ROLE OF BUFFER LAYER IN CIGS SOLAR CELLS

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ABSTRACT

For CIGS solar cells, the study of junction buffer layers can be fruitful in developing its efficiency. Among the main selection criteria of buffer materials are the band gap, resistivity lattice matching with the absorber buffer absorber conduction band offsets, chemical constituents and manufacturability. Numerical modeling is an important tool to test the viability of physical explanations and to predict the effect of physical changes on cell performance . For consistent comparisons, it is always useful to have a common starting point or baseline. The modeling results for the base line parameters have been used to describe some complications which are observed in experimental study of CIGS solar cells.

INTRODUCTION

Any layer between the highly-doped ZnO transparent conducting oxide (TCO) and the absorber in fig.1 can be referred to as a “buffer” or “window”; the term “window”, however , is logically extended to TCO’ as well.[1]

From the electronic point of view , since buffer layers are usually highly- resistive , they serve as intermediate layers that can prevent shunting between the TCO and the absorber. From the technological point of view , buffer- layers can protect the absorber surface from damage by high- energy ions during the ZnO deposition by RF-sputtering(2). From the chemistry point of view , chemical constituents of buffer material passivate CIGS surface defects and dope the CIGS near-surface layer. And finally, from the physics point of view , buffer layers affect the band structure. Specifically, they affect the band offsets and the electric field in the junction, and thus the current transport.

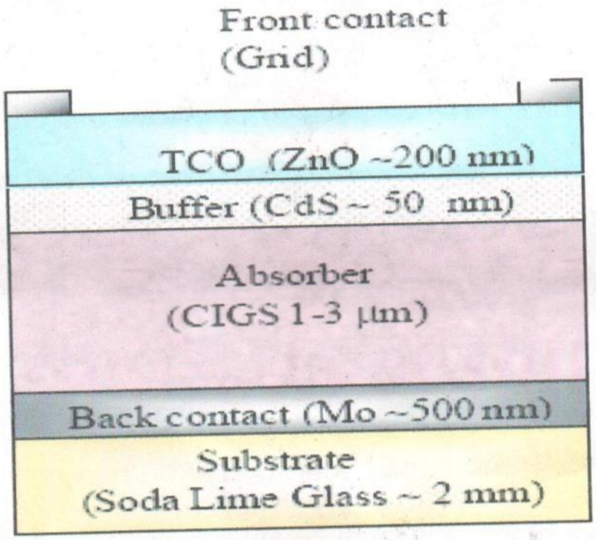

Figure-1 Layer structure of CIGS solar cells

Criteria for buffer-layer selection

To make a good junction partner with a p-CIGS absorber, a buffer material should be n-type, or possibly intrinsic (i-type). Buffers with high resistivity are preferred to reduce the possibility of shunting of a junction. Matching the absorber and the buffer lattice constants should also be considered when choosing a buffer. Poor matches may result in interfacial defects, which cause undesirable recombination of carriers. [3,4] Technological feasibility of the incorporation of a buffer layer into the cell manufacturing process must also be considered.

One other major criterion in selection of a buffer material is its band gap (Eg). Eg needs to be sufficiently wide that as few photons as possible are absorbed in the buffer. This point is illustrated with Fig.2 that shows the standardized solar spectrum, termed Air Mass 1.5 (AM 1.5), in the units of photon current. The figure also shows the maximum photocurrent density that the light can generate in a solar cell as a function of the absorber Eg. For 1.0-eV CIS, the maximum Jsc is near 46 mA/sq.cm, whereas it is nearly 6 mA/sq.cm lower for 1.15-eV CIGS. We note that despite the loss of current one will still gain in efficiency by widening the absorber band gap; the efficiency increase should theoretically occur up to Eg (absorber)= 1.4 eV due to increased Voc. The max. Jsc calculations assume that all photons with hv >Eg (absorber) are absorbed in the absorber and all minority carriers generated are collected at the junction.

Before reaching the absorber, however, the incident light first passes through the front window layers (Fig.1).Photons with energies above the band gap of these layers will be absorbed there and the generated minority carriers will predominantly not be collected due to their low mobilities.. As seen from fig. 2, the band gap of the ZnO TCO is Eg =3.2 eV , which is nearly optimal in the sense that only a very small fraction of solar spectrum may be absorbed in ZnO resulting in photocurrent loss less than 1 mA/sq.cm.

CdS (Eg = 2.4 eV), however, can lower the photocurrent through absorption by up to = 7 mA/sq.cm. By making the CdS buffer layer thinner, part of the short-wavelength current loss can be recovered.

