Devices based on glass/ITO/$Cu(In,Ga)S_2$ for rear side illumination : evaluation of performance limitations

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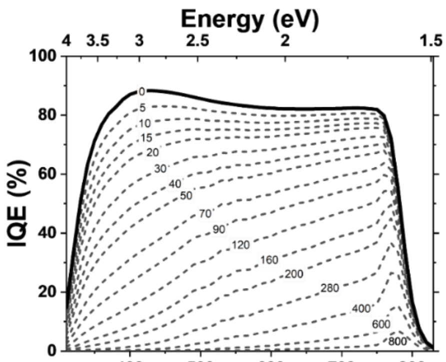
Thin film solar cells based on $Cu(In,Ga)S_2$ (CIGS) with band gap above 1.6 eV have recently gained interest for their potential application as top cell in tandem devices. In fact, efficiency close to 15 % with front side illumination has been achieved using glass/ITO transparent back contact. Interestingly, by using transparent electrodes on both front and back contacts, the glass substrate could be used as front protective glass, hence minimizing production costs and panels weight. Nonetheless, this configuration implies the light is shined on the rear side of the device, which is opposite to the PN junction.

The performance of the solar cells with rear side illumination has been observed as strongly dependent on the thickness of the absorber [1], the thicker the absorber, the poorer the carrier collection. This is clearly observed on the external quantum efficiency measured from the rear side. Through the thorough analysis and modelling of quantum efficiencies, comparing both front and rear illuminations, we have attributed this limited carrier collection to the existence of an area at the back side of the CIGS where the collection is extremely low or null. One should note that this area corresponds to about 10% of the total absorber thickness, regardless of wether the latter is between 300 nm and 3000 nm. We have proposed this area corresponds to a region of the CIGS where an unfavorable conduction band gradient exists, resulting in an unfavorable electric field for minority carrier collection.



Simulated rear-illuminated internal quantum efficiency (IQE) for a 1000 nm CIGS absorber, and diverse width of the "null-collection zone".

This latter is an indirect consequence of the consumption of gallium inherent to the formation of gallium oxide at the ITO/CIGS interface, leading to lowered gallium content in this region.

The figure beside plots the simulated internal quantum efficiency with rear illumination for diverse thickness of null-collection zone in the case of a 1000 nm-thick absorber. Due to the strong absorption coefficient of the CIGS, a null-collection zone as thin as 42 nm yields 50 % loss in J_{sc}. Through the fine tuning of absorber growth process, we could minimize the thickness of this null-collection area and reach J_{sc} values above 20 mA/cm² with rear side illumination, which is about that achieved with front side illumination.

The present contribution aims at presenting the details of the proposed model. Furthermore, the relevance of the model will be discussed in light of recent findings from advanced local characterizations techniques such as Atom Probe Tomography, Cathodoluminescence and Electron Beam Induced Current.

[1] F. Pineau *et al.*, "*Investigation of $Cu(In,Ga)S_2$ thin-films based solar cells deposited on In_2O_3:Sn transparent back contacts for rear-side illumination applications",* submitted to 'Progress in Photovoltaics, Research and Application.