Electrical Properties of AlGaAs/GaAs-Based Two-Step Photon Up-Conversion Solar Cells with Doubled heterointerfaces

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Two-step photon up-conversion solar cells (TPU-SCs) have been experimentally realized based on AlGaAs/GaAs semiconductors. The TPU-SCs consist of a heterointerface between $Al_{0.3}Ga_{0.7}As$ and GaAs where InAs quantum dots (QDs) are present. The heterointerface enhances below-bandgap photoabsorption allowing the intraband transition in addition to the interband transition [1]. Here, we fabricated a novel structure of TPU-SCs by incorporating a substantial layer of $Al_{0.7}Ga_{0.3}As$ aiming to create two heterointerfaces. These novel TPU-SC devices consist of $Al_{0.7}Ga_{0.3}As$, $Al_{0.3}Ga_{0.7}As$, and GaAs with different bandgaps. Hence, there are two heterointerfaces i.e., the heterointerface between $Al_{0.7}Ga_{0.3}As$ and $Al_{0.3}Ga_{0.7}As$ (called HI-I), and the heterointerface between $Al_{0.3}Ga_{0.7}As$ and GaAs (called HI-II). We named this novel structure doubled-heterointerface TPU-SCs (called DTPU-SCs). In this work, we studied optical excitation influences on the electrical properties of DTPU-SCs.

The 784-nm photons were generated by a continuous-wave laser diode in order to selectively excite GaAs and collect photocurrent data at room temperature. Figure 1(a) shows the interband excitation intensity-dependent photocurrent measured under short-circuit conditions (J_{sc}) with and without additional intraband (1319-nm infrared) photoexcitation. The photocurrent, without additional infrared photons, increases as interband excitation increases as elucidated in Fig. 1(a). Comprehensively, the photogenerated electrons in GaAs across the doubled-heterointerface via the thermal activation process reach the front electrode. Notably, the data points cannot be fitted using a linear power function. Such a phenomenon is expected to be caused by the structure of HI-I. That is, the structure is a so-called dot-in-well structure (DWELL) in which the photocurrent characteristics exhibit a saturation feature under high interband excitation intensity [2]. With additional infrared photons, the photocurrent improves with a similar tendency as without infrared conditions, which suggests the tripled-photoexcitation, i.e., an interband excitation and an intraband excitation at each heterointerface. In addition, we measured the difference between photocurrent with and without intraband photon irradiation (ΔJ_{sc}) under 784-nm interband excitation. Figure 1(b) shows the linear dependence feature of ΔJ_{sc} on intraband excitation intensity. Interestingly, the unique super linear characteristic observed at small intraband excitation intensity is caused by the doubled-heterointerface that enhances the photocurrent generation as indicated by the power index (n). With increasing the intraband excitation intensity, the index decreases due to several factors, e.g., thermal energy produced by intervalley scattering in $Al_{0.7}Ga_{0.3}As$ and the environment, specifically from $n = 1.137$ to $n = 0.742$. We believe that the reduced n additionally indicates the saturation effect caused by DWELL structure at HI-I. The power index, in the case of interband excitation of 93.3 mW/cm^2, is $n = 0.856$ with a single fitted function caused by the saturation characteristics due to the accumulation of electrons excited by dense 784-nm photons. Furthermore, the power index is nearly similar to $n = 0.742$ which is caused by the assistance of interband photons on the intraband excitation at the doubled-heterointerface.

In this work, we achieved the detection of photocurrent of DTPU-SCs under 784-nm photoirradiation suggesting carrier transport at the doubled-heterointerface via the thermal activation and intraband excitation which may enhance the intraband absorptivity as well as a notable feature of intensity-dependent photocurrent.

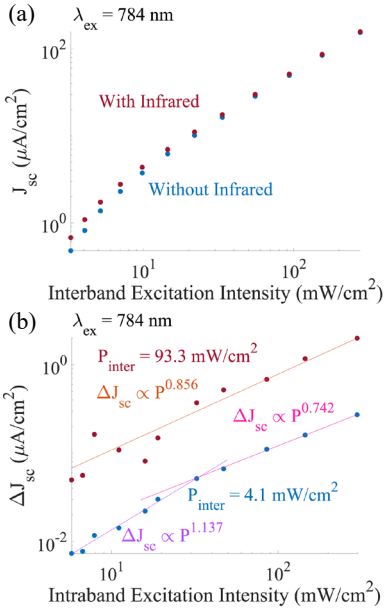

Figure 1 (a) The photocurrent as a function of interband excitation intensity, **(b)** ΔJ_{sc} with increasing intraband intensity at specified interband intensity indicated by P_{inter} symbol. The power indices (n) are also indicated as $\Delta J_{sc} \propto P^n$.

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[2] S. Asahi, H. Teranishi, N. Kasamatsu, T. Kada, T. Kaizu, T. Kita: IEEE J. Photovolt., 6 (2016)