Effects Of Buffer Layers On CIGSS Cell Performance

Larry C. Olsen, Peter Eschbach and Sambhu Kundu
Washington State University /Tri-Cities, Richland ,WA 99352
and
Dan Gaspar and Mark Engelhard
Environmental Molecular Science Laboratory, PNNL, Richland ,WA 99352

ABSTRACT

This paper describes investigations of the effects of buffer layers on CIGSS-based solar cells. Two general types of cells have been investigated, namely, direct ZnO devices and cells with either a CdS or i-ZnO buffer layer. The CIGSS absorber in all cases is Siemens Solar material. The CdS buffer layers were grown by CBD at Siemens Solar, and the i-ZnO buffer layers were grown by MOCVD at WSU. Typical efficiencies for the three types of cells were; 7 to 9 % for direct ZnO/CIGSS structures; 11 to 14 % for cells with CdS or I-ZnO buffer layers. Characterization studies included current-voltage analysis to identify current loss mechanisms, and SIMS depth concentration profiles. These studies indicate that a key purpose of the buffer layer is to provide a barrier to diffusion of impurities into the absorber.

1. Introduction

In an effort to understand the effects of buffer layers on CIS-based solar cells, two types of devices are being investigated, namely, direct ZnO cells defined as a structure with conductive n-ZnO deposited directly onto a CIGSS substrate, and cells with effective buffer layers. In particular, CdS grown by CBD and highly resistive ZnO (i-ZnO) grown by MOCVD were utilized as buffer layers. Although buffer layers probably serve more than one purpose, it would seem that one strong possibility is that they act as barriers to diffusion of impurities from TCO layers into absorbers. Clearly, buffer layers may serve other purposes such as to provide interface passivation or to establish an inverted region in the absorber. The focus of this paper is to examine the possibility that buffer layers serve as barriers to diffusion of undesirable impurities into CIS-based absorbers.

2. Cell Fabrication and Performance

Three cell structures were investigated. Layered structures appropriate for direct n-ZnO/CIGSS and n-ZnO/CdS/CIGSS cells were provided by Siemens Solar Industries (SSI) in the form of 10 cm x 10 cm plates. After dicing the plates into 2 cm x 2 cm substrates, Ag collector grids were deposited onto the substrates, cells defined and characterized. SSI also provided 10 cm x 10 cm plates of CIGSS on Mo coated glass. These plates were diced into 2 cm x 2 cm substrates and used to fabricate cells with i-ZnO buffer layers. Measured efficiencies for the three types of cells are typically 7 to 9 % for direct cells, 11 to 14 % for cells with CBD CdS and MOCVD i-ZnO buffer layers.

3. Physical Characterization

SIMS depth concentration profiles of the CIGSS absorber regions have been carried out for direct cells and devices with CdS buffer layers. Profiles have not yet been carried out on cells with i-ZnO buffer layers. SSI TCO layers (boron doped ZnO) and CdS layers were removed using a 15 second etch in 50% (by volume) HCl in water solution. It was determined that this procedure removes the SSI TCO layer (typically 1.7 um) and CdS buffer layer. The required time of etching was determined by creating a step height with photoresist and then measuring the step height with a Zygo interferometer. A similar method was used to determine that the HCl solution only removes CIGSS at a rate of 0.25 A/s. Thus, the process used to remove the TCO and CdS layers only removes a few angstroms of the CIGSS absorber.

Depth concentration profiles for a given sample were acquired after various amounts of CIGSS was removed with a bromine etchant. This approach results in smoother surfaces which improves one's ability to interpret data. The bromine etching solution consisted of a mixture of 0.02 mol/l Br_2 and 0.1 mol/l KBr. Again using a Zygo interferometer, we determined that this etchant removed CIGSS at rate of 2.4 A/s. Following a bromine etch all samples were cleaned with hot trichlorethylene, acetone, methyl alcohol and deionized water. Zygo images clearly established that substantial surface smoothing occurs with the bromine etching process.

TOF-SIMS was chosen for depth profiling because of its sensitivity to impurities that might diffuse into CIGSS absorbers from TCO layers during cell fabrication. Nominal sensitivity of the TOF-SIMS is in the parts per billion range. The data reported here were obtained by averaging two areas on the CIGS surfaces. Residual hydrocarbons were removed with a light sputter, namely, 30 seconds at 600 pA Ga^+ over a 200 x 200um region.

