue" response, which results in a 1.1 mA/cm^2 increase in J_{sc}. However, as seen from the JV graph, “Cd PE” devices had a lower V_{oc} (and also more shunting) than CdS/CIGS devices. The trade-off here is similar to that of the ZnS vs. CdS devices.

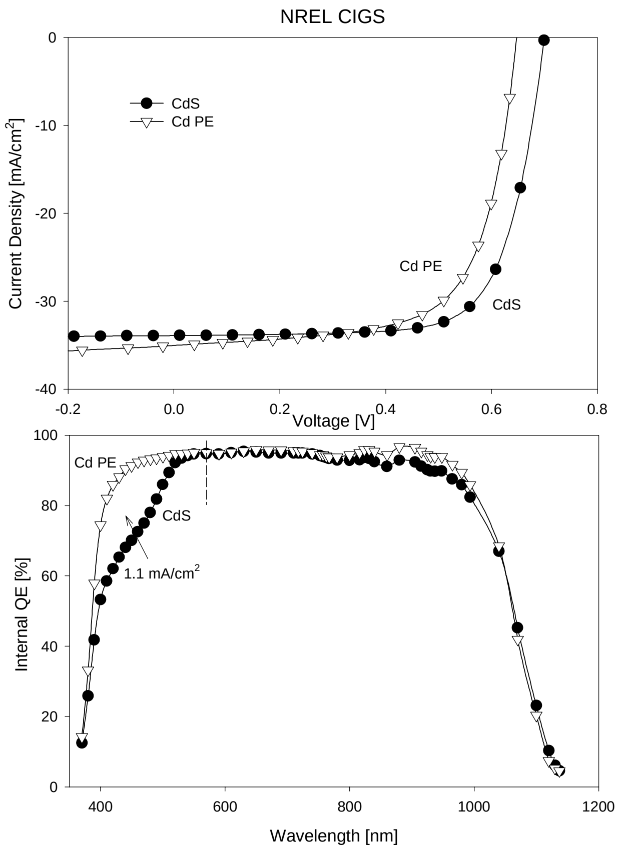

Fig. 2. JV and QE characteristics of CdS/CIGS vs. CIGS with Cd PE treatment devices.

3. CdTe-Based Devices

CdS is also commonly used in CdTe-based cells, and has the same problem as CIGS devices regarding J_{sc} losses. Fig. 3 depicts JV and QE characteristics of three devices: a former record 15.8 % cell made at the University of South Florida (USF) [6], a 14.8 % cell made at Golden Photon Inc. (GPI) [7], and a recent NREL 15.8 % cell [8]. All three devices have similar JV characteristics, though the GPI device has a slightly lower V_{oc}.

Both the USF and NREL cells use thin CdS layers and have respectable QE at short wavelengths. In fact, the CdS thickness following CdTe deposition is typically reduced by interdiffusion of S and Te. The GPI cell has taken this process a step further by using so little CdS that it is effectively subsumed by the CdTe layer. As with the CIGS cells, there is a reduced-voltage tradeoff. Data to be published suggest that the present record CdTe cell has used sufficiently thin CdS that its thickness in the completed cell is also near zero [9].

4. Conclusions

Three different strategies have been used to effectively eliminate short-wavelength QE losses in CIGS and CdTe cells without major compromise elsewhere: (1) use of ZnS

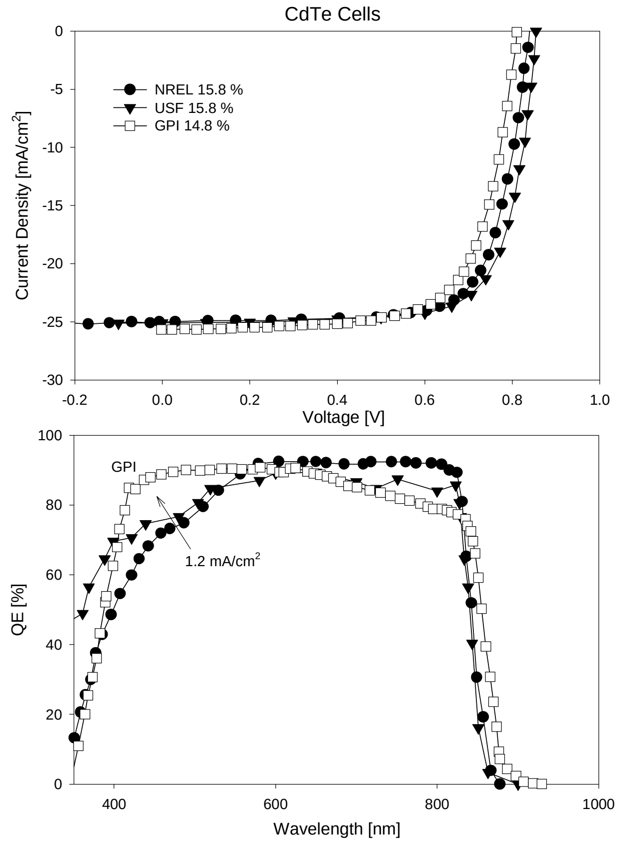

Fig. 3. CdTe solar cells with different thicknesses of CdS.

instead of CdS with CIGS, (2) Cd doping of CIGS without forming an actual layer, and (3) adjustment of CdS thickness so it is reduced to near zero by intermixing with CdTe. Hence, the evidence is strong that the presence of a CdS layer in CIGS and CdTe cells is not essential.

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