Bandgap engineering for enhancing photovoltaic properties of PbS quantum dot solar cells

°(D1) Chao Ding,[1] Yaohong Zhang,[1] Shuzi Hayase,[2,3] Yuhei Ogomi,[3] Taro Toyoda,[1,3] and Qing Shen [1,3]
Univ. Electro-Commun.[1], Kyushu Inst. Tech.[2], CREST JST[3]
Email: shen@pc.uec.ac.jp

Introduction

Colloidal quantum dots solar cells (CQDSCs) have recently reached promising power conversion efficiencies (η) of over 10%.[1] However, CQD solids have relatively short minority carrier diffusion length (≤100nm), which limited the further improvement in the photovoltaic performance of CQDPV devices. Colloidal quantum dots offer broad tuning of semiconductor band-structure via the quantum size effect. Using a spatial energy band gradient engineering with quantum dots (QDs) of different sizes to enhance the minority carrier diffusion length of a photovoltaic device is a promising strategy for increasing the solar cell efficiency. In this study, we developed an air condition solution-processed TiO_2/PbS quantum dot heterojunction solar cells, by applying a band alignment method to the active layer by means of 4 kinds of PbS QDs with different sizes. We found that carrier lifetime and short circuit photocurrent could be enhanced largely.

Experimental Method

TiO_2-PbS graded bulk heterojunction solar cells (Fig.1) were fabricated by solution-processed methods.[3] Firstly, thin TiO_2 compact layer was coated on FTO glass (25 mm × 25 mm). The TiO_2 compact film was prepared according to a standard procedure which has been reported by a literature.[4] Then, TiO_2 compact film was coated with PbS QDs. Finally, the device was then completed with an Au contact deposited via a shadow mask resulting in a device of area 0.16 cm^2.

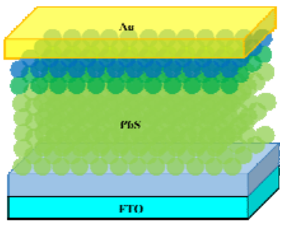

Figure 1. Schematic of graded device structure.

Results and Discussion

Figure 2 illustrates a spatial band diagram of a photoelectron cascade within the PV devices. In this work we design and characterize an ungraded device and 3 types of graded devices wherein different electron collection efficiency was supposed. The graded structure drives minority electrons, the performance-limiting charge carrier, in the same direction as the built-in electric field formed by the N-P heterojunction at the TiO_2/PbS CQD interface.

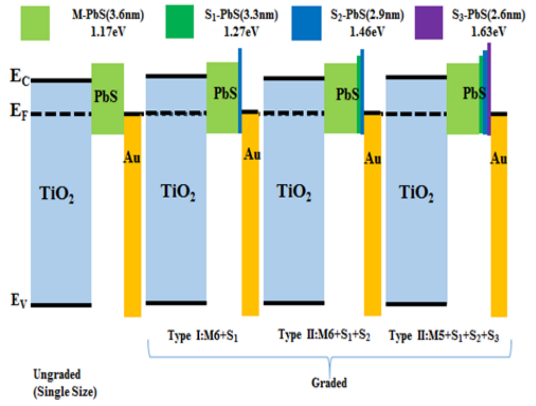

Figure 2. Spatial band diagrams of ungraded and 3 types of graded CQD solar cells. Color coding corresponds to larger bandgaps (more blue/violet).

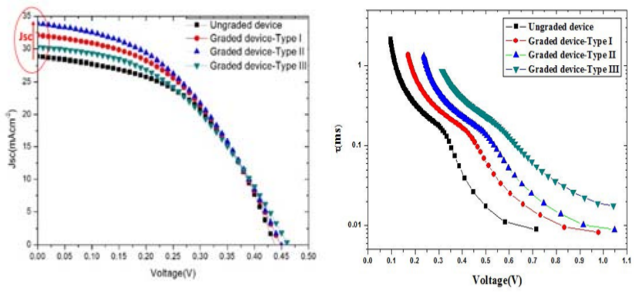

Figure 3.（a）J-V characteristics under simulated AM1.5G illumination and (b) the effective carrier lifetime calculated from the voltage decay curves for the ungraded and three types of graded devices .

As shown in Fig. 3, the graded architecture solar cells exhibited a great increase (from 28 mA/cm^2 to 34 mA/cm^2) in short-circuit current density (Jsc), a high efficiency of 7.25% has been reached, as a result of the enhanced minority carrier lifetime and the improved charge transfer. Furthermore, the performance of unencapsulated devices remains unchanged for over 100 days of storage in air. Our results demonstrate that the band alignment of the active layer of CQDSCs is one effective method for improving the photovoltaic properties of CQDSCs.

References

1. Kim, G.H., et al. Nano Lett.2015,15,7691-7696.
2. J. M. Luther., et al. Nano Lett. 2008, 8, 3488 – 3492.
3. J. Chang., et al. Nanoscale, 2015, 7, 5446-5456.
4. Ajay Kumar Jena., et al. ACS Appl. Mater. Interfaces 2015, 7, 9817−9823

© 2016年 応用物理学会