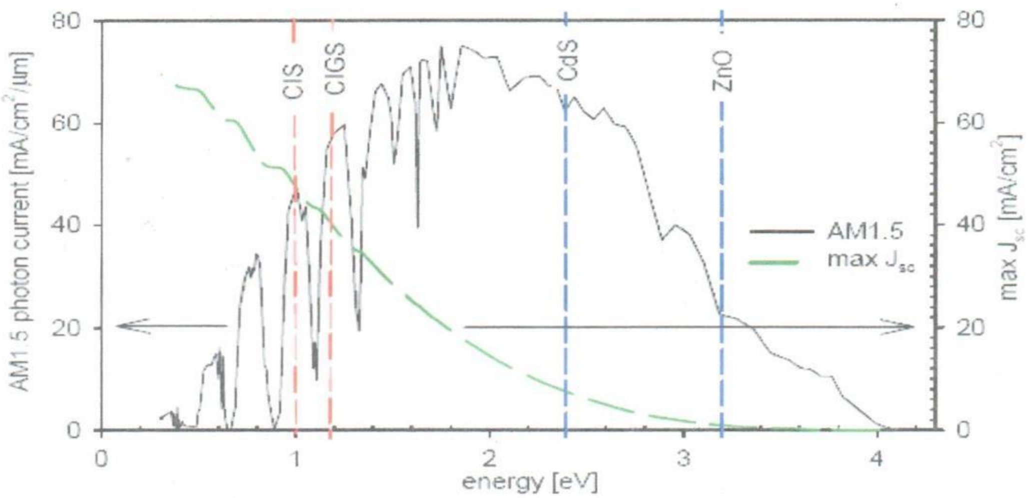

Figure-2 Standard AM1.5 solar spectrum; maximum attainable solar-cell short-circuit current density as a function of the absorber band gap.

	Cd		Zn		In		Sn
	Chalcogenides						
S	CdS		ZnS		In_2S_3		
Se			ZnSe	$ZnIn_2Se_4$	In_2Se_3		
	Oxides						
O			ZnO				SnO_2

Another important buffer-material selection criterion is its electron affinity , which will determine discontinuities in the energy bands at the buffer/absorber interfaces. The positive discontinuities (spikes) in the conduction band, causes deviations from the standard-diode behavior in solar cells. There have been a number of various buffer materials and surface treatments incorporated in CIGS solar cells by various groups. Above table lists the majority of buffer materials. Here even a fraction of solar-spectrum blue photons can be effective in removing the distortion from the CdS/CIS diode curves. Designing the tandem top cell to partially transmit high-energy photons is, therefore, recommended. Second, making the buffer layer(s) thinner, can effectively reduce secondary barriers and restore the standard behavior to the red- light J-V curves of CdS/CIGS solar cells.

Numerical Modeling-

The input parameter sets used to fit only experiment J-V data may not be unique. Therefore, fitting of experimental data is only conclusive if a wide set of data, i.e. J-V at different temperatures, and QE at different biases, is used. Input parameters that are well known, should not be changed at any time, whereas parameters that have only marginal effect on output can be tested and then changed. These parameters are excluded and the remaining parameters are available for fitting purposes.

For CIGS, several issues are frequently addressed with modeling tools. Most prominent are the explanation of superposition failure [5-6] and absorber grading [7-8]

Superposition- Fig.3 shows the conduction band diagram for the baseline in the dark and under illumination at OV bias. The choice of electron affinities generates a barrier at the CdSCIGS interface; under illumination this barrier is considerably reduced due to trapping of holes into the deep acceptor stats. The barrier height that is chosen for the baseline case is not sufficiently high to influence J-V results at room temperature.

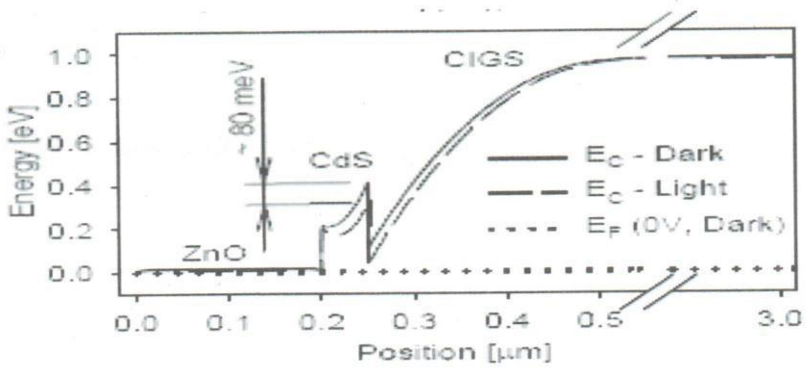

Figure-3 CIGS baseline: Conduction band diagram - 0V Bias

However, it has been shown that in the increased offset, 0.4 eV instead of 0.3 eV , generates the superposition failure often observed with CIGS cells. This type of non-superposition can only be described with DD models since it requires charge trapping in defect states. To a certain extent, manually adjusted free carrier concentrations, between light and dark simulation, can model trapping effects in LT models.

Absorber grading. Preferred software tools are those are those that allow a continuous variation of material parameters within a layer. A stepwise grading has to be done with care since it generates unrealistic discontinuities in the band structure. Often only the band gap is adjusted and changes in other material parameters are neglected due to insufficient experimental data. Numerical simulations have shown that grading can increase the calculated efficiency by several percent.

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