Analysis of recombination mechanisms in KF-treated CIGS solar cells: Case of long-term Heat Light Soaking (HLS)

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Heat light soaking (HLS) has been reported to boost the efficiency of CIGS cells by increasing the net acceptor concentration [1]. However, some negative effects of the method such as an increase of the recombination center density have also been reported [2]. Thus, a careful evaluation of the impact of HLS on the properties of CIGS devices is necessary. In this work, we analyze the impact of the HLS on the V_{OC} loss mechanism in potassium treated (KF-PDT) CIGS solar cell devices using calculations based on the Shockley and Queisser detailed balance theory (SQ theory).

CIGS solar cells were deposited on Mo-coated soda-lime glass (SLG) by a three-stage co-evaporation process.[3] The [Ga]/([Ga]+[In]) (or GGI) was 0.4 in the first stage and changed to 0.25 in the third stage to modify the Ga gradient. HLS was performed under open-circuit conditions at 90˚ C in a dry nitrogen atmosphere using a combination of a metal-halide and a halogen lamp.

The I-V measurement shows a higher V_{OC}, short circuit current (J_{SC}), and fill factor (FF) leading to higher efficiency for the KF-treated sample compared to the untreated one. This may be due to an increase in the p-type conductivity as well [4,5] reduced interface recombination in treated samples.[6] Following HLS, a significant increase can be observed for all the parameters but J_{SC}, which decreases slightly. The effect of HLS is less pronounced for the untreated sample. To further study the impact of HLS, we analyze the V_{OC} loss due to nonradiative recombination in the bulk ΔV_{OC}^{bulk} expressed as:

$$\Delta V_{OC}^{bulk} = V_{OC}^{rad} - V_{OC}^{bulk} = \frac{kT}{q}\ln\left(\frac{J_0^{rad}}{J_0}\right) \qquad (1)$$

Here J_0 represents the saturation current due to nonradiative recombination in the bulk. J_0^{rad} is the dark saturation current in the radiative limit and can be calculated as:

$$J_0^{rad} = \frac{qWn_i^2 B}{n_r^2} = \frac{qWn_i^2}{n_r^2}\left(\frac{1}{N_A \tau_{rad}}\right) \qquad (2)$$

where W is the films thickness, n_i the intrinsic carrier concentration, n_r the refraction index, B the radiative recombination constant, N_A the net acceptor concentration and τ_{rad} is the radiative lifetime. In non-ideal case, τ_{rad} is substituted to the minority carrier effective lifetime τ_{eff} yielding the value of J_0. The total V_{OC} loss (ΔV_{OC}^{total}) is given by the difference (V_{OC}^{rad}-V_{OC}^{exp}) where V_{OC}^{exp} is the experimental V_{OC} values. Fig.1 compares the JV curves in the SQ, radiative, bulk limits, and experimental results for the treated and untreated sample before and after HLS. The results show that although the total V_{OC} loss (ΔV_{OC}^{total}) decrease after HLS, ΔV_{OC}^{bulk} increase following indicating a sharp decrease of interface recombination. In contrast to the treated one, the untreated sample shows only a slight decrease in the ΔV_{OC}^{total} and a drastic increase in ΔV_{OC}^{bulk}.The presence of (V_{Se}-V_{Cu}) in acceptor configuration [2] or antisite In_{Cu} [7] have been proposed as possible origins of the increased bulk recombination center density upon illumination.

KF-treated sample shows mitigation of the detrimental effects of HLS resulting in an improvement of 0.8% of the efficiency(from 21.2% to 22.0%) whereas no improvement was observed for the untreated sample. Therefore, a combination of HLS and KF/NaF-PDT can be used to achieve high-efficiency CIGS solar cells.

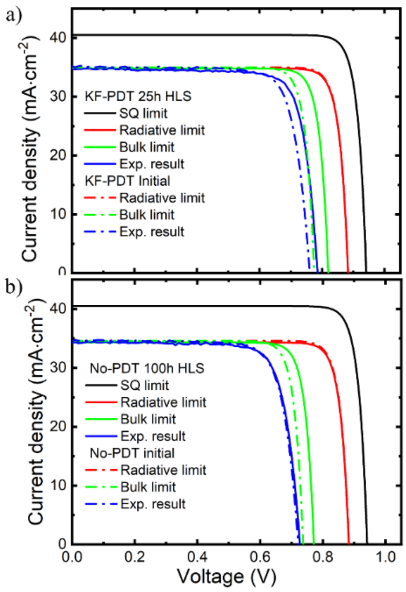

Fig. 1: J-V curves in the SQ, radiative and bulk limits, and experimental results for a) KF-treated sample and b) untreated sample before (dashed lines) and after

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References

[1] S. Heise *et al*. Sol. Energ. Mater. Sol. Cells **163**,270 (2017).
[2] S. Lany and A. Zunger, J. Appl. Phys.,**100**,113725 (2006).
[3] J. Nishinaga *et al*. App. Phys. Express, **10,** 092301 (2017).
[4] A. Laemmle *et al*. Phys. Status Solid (RRL),**7**,631 (2013).
[5] D. Rudmann *et al*. Appl. Phys. Lett. ,**84**,1129 (2004).
[6] F. Pianezzi *et al*. Phys. Chem Chem Phys.,**16**,88431 (2014).
[7] M. Igalson and H.W. Schock. J. Appl. Phys.,**80**,5765 (1996).