Area: 6 Advanced Concepts and New Emerging Materials for Future PV.

TWO-STEP PHOTON UP-CONVERSION SOLAR CELLS INCORPORATING A VOLTAGE BOOSTER HETERO-INTERFACE

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Realizing high-efficiency solar cells (SCs) is one of the attractive challenges in renewable energy technologies. Photon up-conversion can reduce the transmission loss and is the promising way which improve the conversion efficiency. One of the concepts utilizing the photon up-conversion is so-called intermediate-band SC [1, 2]. Recently, we have proposed a different type of SC structure, called two-step photon up-conversion SC (TPU-SC), which consists of a single-junction SC (SJSC) incorporating a semiconductor hetero-interface [3]. In this paper, we present the theoretical calculation of TPU-SC based on the detailed balance framework.

Figure 1 shows a schematic band diagram of a typical TPU-SC used in our calculations. The TPU-SC is a *p-i-n* single junction diode structure comprising a wide gap semiconductor (WGS) and narrow gap semiconductor (NGS). We deal with a SC with an *n*-on-*p* structure The WGS / NGS hetero-interface is formed in the intrinsic layer. Sunlight irradiates the WGS side (left-hand side of Fig. 1). High-energy photons are absorbed in the WGS, and excited electrons and holes drift in opposite directions towards the *n*- and *p*-type electrodes, respectively. Below-gap photons for the WGS pass through the WGS layer and excite the NGS, in which excited electrons drift towards the WGS / NGS hetero-interface and accumulate there, while holes reach the *p*-layer. The accumulated electrons at the hetero-interface are pumped upwards into the WGS by the below-gap photons, resulting in the efficient TPU. Figure 2 shows the calculated open circuit voltage (V_{oc}) and quasi-Fermi splitting (μ_{up}) at the hetero-interface calculated for various valence band discontinuities (ΔE_c : ΔE_v) as a function of sunlight concentration. In this calculation, we used the bandgaps of the WGS (E_{WGS}) and NGS (E_{NGS}) at 1.8 and 1.4 eV, respectively. In Fig. 2, the slope of V_{oc} for the TPU-SC becomes slightly steeper than that of the SJSC (blue line) at lower sunlight concentrations. On the other hand, at higher concentrations, all the slopes coincide with that of the SJSC. With the increase in solar concentration, the boosted voltage of μ_{up} increases and finally reaches ΔE_c. Once μ_{up} saturates, the change in V_{oc} becomes small. At lower concentrations, the increases in μ_{NGS} and μ_{up} contribute to the increase in V_{oc}. Conversely, at higher concentrations, only the increase in μ_{NGS} drives the increase in V_{oc}. Thus, our calculated results unveil the effect of the voltage boost at the hetero-interface.

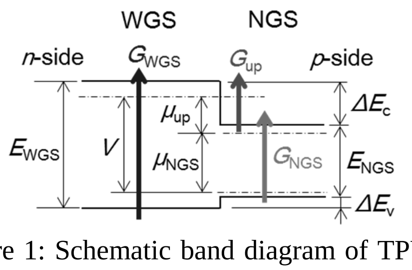

Figure 1: Schematic band diagram of TPU-SC. E_{WGS} and E_{NGS} are the bandgaps of the WGS and NGS, respectively. μ_{WGS} and μ_{NGS} are the quasi-Fermi level splitting in the WGS and NGS, and μ_{up} is the quasi-Fermi level splitting at the hetero-interface. ΔE_c and ΔE_v are the conduction band and valence band discontinuity, respectively. G_{WGS} and G_{NGS} are the carrier-generation rates in the WGS and NGS, and G_{up} is the carrier-generation rate at the hetero-interface.

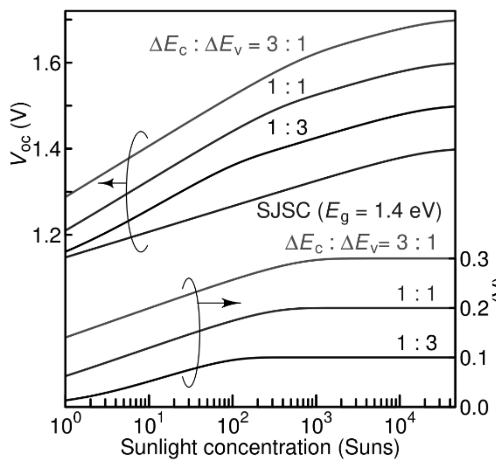

Figure 2: Calculated open circuit voltage (V_{oc}) and quasi-Fermi splitting at the hetero-interface (μ_{up}) as a function of sunlight concentration. In this calculation, E_{WGS} and E_{NGS} are fixed at 1.8 and 1.4 eV, respectively. Calculated V_{oc} curve for the single junction solar cell (SJSC) with a bandgap (E_g) of 1.4 eV is also indicated.

[1] A. Luque *et al*., *Phys. Rev. Lett.* **78**, 5014. [2] Y. Okada *et al*., *Appl. Phys. Rev.* **2**, 21302.
[3] S. Asahi *et al*., *Nat. Commun.* **8**, 14962.