Impact of quasi-fermi level splitting and sub-bandgap absorptivity on the V_{OC} loss in CIGS solar cells

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The Shockley and Queisser principle of detailed balance (SQ model) between absorbed and emitted radiative fluxes from a photovoltaic absorber is the most common method used to evaluate the loss mechanisms in solar cells. The model assumed a step-like absorption coefficient thus neglecting the effect of band tailing for material with non-abrupt band edges wherein the electron-hole quasi fermi level splitting (QFLS) can modify both the absorption and emission spectrum. Here, we analyze the impact of the QFLS and sub-bandgap absorptivity on the V_{OC} loss mechanism in CIGS solar cell devices using full-spectrum fitting of the photoluminescence (PL) emission.

CIGS solar cells were deposited on Mo-coated soda-lime glass (SLG) by a three-stage co-evaporation process.[1] 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. The PL spectra were recorded on a CIGS absorber with a 640 nm laser as an excitation source and under one sun illumination condition.

Equation 1 represents the PL spectral flux and takes into account the sub-bandgap absorptivity of the material characterized by θ, the power of the tail, γ the energy of the tail (Urbach energy), and Δμ which denoted the QFLS. Fig. 1(a) shows the parameters extracted from the fitting of the recorded PL spectrum with Eq. 1. By considering the sub-bandgap absorptivity, the V_{OC} in the radiative limit (V_{oc}^{rad}) change by an amount $\Delta V_{oc}^{rad} = (k_B T/q)\ln(1-\gamma/k_B T)$[2] leading to a lower and more accurate value of the total V_{OC} loss. Fig. 1(b) shows the impact of the combined effect of the QFLS and γ on the V_{OC} loss. For values of γ less than 25.8 meV, the QFLS has a negligible impact, and the change in the radiative voltage loss ΔV_{oc}^{rad} , is mainly driven by the energy of tailing states (Urbach energy). For higher values of γ (>25.8 meV), ΔV_{oc}^{rad} will decrease due to the increased impact of the QFLS. This can be understood by the fact when the Urbach energy increases, the tailing will go deeper in the bandgap and suppress the radiative effect of deep-level states but will also lead to an increase of nonradiative recombination.

Such analysis can thus be useful in determining more realistic efficiency limits for photovoltaic technology.

$$\phi_{PL}(E) = \frac{2\pi}{h^3 c^2}\frac{E^2}{\exp\left(\frac{E-\Delta\mu}{k_B T}\right)-1} \times \left\{1-\exp\left[-G(\Delta E)\alpha_0 d\left(1-\frac{2}{\exp\left(\frac{E-\Delta\mu}{2k_B T}\right)+1}\right)\right]\right\} \quad (1)$$

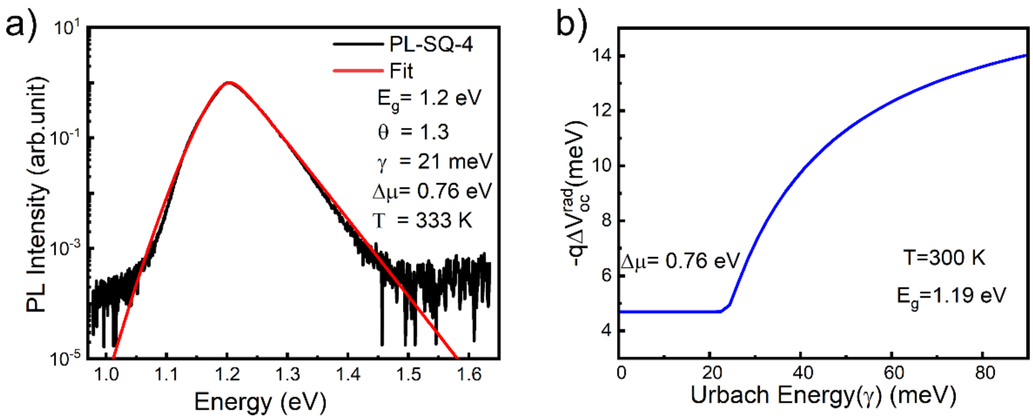

Fig. 1: a) PL spectrum under one sun fitted with Eq. 1. b) Effect of QFLS and Urbach energy on ΔV_{OC}

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