On the Simulation of Two-Step Photocurrent Generation in an InAs Quantum Dot-in-Well Intermediate Band Solar Cell

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The intermediate band solar cell (IBSC) follows a single junction solar cell prototype with an additional intermediate band forming in the semiconductor bandgap, which works as a step-stone for the below-gap photon absorptions excluded by fundamental excitations. The reduced transmission loss in IBSC leads to an improvement on the conversion efficiency; the Shockley–Queisser limit for conventional single junction solar cell can be surpassed by IBSCs. Recently, we've proposed an $Al_{0.3}Ga_{0.7}As$ *p-i-n* IBSC incorporating with InAs/GaAs quantum dot-in-well (DWELL) structures, in which the photoexcited carriers efficiently separate in quantum confined states owing to the asymmetric band structure in DWELL region [1-2]. An extremely long-lived electron state has been revealed in QDs at room temperature, which favors the adiabatic carrier two-step sub-band transition process. We've studied the two-step current generation in this cell design with multiple DWELL layers and observed saturated outputs under unbalanced excitation conditions [1]. Though it is well explained by a changed occupation state in the QDs, a detailed study on the carrier behaviors is still missing. In this report, we further studied the two-step current generation process in DWELL IBSC, which is representatively demonstrated with a sample containing single DWELL layer. A mathematical model is given to simulate the results we detected in the response range of DWELL structure.

The two-step excitation experiment involves carrier interband excitation in different solar cell components and carrier intraband excitation in QDs. Figure (a) shows the current response detected through external quantum efficiency (EQE) measurements. An additional intraband excitation brings out the electron collection efficiency by reducing the recombination in QDs; saturated EQE improvements were observed regradless of the primary interband excitation wavelengths. We focused on the current response in the DWELL structure as the sub-band absorptions occurs there. Figure (b) demonstrates a comparison between experimental result and simulated current response at an excitation wavelength of 1040 nm. For the simulation, four fundamental processes are considered, including QD interband excitation, QD intraband excitation, electron/hole thermal escape process and recombination process. We succeeded reproducing the output tendency in the subplot. Detailed carrier dynamics are studied from the change of excess carriers in QDs, which is given in Fig. (c). Both electron and hole numbers are affected by the intraband excitations, and there is an increase on the hole numbers as less recombination occurs at higher intraband excitations. In previous report, it is related that the saturated current as a sign of exhausted electron state in QDs [1]. However, we concluded that there is an excess of electrons in the QDs even under dense intraband excitaions.

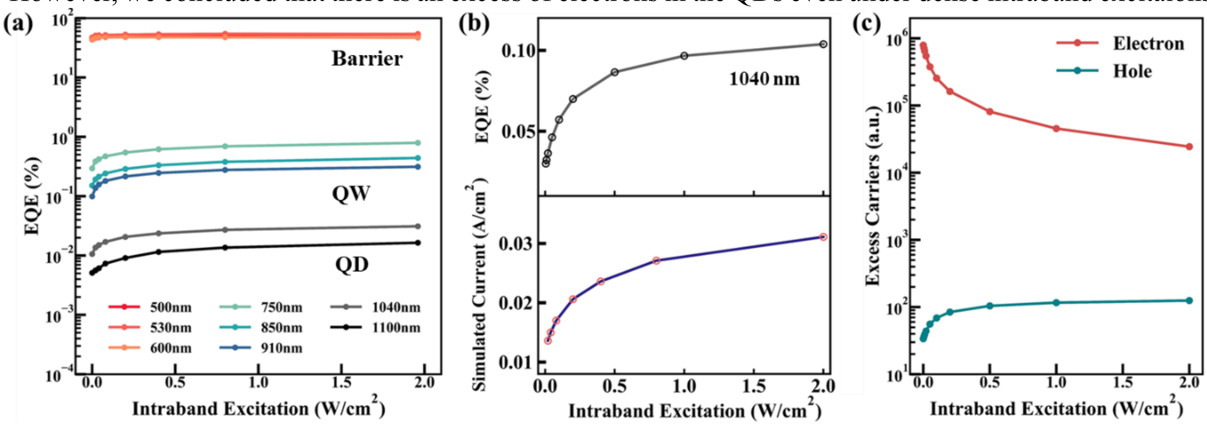

Figure (a) EQE of device under two-step excitations. Data were taken at 295K. (b) EQE (above) and simulated current result (below) at QD excitation of 1040 nm. (c) Simulated excess carriers in process.

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References

[1] S. Asahi, H. Teranishi, N. Kasamatsu, et al. *IEEE Journal of Photovoltaics*, **6**, 465-472 (2016).
[2] S. Asahi, T. Kaizu, T. Kita. *Sci. Rep.*, 9, 7859 (2019).

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