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Optimization of Passivation Layer for a Quantum Dot Superlattice Fabricated with Bio-template and Neutral Beam Etching Technology for High Efficiency Solar Cell

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Recently a sub-10-nm 3D Si-ND structure as a quantum dot superlattice (QDSL) fabricated by the fusion of bio-templates of a 2D array of Listeria-Dps (Li-Dps) or Ferritin iron oxide cores as a uniform etching mask and damage-free neutral beam (NB) etching methods has been very important in photovoltaic application due to its controllable QD size, shape, uniformity and high density [1]. The 3D QDSL consists of 4 stack layer of 4 ~8 nm thick Si NDs layer and 2nm interlayer of SiC being alternately arranged into a periodic array inside nanopillar (height <100 nm) structures with the density 1.4×10^{12} cm^{-2} and few nm distance between two nanopillars as shown in Fig. 1 (a). In fabrication process of QDSL, one of the most significant steps is how to passivate the side walls of the nano pillars. This is because the existing air gap due to lack of proper passivation between two nano pillars and their interface defects in between QD and SiC interlayer in the super lattice structure causes high leakage current resulting photo carrier recombination that poorly affect solar cell performance. In the present study we aim to optimize the passivation layer for the QDSL structure with several films such as conventional sputtered amorphous SiC, hydrogen (H_2) treated a-SiC (a-SiC:H), and an atomic layer deposited aluminum oxide ALD_Al_2O_3 films, respectively. Fig. 1(b)-(d) shows the cross-sectional and top-view (insets) SEM images of the QDSLs with these passivated films from which it was clearly observed that by changing passivation layer from a-SiC to ALD_Al_2O_3 the gap between two nano pillars were smoothly getting to be reduced. In order to investigate leakage current suppression between the QDSL and its substrate a conductive atomic force microscopy (CAFM) with the three QDSLs were studied as shown in Fig. 2. In Fig. 2, current voltage (*IV*) relation ship of the CAFM analysis exhibits that QDSL with a-SiC (blue) responded to generate larger leakage current and its was getting lower after its modification (green) by a H_2 treatment (a-SiC:H) and finally become zero by ALD_Al_2O_3 (red) passivation. To realize the photovoltaic performance from the QDSLs we fabricated p^{++}-i-n solar cells with QDSLs (as a i-layer) with different passivation layers same as mentioned above. Here high doping density ($>10^{20}$ cm^{-3}) of p^{++} Si substrate prevents the generation of photocurrent inside the substrate itself and as a result we could generate photocurrent from QDSLs only. We summarized the values of the photocurrent density (J_{sc}) and open circuit voltage (V_{oc}) generated from QDSLs in Table 1, from where it was revealed that a few nm ALD_Al_2O_3 performed as the best material to reduce dangling bond forming a true QDSL that generated an open V_{oc} of 40 mV and also enhanced photo generated carriers to be transported smoothly thorugh the nano pillar walls of the QDSL so that a large value of J_{sc} of 4.78 mA/cm^2 were possible to achieved. Therefore, from this investigation we conclude that ALD_Al_2O_3 shows its suitability as a passivation layer to form an ideal QDSL for solar cell.

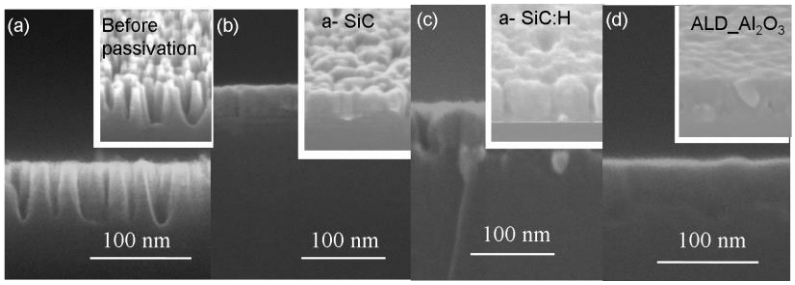

Fig. 1. SEM images of QDSLs at (a) before passivation and after passivation with (b) a-SiC, (c) a-SiC:H, and (d) ALD_Al_2O_3 films, respectively.

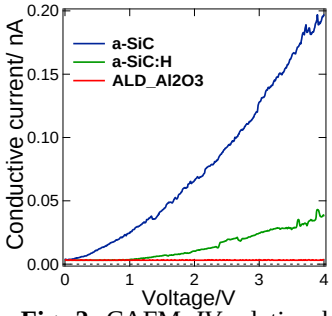

Fig. 2. CAFM_*IV* relationships for QDSLs with different passivation layers.

Table 1: Photocurrent densities and open circuit voltages generated from QDSLs with different passivation layers.

Passivation	J_{sc} (mA/cm2)	V_{oc} (mV)
ALD_Al2O3	4.78	40
SiC_H	0.67	0.07
as depo	0.04	0.04

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