Quantum dot intermediate band solar cells: proving the concept and beyond

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High-density array of quantum dots (QDs) incorporated in the active region of a p-i-n junction solar cell has attracted significant attention as a means of utilizing the sub-bandgap infra-red photons to generate additional photocurrent beyond that corresponding to the valence-to-conduction band transition, thereby achieving conversion efficiencies exceeding the Shockley-Queisser limit of a conventional single-junction solar cell.

In a QD solar cell, QDs are required to be homogeneous and small in size as well as tightly spaced, which would then lead to formation of an intermediate-band (IB) or a miniband structure that is well separated in energy from the higher-order states. Further, IB should be partially filled with electrons in order to assure an efficient pumping of electrons by providing both empty states to receive electrons being photo-excited from the valence band (VB), and filled states to promote electrons to the conduction band (CB) via absorption of second sub-bandgap photons.

Recently, we have developed strain compensation technique to fabricate multiple stacked InAs/GaNAs QD solar cells grown on GaAs substrate by molecular beam epitaxy (MBE) [1,2]. Compensating for lattice strain induced by a QD layer with a spacer layer which exerts an opposite biaxial strain in order to cancel out the average strain to zero, works remarkably well to achieve improved size uniformity, and to avoid generation of defects and dislocations in multiple stacked QD structure. Up to 100 layers of multi-stacking of InAs/GaNAs QDs have been demonstrated using this technique.

Next, we have developed a growth technique to directly dope InAs QDs with Si in order to control the quasi-Fermi level of intermediate QD states as schematically drawn in Fig. 1 [3]. The short-circuit current density I_{sc} of QD solar cell has increased from I_{sc} = 24.1 (non-doped QD solar cell) to 30.6 mA/cm^2 (direct Si-doped QD solar cell). Further, a clear photocurrent production due to two-step photon absorption has been detected for the first time at room temperature under a filtered AM1.5 solar spectrum.

References

[1] R. Oshima, A. Takata, and Y. Okada, Appl. Phys. Lett. 93 (2008) 083111.

[2] R. Oshima, A. Takata, Y. Shoji, K. Akahane, and Y. Okada, Physica E, 42 (2010) 2757.

[3] Y. Okada, T. Morioka, K. Yoshida, R. Oshima, Y. Shoji, T. Inoue, and T. Kita, J. Appl. Phys. 109 (2011) 024301.

Figures

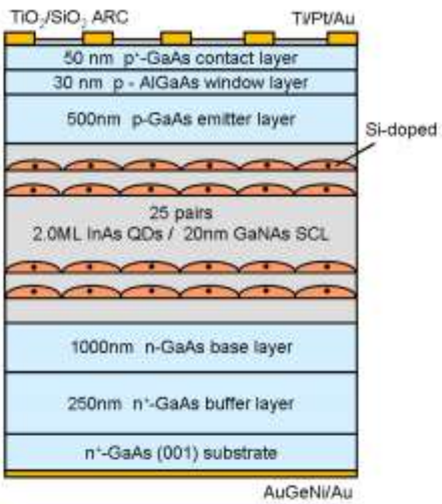

Figure 1: Schematic structure of QD intermediate band solar cell fabricated on GaAs substrate with multiple stacks of strain-compensated InAs/GaNAs QDs, direct-doped with approximately one Si atom per QD.