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DOI
10.1364/OSE.2018.OM2D.5

Publication date
2018

Document Version
Final published version

Published in
Proceedings of Optics for Solar Energy, OSE 2018

Citation (APA)
Rezaei, N., Isabella, O., Vroon, Z., & Zeman, M. (2018). An optical study of back contacted CIGS solar cells. In *Proceedings of Optics for Solar Energy, OSE 2018* (Vol. Part F116-OSE 2018). OSA - The Optical Society. https://doi.org/10.1364/OSE.2018.OM2D.5

Light, Energy and the Environment Congress 2018 (E2, FTS, HISE, SOLAR, SSL) © OSA 2018

An optical study of back contacted CIGS solar cells

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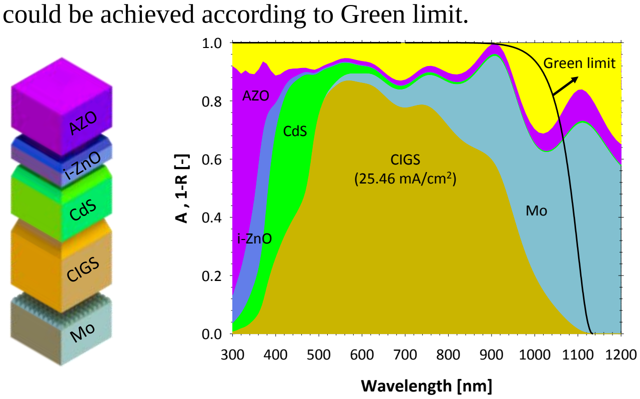
Abstract: An optical investigation of ultra-thin CIGS solar cells and guidelines for elimination of optical losses is presented. Then, a novel back contacted structure for CIGS solar cells is suggested and optimized for best implied photocurrent density.
OCIS codes: (040.5350) Photovoltaic; (050.2770) Gratings

Thin film solar cells based on high-absorption and large bandgap copper indium gallium (di)selenide (CIGS) have reached record efficiency of 22.9% [1]. Even so, CIGS solar cells still have room for improvement towards their theoretical efficiency limit [2]. One of the main obstacles on the way is the parasitic absorption of the front layers, which results in significant optical losses.

In this contribution, we first present the optical performance of a CIGS solar cell with a 500-nm thick absorber and compare it to the absorption limit formulated by Green [3]. Then, we show the potential optical gain when i) there is no front reflection, ii) the parasitic absorption of the front layers is quenched, and iii) the rear reflectance is increased by replacing molybdenum with silver. Finally, a back contacted CIGS solar cell design is suggested and investigated to approach the Green absorption limit. This optical study has been accomplished by means of a 3-D Maxwell's equation solver based on finite element method. The implied photocurrent density (J_{ph}) was calculated by convoluting the absorptance spectrum of each layer with standard AM1.5G spectrum [4].

The accuracy of the model was ensured by software calibration for two absorber thicknesses of 1600 nm and 750 nm. More details about this process can be found in our previously published work [4]. The simulated reference solar cell and its respective absorptance/reflectance spectra are presented in Fig. 1. As can be seen in Fig. 1(b), a large part of incident light is lost due to reflectance and parasitic absorption, leading to only 25.46 mA/cm^2 of J_{ph} compared to 41.6 mA/cm^2 that could be achieved according to Green limit.



(a) (b)

Fig. 1: a) Simulated model. Thicknesses of the layers from bottom to top (in nm): 200, 500, 70, 60 and 230. b) Simulated absorptance and reflectance (yellow) compared to Green absorption limit (solid black line) for a 500-nm CIGS layer.

It has been shown in the past that the presence of high aspect ratio (AR) features at the front surface of a solar cell can lead to elimination of reflectance and hence, to maximum light in-coupling [5, 6]. In this respect, we carried out a theoretical study to demonstrate the possibility of approaching or even surpassing the Green limit. At first, the Mo back contact was replaced by silver as a highly-reflective metal and all the front layers (i.e. CdS, i-ZnO and AZO) were removed. High AR pyramids with base dimensions of 300×300 nm^2 (close to correlation length of textures as-grown on CIGS, measured by atomic force microscopy) were placed on CIGS surface. The height of pyramids (h) was varied until maximum light was coupled into the absorber. The optimal value for h, therefore, was 390 nm, leading to height to width ratio of 1.3. As indicated in Fig. 2, even though optical losses at short-wavelength are quenched, the performance in long wavelength part of the spectrum needs to be improved. This was achieved by insertion of a low refractive index dielectric (MgF_2 in this case, according to our previous study [4]) together with gratings at the rear side of the cell for improving the rear reflectance and enabling scattering. The optimal values for dielectric thickness, grating height and width to period ratio of gratings are 100 nm, 300 nm and 50%, respectively. The latter was chosen based on a previous study done by Isabella et. al. [7] for maximal diffraction of light by the grating. The result is a significant increase in absorption spectrum of CIGS which leads to even outperforming the Green absorption benchmark at two wavelengths.

