Novel Approaches to an Efficient Organic Photovoltaic Solar Cell using Nano-Controlling Technology in Bacterial Photosynthesis - Current Research and Development of Organic Thin Film Photovoltaic Devices-

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A few key problems for much higher performance of organic photovoltaic devices are left to be solved: 1) absorption spectrum matching the photon flux from solar irradiation, 2) longer exciton diffusion length, 3) efficient photo-charge-separation, and 4) separation of electron and hole without charge-recoupling. Bacterial photosynthesis system fulfill these key points enable novel approaches to an efficient photovoltaic device.

Bacterial photosynthesis system has an elegant light-harvesting apparatus as an antenna system and an efficient photo-electric conversion apparatus as a reaction center. A model of primary processes in photosynthesis shown in Fig. 1 suggests a concept of separated pathway of electron-transport from exciton-transport. Introduction of silver (Ag) nano-clusters as a charge-transport pathway (Fig. 2) or bacteriochlorophyll (BChl) *e* naro-rod aggregates as an exciton-transfer pathway (Fig. 3) into the bulk layer of a regio-regular poly(3-hexylthiophene) (P3HT) sandwich cell Al/P3HT/Au resulted in a remarkable improvement of photo-electric conversion efficiencies by several times. A size of Ag nano-cluster was controlled by Anodisk with different pore-size used as a mask for Ag vacuum-deposition. The cell (Fig. 2a) was constructed as follows: P3HT film was cast onto the Al electrode vacuum deposited on a glass plate and then Ag nano-cluster was deposited onto P3HT surface, followed by an additional cast of P3HT and by vacuum-deposition of Au semi-transparent electrode. The cell (Fig. 2b) was prepared by casting from a mixed toluene solution of P3HT and BChl *e* onto Al electrode deposited on a glass plate followed by vacuum-deposition of Au semi-transparent electrode. BChl *e* formed a nano-rod by self-aggregation (SEM and AFM pictures are not shown). Introduction of BChl e into P3HT:PCBM also increased the efficiency of the bulk heterojunction cell up to 2 times.

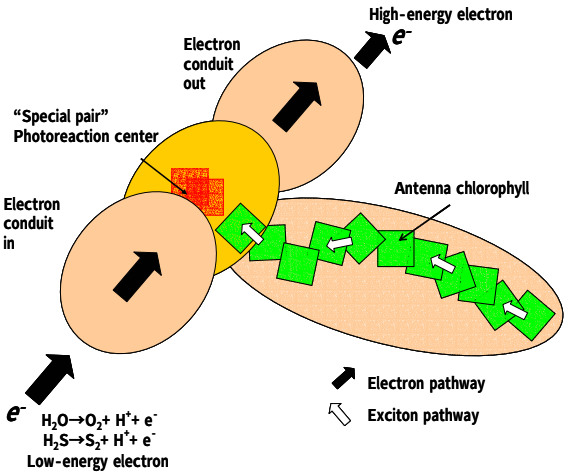


Fig. 1. A concept of separated pathway of electron-transport from exciton-transport for the primary processes in photosynthesis.

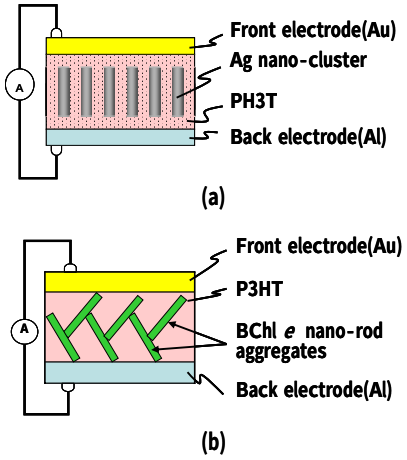


Fig. 2. Introduction of Ag nano-clusters as a charge-transport pathway(a) and BChl *e* naro-rod as an exciton-transfer pathway(b) into Al/P3HT/Au cell.

