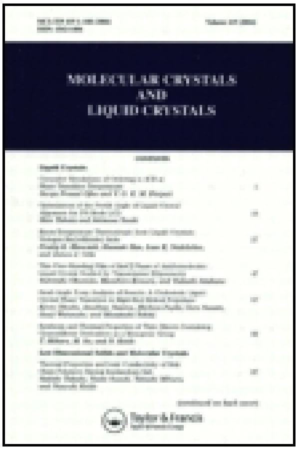


Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Effect of Charge Mobility for Organic Photovoltaic Devices

Bum Jin Jang [a], Jung Yong Kim [a], Jai Kyeong Kim [a], Jae-Woong Yu [a] & Changhee Lee [b]

[a] Optoelectronic Materials Research Center, KIST, Seoul, Korea

[b] School of Electrical Engineering, Seoul National University, Seoul, Korea

Version of record first published: 20 Aug 2006

To cite this article: Bum Jin Jang, Jung Yong Kim, Jai Kyeong Kim, Jae-Woong Yu & Changhee Lee (2006): Effect of Charge Mobility for Organic Photovoltaic Devices, Molecular Crystals and Liquid Crystals, 444:1, 67-71

To link to this article: http://dx.doi.org/10.1080/15421400500379822

Mol. Cryst. Liq. Cryst., Vol. 444, pp. 67–71, 2006
Copyright © Taylor & Francis LLC
ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400500379822

Taylor & Francis
Taylor & Francis Group

Effect of Charge Mobility for Organic Photovoltaic Devices

Bum Jin Jang
Jung Yong Kim
Jai Kyeong Kim
Jae-Woong Yu
Optoelectronic Materials Research Center, KIST, Seoul, Korea

Changhee Lee
School of Electrical Engineering, Seoul National University,
Seoul, Korea

Influence of charge mobility of n-type organic semiconductors for the performance of organic p-n junction type photovoltaic devices has been studied. Two n-type organic semiconductors with same main moiety (i.e., perylenebiscarboximide derivates), which posses similar HOMO, LUMO and band gaps; however with different charge mobility especially electron mobility have been utilized in this study. The electron mobility was measured by time of flight method. The electron mobility difference was caused by molecular packing characteristics since one of the semiconductor showed a liquid crystalline behavior.

Keywords: charge mobility; organic photovoltaic; perylenediimide derivates

INTRODUCTION

Organic photovoltaic devices have received growing attentions because of their excellent processability and capability to form large area devices at low cost. However, these organic photovoltaic devices suffer from low conversion efficiency and stability of device. Numerous efforts have been performed to improve relatively poor conversion efficiency of organic photovoltaic devices compare to that of inorganics. Relatively low photon to electron conversion efficiency of these organic based photovoltaic devices attributed to fundamentally different photocurrent producing

Address correspondence to Jae-Woong Yu, Optoelectronic Materials Research Center, KIST, P.O. Box 131, Seoul 130-650, Korea. E-mail: jwyu@kist.re.kr

process in organic semi-conducting materials such as a driving force required to break up the photogenerated excitons and low charge carrier mobility. Even though low exciton diffusion length and carrier mobility are also important factors for conversion efficiency, many researches have been concentrated for interfacial areas and energy gaps of semiconductors. For improving input photon to converted electron, using advanced device structures for higher interfacial areas and synthesizing high quality new materials [1] for high difference in HOMO and LUMO for easier exciton splitting have been usually carried out.

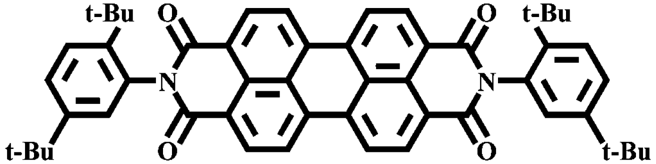
Among three basic elements (open circuit voltage, fill factor and short circuit current) that deciding power conversion efficiency, short circuit current is the major targeted factor that has to be enhanced. Since charge transporting mechanism in organic semiconductors is mainly hopping between organic semiconductors, the charge mobility is one of the important factors. In this research, we have used two organic compounds with same main moiety (i.e., perylene derivates), which posses similar HOMO, LUMO and band gap, however with different charge mobility especially electron mobility to elucidate the influence of charge mobility on the performance of organic photovoltaic devices.