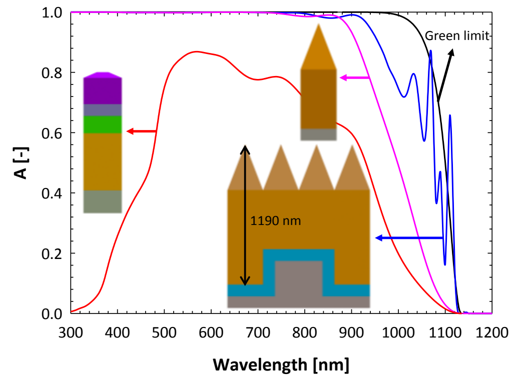
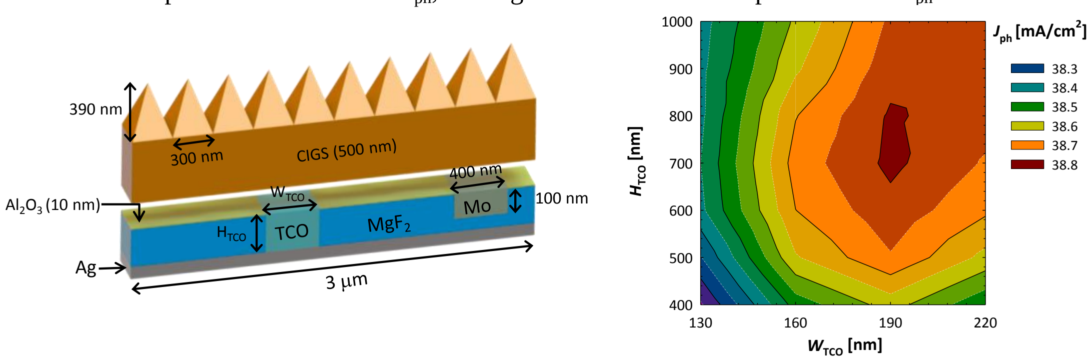


Fig. 2: Absorption spectra of the reference cell with a 500-nm thick absorber (red), a CIGS slab endowed with high aspect ratio pyramids and silver back reflector (pink), the same, but with the addition of diffraction gratings and a dielectric spacer at the back side (blue) and the Green absorption limit for a 1190-nm thick CIGS slab.

As the possibility of approaching the Green absorptance limit has been shown, we introduce the design of a novel back contacted CIGS solar cell. Fig. 3(a) shows a 500-nm thick CIGS absorber endowed with high AR pyramids at the front (with height to width ratio of 1.3) for minimal front reflection. In this 1-D periodic structure with a 3-μm wide pitch, the hole collection is done by conventional Mo contacts, while the electrons can be collected through an n-type transparent conductive oxide (TCO), In_2O_3:H in this case, with low long-wavelength absorption. A high rear reflection and isolation of p- and n-contacts were insured by an MgF_2 spacer. Silver was used as the back reflector and a thin layer of Al_2O_3 was placed on the spacer to guarantee electrical passivation. The TCO structural parameters, namely, height (H_{TCO}) and width (W_{TCO}) were optimized for maximizing J_{ph}, while all other parameters were kept constant. As shown in Fig. 3(b), for the parameter space so far investigated, maximum J_{ph} can be realized by an n-contact with height and width of 700-800 nm and 190 nm, respectively. This leads to 38.8 mA/cm^2 of J_{ph}, which shows a significant improvement of 52.4% compared to the reference CIGS solar cell. Considering the fact that this value of J_{ph} is much higher than that of a previously fabricated cell [4,8] with a more-than-three-times thicker absorber, this new structure is valuable for further research and therefore opening new ways towards high-efficiency and cost-effective CIGS solar cells. An extensive electrical modelling is essential for optimizing also the electrical performance, which will be provided by authors by the time of the conference.

In conclusion, we presented an optical study of ultra-thin CIGS solar cells and proposed a back contacted structure which no longer suffers from front reflection and parasitic absorption losses. The structural parameters of the n-contact were optimized for maximal J_{ph}, leading to more than 50% improvement in J_{ph}.



(a) (b)

Fig. 3: a) Rendering of the back contacted CIGS solar cell and b) implied photocurrent density as a function of height and width of n-contact.

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