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Effect of Vertical Miniband on the Photovoltaic Performance of a Solar Cell with Quantum Dot Superlattice Fabricated by Using Bio-Template and Neutral Beam Etching Technology

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Silicon quantum dots (QDs) hold the potential to drastically improve solar power technologies and provide a transformative improvement to traditional Si photovoltaic cell. However to form and realize a true QD and its super lattice (QDSL) by using conventional bottom up process seems to be quite challenging. Recently we developed a sub-10-nm 3D Si-ND structure as a QDSL by fusion of bio- templates of a 2D array of Listeria-Dps (Li-Dps) iron oxide cores (diameter: 4.5 nm; density: ~1.4×10^{12} cm^{-2}) as a uniform etching mask and damage-free neutral beam (NB) etching techniques [1]. Our quantum dot superlattice (QDSL) consists 4 stack layer of 4nm Si NDs layer and 2nm interlayer of SiC being alternately arranged into a periodic array inside the structure and finally the whole structure were fully covered with dielectric SiC matrix material in which the carrier wave functions with close-packed and well-aligned QDs overlap one another and discrete confined energy levels merge into broadened miniband[1]. In the present study it is our goal to realistically clarify the role of QDSL (effect of miniband formation) by observing its photovoltaic performance in a solar cell. In this regard we fabricated and characterized two kind of p-i-n solar cells: one with an inter layer of the 3D array of Si -NDs (i-QDSL) in between p-Si and n-Si emitters and other with an interlayer of multi quantum well (i-QW) of 4 stack Si/SiC stack layer (without QD) in between p-Si and n-Si emitters as shown in the inset of Fig. 1(a). From the current voltage (*IV*) relationship as shown in Fig. 1 (a) it is clearly revealed that the photovoltaic performance of the p-i-n solar cell with i- QDSL (red line) holds higher photovoltaic performance with values of photocurrent density (J_{sc}), open-circuit voltage (V_{oc}), Fill Factor (*FF*) and Efficiency (η) of 29.24 mA/cm2, 0.54 V, 0.74, and 11.07%, respectively than the p-i-n solar cell of i-QW layer with the values of 25.27 mA/cm^2, 0.49 V, 0.69, and 8.61%, respectively. Fig. (1b) shows the external quantum efficiency of both solar cells where we observed larger optical enhancement of the p-i-n with i-QDSL solar cell as compared with p-i-n of i-QW solar cell. In order to clarify such photovoltaic enhancement of solar cell with QDSL, we illustrated the electron transport mechanism through the energy band structures of both p-i-n solar cells as shown in Fig. 2 (a) and (b). Fig. 2(a) demonstrated that incident photo-generated electrons inside p-i-n with QDSL solar cell were very smoothly transported through close packed arranged QDs which forms vertical the miniband generating high optical absorption from higher to lower energy solar spectrum and causes drastic improvement of the photovoltaic performance that was obtained shown in Fig.1. On the other hand in Fig. 2(b) we illustrate that the incident photo generated electron inside the p-i-n solar cell with i-QW of Si/SiC stack layer passes through the large band-offset of Si (1.1eV) and SiC (3.0 eV) weakens the photo generated electron resulting lower photovoltaic performance. Therefore, we conclude that the enhanced transport and photo absorption in the QDSL can play a key role in efficient absorption of photons as well as in power generation in high efficiency solar cells.

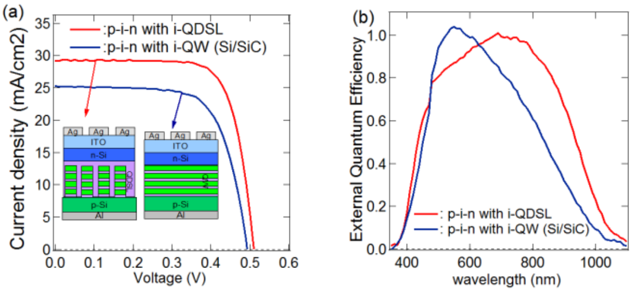

Fig. 1. (a) *IV* curve and (b) EQE of p-i-n solr cell with i-QDSL and i-QW respectively.

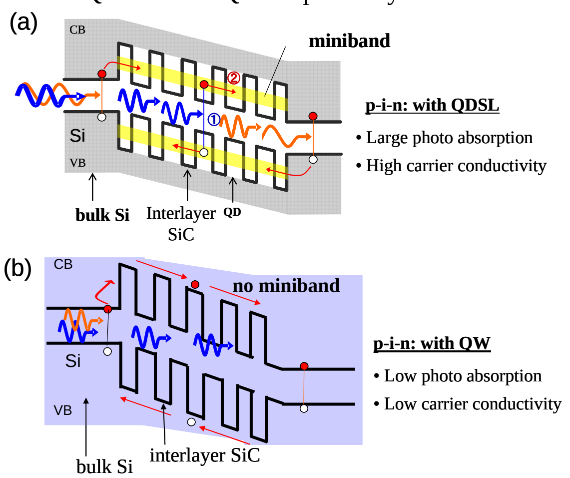

Fig. 2. Illustration of carrier transport mechanism through the p-i-n solar cells with (a) i-QDSL and (b) i-QW.

[1] M. Igarashi, W. Hu, M. M. Rahman , N. Usami, and S. Samukawa, Nanoscale Research Letters **8** (2013) 228.