Based on calibration with SiO_2 this procedure should remove less than five angstroms of CIGSS.

SIMS data taken at various depths for direct and CdS buffered cells are shown in Figure 1. The data for direct cells show a significant concentration of an impurity with a mass of 27. Since SSI dopes their TCO with boron we tentatively identify this impurity as due to boron + oxygen. Further data analysis is being carried out to determine if we can clearly identify boron. The key point to be made, however, is that impurity diffusion into CIGS absorbers is not evident for cells with CdS buffer layers.

4. Current Loss Mechanisms

Current-voltage characteristics near the maximum power point were analyzed for the two types of cells to determine J-V parameters for the current loss component. Typical J_o and A-factors are given in Table 1. Results will be reported at the meeting for n-ZnO/i-ZnO/CIGSS cells. Recently, a cell with a WSU i-ZnO buffer layer was determined by NREL to have an efficiency of 13.4 %. Results for this cell will be available at the meeting, but it is clear that its J-V parameters are similar to those exhibited by CIGSS cells with CdS buffer layers.

Table 1 -- Typical Current Loss Parameters

	J_o (A/cm^2)	A-Factor
Direct n-ZnO/CIGSS	$5x10^{-6}$	2.4
n-ZnO/CdS/CIGSS	$2x10^{-8}$	1.6

Although only limited studies have been conducted, results for the direct ZnO cells suggest that the current loss mechanism in these devices is not explained by SRH recombination. These cells are usually characterized by an A-factor significantly greater than 2.0. Simulation studies conducted with the aid of PC-1D for CIS-based cells indicate that SRH recombination due to traps in the depletion region should lead to A-factors in the range of 1.3 to 1.7, as the trap level is varied from the band edge to midgap point. A-factors greater than 2.0 can be due to multiple step tunneling, or tunneling mechanisms combined with recombination processes. Such an explanation would be consistent with the higher impurity concentartion level in direct cells. On the other hand, simulation studies suggest that CIGSS cells with CdS buffer layers are characterized by current loss mechanisms due to SRH recombination via midgap states.

5. Conclusions

Two types of CIGSS-based cells are being investigated in an effort to improve understanding of the effect of buffer layers on cell performance, namely, direct n-ZnO/CIGSS cells and devices with effective buffer layers. The approach to these studies involves combining information from SIMS profiles, current-voltage analyses and simulation studies. Tentative conclusions are as follows:

(1) Direct n-ZnO/CIGSS cells are characterized by enhanced current losses probably due to tunneling/recombination processes via trap levels associated with boron impurities that diffuse into the absorber during TCO deposition;

(2) CdS buffer layers act as effective diffusion barriers to boron and other impurities during cell processing resulting in cells with significantly reduced current losses relative to the direct cells;

(3) Current losses in CIGSS cells with CdS buffer layers are due to SRH recombination via midgap states.

ACKNOWLEDGEMENTS

This work was funded by NREL. We are also grateful to SSI for providing CIS substrates and cell structures, and to PNNL for allowing surface analyses to be done at the Environmental Molecular Science Laboratory.

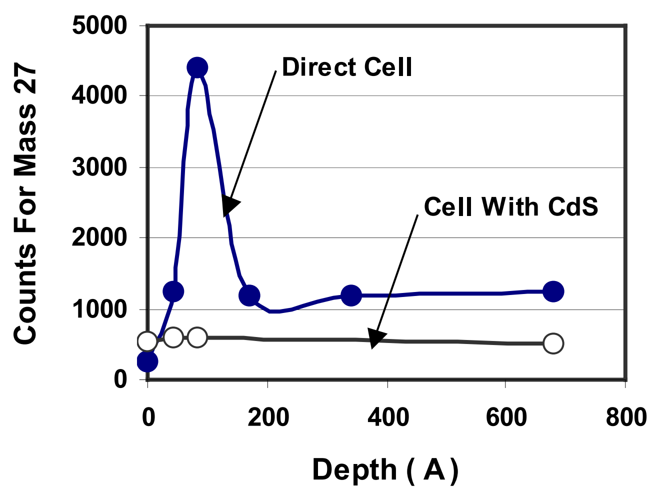

Figure 1. TOF-SIMS profiles due to a mass 27 species in direct ZnO(B)/CIGSS and ZnO(B)/CdS/CIGSS cells.