High-Efficiency Polymer-Titanium Oxide Hybrid Solar Cells

*Kwanghee Lee**

Department of Physics, Pusan National University, Busan 609-735, Korea
kwhlee@pusan.ac.kr

Introduction

Photovoltaic technology based on conjugated polymer-fullerene composites continues to be of interest as a potential source of renewable energy [1,2]. In particular, because of the advantages implied for polymer-based electronics, including low cost fabrication in large areas and low weight on flexible substrates, efficient "plastic" solar cells would have major impact on the need of energy in our society. Although encouraging progress has been made in recent years with 3-4% power conversion efficiencies under AM1.5 (AM=air mass) illumination [3], this efficiency is not yet sufficient for large scale implementation. The need to improve the device efficiency requires the exploration of new device architectures with the implementation of new materials.

One approach toward improving the device efficiency is to change the device architecture with the goal of spatially redistributing the light intensity inside the device by introducing an optical spacer between the active layer and the Al electrode as shown in Fig. 1 [4].

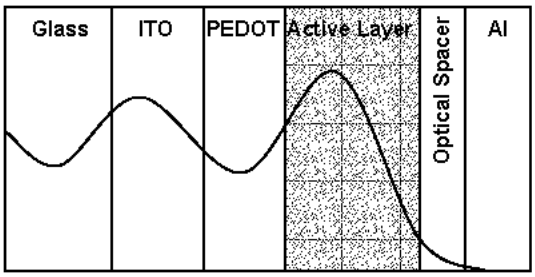

Figure 1. Schematic description of the optical spacer concept. The line represents the distribution of the light intensity.

Although this revised architecture with the optical spacer would appear to solve the problem, the prerequisites for an ideal optical spacer limit the choice of materials: The layer must be a good acceptor and an electron transport material with a conduction band edge lower in energy than that of the lowest unoccupied molecular orbital (LUMO) of C_{60}, the LUMO must be above (or close to) the Fermi energy of the collecting metal electrode, and it must be transparent to light with wavelengths within the solar spectrum. In this work, we have used a solution-based sol-gel process to fabricate a titanium oxide (TiO_x) layer on top of the polymer-fullerene active layer. By introducing the TiO_x optical spacer, we demonstrate polymer photovoltaic cells with power conversion efficiencies that are increased by approximately 50% compared to similar devices fabricated without the optical spacer.

Experimental

In our experiments, bulk heterojunction solar cells using P3HT as the electron donor and PCBM as the acceptor were fabricated in the following simple structure: ITO/PEDOT/P3HT:PCBM/Al; each device had an active area of 14.8mm^2. A transparent bilayer electrode comprising PEDOT:PSS (Baytron P) on ITO glass was used for hole collection, and an Al electrode was used for electron collection.

Results and discussion

Figure 2 compares the incident photon to current collection efficiency spectrum (IPCE) of devices fabricated with and without the TiO_x optical spacer. The IPCE is defined as the number of photo-generated charge carriers contributing to the photocurrent per incident photon. The conventional device (without the TiO_x layer) shows the typical spectral response of the P3HT:PCBM composites with a maximum IPCE of ~60% at 500 nm. For the device with the TiO_x optical spacer, the results demonstrate substantial enhancement in the IPCE over the entire excitation spectral range; the maximum reaches almost 90% at 500 nm, corresponding to a 50% increase in IPCE.

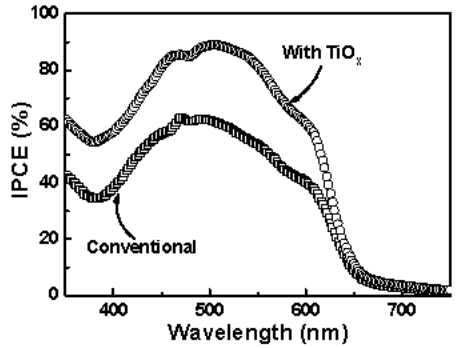

Figure 2. Incident monochromatic photon to current collection efficiency (IPCE) spectra for the two devices with and without TiO_x optical spacer layer.

We attribute this enhancement to increased absorption in the bulk heterojunction layer as a result of the TiO_x optical spacer; the increased photo-generation of charge carriers results from the spatial redistribution of the light intensity. This enhancement in the device efficiency that results from the optical spacer can be directly observed in the current density vs voltage characteristics under under AM1.5 illumination as shown in Figure 3. The device without the TiO_x layer shows typical photovoltaic response with device performance comparable to that reported in previous studies; I_{sc} = 10.1 mA/cm^2, V_{oc} = 0.56 V, FF = 0.55 and η_e=3.5%. For the device with the TiO_x layer, the results demonstrate substantially improved device performance; I_{sc} = 11.1 mA/cm^2, V_{oc} = 0.61 V, FF = 0.66. The corresponding power conversion efficiency is η_e = 5.0%, which corresponds to ~40% increase in the device efficiency.

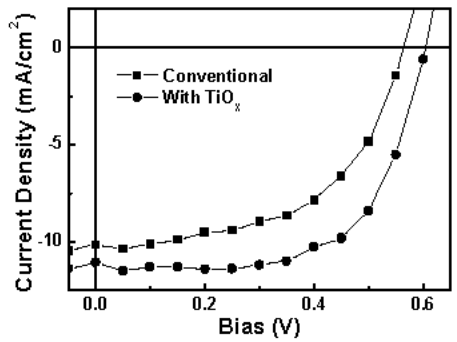

Figure 3. The current density-voltage (J-V) characteristics of polymer solar cells with (circle) and without (square) TiO_x optical spacer under AM1.5 irradiation.

Conclusions

In conclusion, polymer solar cells with 5% power conversion efficiency are demonstrated. We attribute the higher efficiency to optical spacer-induced enhancement in electric filed intensity inside of the devices. By inserting a TiO_x layer (fabricated from sol-gel process) between the active layer and the electron collecting aluminum electrode the devices exhibit approximately 50% enhancement in power conversion efficiency compared to similar devices without the optical spacer.

References

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