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Effect of Carrier Doping of InAs Quantum Dots on the Performance of QD Intermediate-Band Solar Cells

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The intermediate band solar cell (IBSC) is one of the promising candidates for the next generation of photovoltaic cells with a maximum theoretical efficiency of 63% at full sunlight concentration [1], and quantum dot (QD) based IBSCs are intensively studied. The QD-IBSCs reported to date often show a drop in the open-circuit voltage at 1 sun, however, the voltage and hence the cell efficiency recover fast under concentrated illumination of sunlight [2]. The QD-IBSCs is thus expected to perform better under concentrated sunlight condition in which the photo-generation rate will outperform the recombination rate via IB states. To this end, the QDs are required to be homogeneous and small in size and be tightly packed in the active region of the cell, in order to form an IB or a superlattice miniband that is well separated in energy from the higher energy states. Further, the control of total density of QDs and carrier filling ratio in IB are essential to achieve high efficiency.
In this work, we have investigated the effect of n-type doping of InAs/GaAs QDs and of sunlight concentration on the SC performance. The pre-filling of InAs/GaAs QDs by Si-doping up to 8 electrons/QD was achieved by delta and direct-doping techniques in molecular beam epitaxy (MBE) [3]. A gradual recovery in the open-circuit voltage of QDSC with increasing Si-doping concentration was observed as a result of decrease of recombination via QD states. Under concentrated sunlight illumination, QD states became additionally filled with photo-excited carriers and the open-circuit voltage and efficiency increased non-linearly with concentration ratio in both non-doped and Si-doped QDSCs. We show that both the pre-doping of QDs and the photo-filling by sunlight concentration are effective way to improve the cell performance.
Ref. [1] A. Luque, A. Martí, and C. Stanley, Nature Photonics, 6, 146 (2012), [2] Y. Okada, N. J. Ekins-Daukes, T. Kita et al, Appl. Phys. Rev., 2, 021302 (2015), [3] S. Naito, Y. Okada et al, J. Photon. Energy 7, 025505 (2017).

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