The two-step photon absorption (TSPA) via the intermediate-band (IB) is the key process for the efficient operation of quantum-dot IB solar cells (QD-IBSCs) and has been reported experimentally [1]. However, detailed analysis of effects of TSPA and IB carrier capturing on quantum efficiency (QE) has not been developed. In this paper, we study how carrier capturing rate affects quantum efficiency (QE) and TSPA by the drift-diffusion simulation.

We carried out the drift-diffusion simulation for QD-IBSC [2] incorporating with a non-radiative carrier relaxation process between IB and the conduction band (CB) to effectively include the fast carrier capturing to IB. The rate constant of the relaxation process was simply assumed as a product of the effective density of state of IB and the inverse of time constant \( \tau \). The device structure employed in this study is presented in Fig. 1. GaAs parameters at 300 K were employed for the host material. QE was calculated by taking a difference of current densities with and without the incident light and by dividing by a product of the incident photon flux density and the elementary charge. We considered the dark and the light biased conditions as the background. The effect of the bias light illumination was evaluated by the difference of QE\(_s\) (\(\Delta\)QE) between cases with and without the light under the short-circuit condition.

Figure 2 shows \(\Delta\)QE dependence on the carrier capturing time constant. The bias light with energy of 0.5 eV was employed for CB-IB carrier excitation. \(\Delta\)QE in the radiative limit case \((\tau \geq 10^{-7}\text{ s})\) has a signal only in the wavelength range for the photon absorption between IB and the valence band (VB) \((1305 \text{ nm} > \lambda > 867 \text{ nm})\). On the other hand, when the capturing process becomes dominant \((\tau = 10^{-11}\text{ s})\), there are an increase and a decrease of \(\Delta\)QE in the ranges of CB-VB \((\lambda < 867 \text{ nm})\) and IB-VB light absorption, respectively. The signal in the short wavelength region indicates that the photo-generated carriers in the top emitter region can be captured by IB but can re-excite into CB by absorbing the bias light. On the contrary, the reduction of the peak in the long wavelength \((1305 \text{ nm} > \lambda > 867 \text{ nm})\) simply implies the reduction of TSAP compared to the result in the radiative limit. In the ultra-fast capturing limit \((\tau \leq 10^{-13}\text{ s})\), \(\Delta\)QE signal significantly decreases because the fast capturing process diminishes the carrier excitation by the bias light.

In conclusion, the profile of \(\Delta\)QE provides the information of the optical absorption of IB-CB photons and the capturing rate to IB. Therefore, we can evaluate TSAP performance and also carrier capturing effects by comparing signals in wavelength ranges for IB-VB and CB-VB absorptions from \(\Delta\)QE measurement.

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**Figure 1**: Schematic of employed QD-IBSC structure. Energy gaps of CB-IB, IB-VB and CB-VB are 0.43, 0.95 and 1.43 eV, respectively. GaAs parameters were used for the host material.

**Figure 2**: \(\Delta\) QE dependence on the carrier capturing time constant with the biased light with an energy of 0.5 eV in short-circuit condition.