The power conversion efficiency of the bulkheterojunction polymer solar cell has been increased markedly in the last few years and achieved up to 4～5%.[1),2)] and is attractive because of its advantages: lightweight, low cost, wide application, and environmental suitability. In the present study, we used TiO_2 as a hole-blocking layer in order to improve the cell. The TiO_2 layer fabricated easily without a vacuum process or a high-temperature treatment is expected to work as an efficient hole and exciton-blocking layer because of its deep HOMO and suitable LUMO close to Fermi level of Al, and a large band gap as shown in Fig. 3. Furthermore, TiO_2 between the active layer and Al electrode should improve the stability of polymer solar cell because TiO_2 layer is expected to inhibit the reaction between the active layer and Al electrode.[3)] After PEDOT:PSS is spin-coated on a pre-cleaned ITO glass substrate, followed by annealing at 110℃ for 10 min, the P3HT:PCBM active layer is spin-coated from chlorobenzene solution (P3HT:PCBM=1:1, each density is 1.5g/l). After annealing at 140℃ for 4 min, TiO_2 layer is spin-coated from $Ti(OC_3H_7)_4$ solution in ethanol. Then the cell is left under the dark and ambient condition for 30min in order that $Ti(OC_3H_7)_4$ hydrolyzes with water vapor in air.[4)] By optimizing the thickness of PEDOT:PSS, the power conversion efficiency of the cell shown in Fig. 4 increased up to 3.65%. (FF=0.65; AM=1.5) as shown in Fig.5.

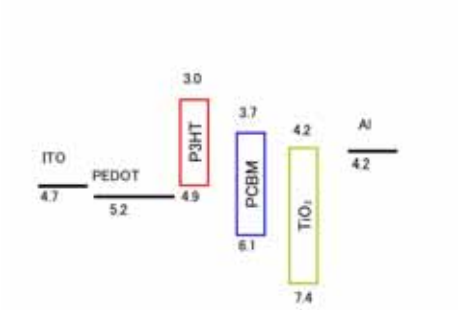


Fig. 3 Energy diagram

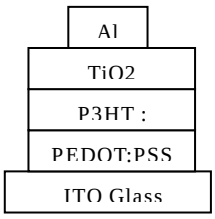


Fig. 4 Structure of the cell

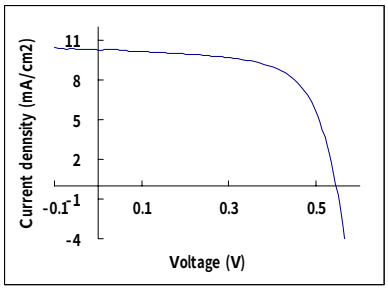
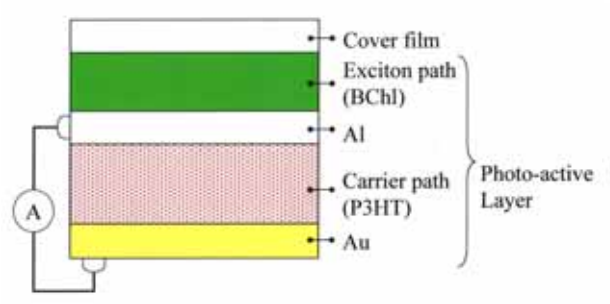


Fig.. 5 I-V curve of the cell shown in Fig. 4

In the present study, we developed another novel organic thin film solar cell based on external exciton path (Fig. 6). A possible mechanism is shown in Fig. 7. Introduction of BChls onto the electrode as an outside antenna layer resulted in an effective improvement of efficiencies overcoming the light shielding effect. This unique cell mimics chlorosome of green sulfur bacteria rather than the dye-sensitized solar cell proposed by McFarland and Tang [5)].



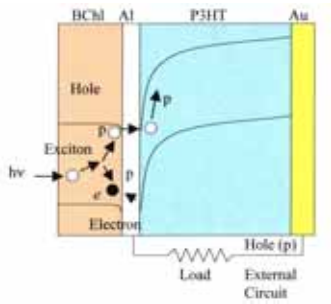


Fig. 6. The cell structure of the out-side antenna cell

Fig. 7. A possible mechanism of the cell shown in Fig. 6.

Reference

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