Efficiency Compensation from Intraband Transitions of Opposite Carrier in a Quantum Dot-in-well Intermediate Band Solar Cell

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Devices incorporating quantum wells (QWs) and quantum dots (QDs) have been widely explored in optoelectronic field, ranging from optical signal amplifiers to lasers. One of the interests is engaged on solar cells. These low-dimensional designments in addition to bulk materials provide a controllable absorption threshold for photovoltaic devices beyond their prototypes, even extend the photon-electron conversion process into the infrared region. Intermediate band solar cell (IBSC) was proposed on the concept toward a reduction of transmission losses for common devices, which specifies multi-step absorption process for below-gap photons in addition to fundamental excitations, providing a larger photogenerated current profile with voltage preservation. Recently, we've reported the electrical performance of an $Al_{0.3}Ga_{0.7}As$ p-i-n IBSC containing InAs/GaAs quantum dot-in-well (DWELL) structures. On the one hand, an extremely long-lived electron behavior has been theoretically revealed in quantum confined states even at room temperature, which is beneficial for adiabatic two-step photoexcitation process [1]. On the other hand, its voltage output undergoes a degradation if strong asymmetric sub-bandgap excitations are applied [2]. In this report, we spectrally studied the external quantum efficiency (EQE) of DWELL IBSC. It is proposed that an efficiency compensation can occur when differed intraband transitions are activated simultaneously.

The detailed device fabrication process can be followed in [1]. Figures (a) and (b) show the infrared-light(IR)-biased (1319nm) EQE results at different wave ranges. As the bias light intensified, EQE increases monotonously at a detection range over 400-930 nm, yet an opposite tendency is observed at the detection range below QW absorption. The different results between two excitation ranges lie in the confined carrier state. In essence, electrons and holes created by the high-energy photons can be separately trapped into QDs, resulting in a relatively long lifetime for electrons. This leads to an efficient electron up-conversion process toward the conduction band of $Al_{0.3}Ga_{0.7}As$ matrix, and consequently, EQE increases. On the contrary, resonant excitation of QD ground states usually generates electron-hole pair within a QD. It limits the photo-carrier lifetime by radiative recombination process, and more holes are obstructed. Given that a decreased EQE is observed under IR excitations, the holes were expected to non-radiative recombine to offset the EQE increase from electrons. It is considered there are some trap states in the valence band continuum that facilitate the intraband transition of holes. Further experiment with additional 532 nm green light (GR) makes the above assumption possible, as indicated in Fig. (c). These high energy photons may directly excite the trap levels and leave holes there, and obtained EQE result then gradually become dominated by electron up-conversion process. An efficiency compensation relationship is thus established between two transitions.

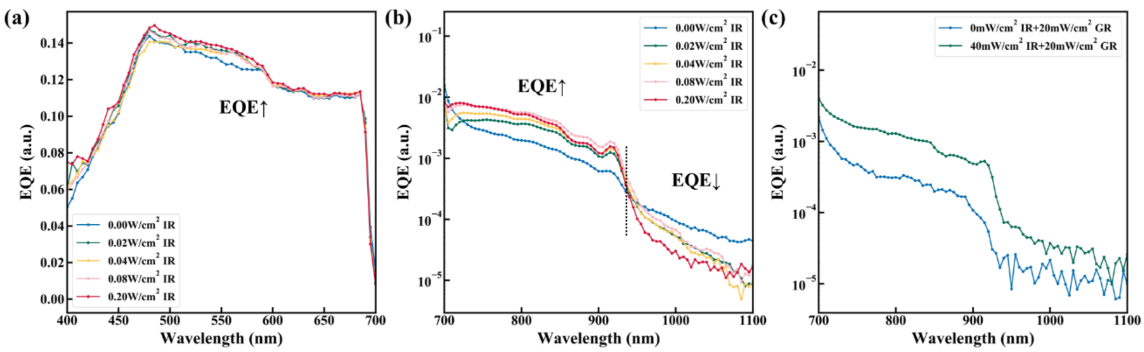

Figure EQE results of DWELL IBSC under an infrared-light bias at the detection range over (a) 400-700 nm and (b) 700-1100 nm. (c) The EQE results of 700-1100 nm detection with bi-color biases. Data were taken at a sample temperature of 295K.

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References

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