

Nanostructure Controls in Polymer Photovoltaic Devices

K. Hashimoto,^{1,2} K. Takanezawa,¹ Q. Wei,¹ and K. Tajima¹

¹Department of Applied Chemistry, The University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656 Japan

²JST-ERATO “Hashimoto Light Energy Conversion Project”

Introduction

Photovoltaic devices based on conjugated polymers have been attracting much attention. Currently, a strategy so-called “bulk heterojunction” is adopted to achieve efficient charge separation inside the film, in which device performances are very sensitive to nanostructures in active layers. If one can construct intrinsic nanostructures in the film by material design, it could provide a methodology to further improve the device performance. We are trying to control nanostructures of polymer photovoltaic cells to improve the charge separation and transport efficiencies. Here we show two examples of our studies. One is to introduce the pre-built nanostructures vertically aligned inside the active layer, and the other is the self-organized nanostructure to control the vertical distribution of the materials in the film.

Pre-built ZnO nanorod arrays^(1,2)

One of the problems in the bulk heterojunction is that the charge transports after the charge separation simply rely on the percolation network of the donor and the acceptor in the mixture films. Introduction of vertically aligned inorganic nanostructures is one of the strategies to improve the charge transport. We developed ZnO nanorod (~30 nm in diameter and 50 ~ 500 nm in length) arrays and used the arrays as the electron carrier for the polymer photovoltaic bulk heterojunction cell. The device structure was ITO/ZnO/PCBM:P3HT/vanadium oxide/Ag. Here, the vanadium oxide layer was introduced as an electron blocking layer. Power conversion efficiency (PCE), fill factor (FF), short circuit current (I_{SC}), and open circuit voltage (V_{OC}) of the devices were investigated as a function of the length of the ZnO nanorods. Although, the changes in I_{SC} and V_{OC} were small, the increase of FF was observed when the longer nanorod arrays were used. In Fig. 1 are shown the I - V curves with nanorod (115 nm) and without rod. Here, the FF was largely improved from 50 % to 65 %, and as a result, the PCE was improved from 3.0 % to 3.9 % by introducing the array. This enhances the performance of the photovoltaic devices even with very thick active layers of over 450 nm, leading the maximum utilization of the incident photons. Such thick active layer could be advantageous when combined with low-band gap polymers with superior matching of the absorption to the solar spectrum.

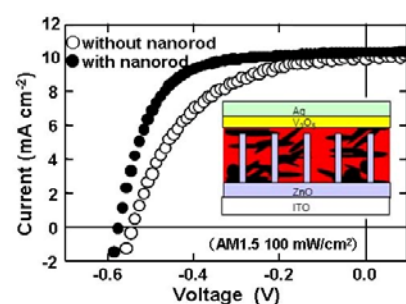


Fig. 1 Current Voltage Curves with and without ZnO nanorods

Self-organized buffer layers with F-PCBM⁽³⁾

It is well known that the materials having low surface energy prefer to migrate to the air/liquid interface during the coating process. Based on this phenomenon, we designed and synthesized a novel fullerene derivative with a fluorocarbon chain (F-PCBM) as shown in the inset of Fig.2. When the small amount of F-PCBM was mixed in the solution for the spin coating, it was expected that the F-PCBM spontaneously migrated to the surface of the organic layer during the spin casting process and formed a very thin layer of F-PCBM in single step, which could be used in organic solar cells as the buffer layer. In fact, F-PCBM formed a buffer layer between the active layer and the metal electrode, resulting in the improvement in the device performance. Fig.2 shows typical I - V curves for the P3HT: PCBM bulk heterojunction devices with and without F-PCBM. The device without F-PCBM showed I_{SC} of 8.72 mA/cm², V_{OC} of 0.55 V, and FF of 0.64, resulting in a PCE of 3.09%. When small amount of F-PCBM was mixed in the spin-coated solution, a considerable improvement of the PCE up to 3.79% was observed with I_{SC} of 9.51 mA/cm², V_{OC} of 0.57 V and FF of 0.70. It is important to note that the FF shows quite high value and the best value we achieved was 0.72. This is, to the best of our knowledge, the highest FF reported in organic solar cells. The improvement in the device performance could be explained by the energy level matching of PCBM and the Al electrode induced by the dipole moment layer of F-PCBM, which was confirmed by the ionization potential measurement using photoelectron yield spectroscopy.

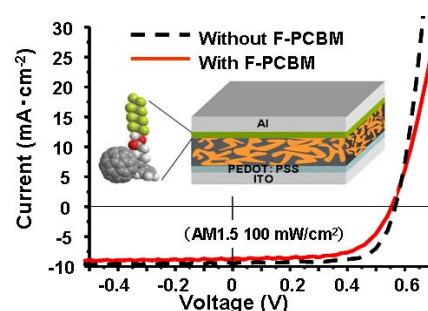


Fig. 2 Current Voltage Curves with and without F-PCBM

Reference

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