EXPERIMENTALS

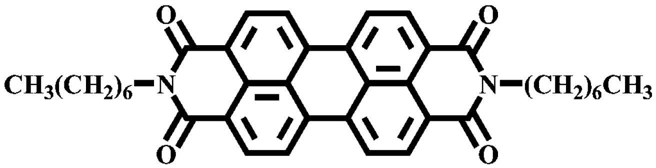
N,N′-Bis(2,5-di-tert-butylphenyl)-3,4,9,10-perylenedicarboximide (PTCDI-PhDTB, purified by chromatography with chloroform eluent) was provided from Kitek Co. (Korea). *N,N′*-diheptyl-3,4,9,10-perylenebiscarboximide (PTCDI-C7) was synthesized as described elsewhere [2]. Poly(3-hexylthiophene-2,5-diyl) [P3HT] has a regio-regular structure and the molecular weight was 87,000 g/mol (purchased from Aldrich). The thickness of P3HT and organic semiconductor were maintained at 50 nm since mobility of organic semiconductor is not high. Same device architectures were maintained for exact comparison of mobility effect only. Cyclic voltammogram (CV) was recorded with a potentiostat controlled by PowerLab/4SP interface (ADInstruments). A N_2 laser pulse (Photon Technology International) with a wavelength of 337 nm and a pulse width of 600 ps was used to form the carriers by illuminating from the ITO side. Then the charge mobility was measured using TOF set-up with Tektronix TDS 644B color four channel digital real-time oscilloscope (500 MHz, 2.5 GS/s) and Keithley 2400 source measure unit.

RESULTS AND DISCUSSIONS

The chemical structures of PTCDI-PhDTB and PTCDI-C7 are shown in Figure 1. The structure of all photovoltaic devices used in this study



PTCDI-PhDTB



PTCDI-C7

FIGURE 1 Chemical structures of PTCDI-PhDTB and PTCDI-C7.

was ITO/PEDOT/P3HT/n-type perylene diimide derivates/Al. The HOMO and LUMO values, determined by CVs and UV-Vis spectra, for P3HT, PTCDI-PhDTB and PTCDI-C7 were −5.15, −3.02, − 6.07 and −3.94, −6.14 and −4.03, respectively. These two materials also have quite close extinction coefficient ($\varepsilon \sim 10^5 M^{-1} cm^{-1}$). According to mobility measurement by time-of-fight (TOF) techniques, these semiconductors have higher electron mobility. Electron and hole mobility of PTCDI-PhDTB were $1.8 \times 10^{-4} cm^2/Vs$ and $1.1 \times 10^{-4} cm^2/Vs$ under the electric field of 500 $(V/cm)^{1/2}$, respectively. PTCDI-C7 shows a liquid crystalline behavior in the temperature range between 214 and 403°C [3]. The device made with PTCDI-C7 was annealed at 220°C under nitrogen environment for 30 minutes. An ITO/organic semiconductor/Al cells were fabricated with 4 μm thick organic layers for TOF measurements by sequentially deposition of 1 nm/s rate. Both organic semiconductors were further purified by sublimation before measurements. The electron and the hole mobility of PTCDI-C7 before heat treatment were 0.00633 and 0.00036 cm^2/Vs and after heat treatment were 0.0139 and 0.0089 cm^2/Vs, respectively, at an electric field of 186 $(V/cm)^{1/2}$. The differences in electron mobility of PTCDI-C7 with that of PTCDI-PhDTB come from more ordered structure formed by simple heat-treatment of PTCDI-C7 converting into by its liquid crystalline phase.

Figure 2 shows the plot of current density vs. voltage for the devices. The device made with PTCDI-PhDTB and PTCDI-C7 showed a short-circuit photocurrent density of 0.019 and 0.176 (mA/cm^2), respectively. Assuming that a close exciton diffusion length for both PTCDI-PhDTB and PTCDI-C7, and ignore a small difference in electron affinity and ionization potential between PTCDI-PhDTB and PTCDI-C7, the current density was higher for device made with PTCDI-C7 which has higher mobility. The mobility differences of 75 times between PTCDI-PhDTB and PTCDI-C7 caused in 9 times

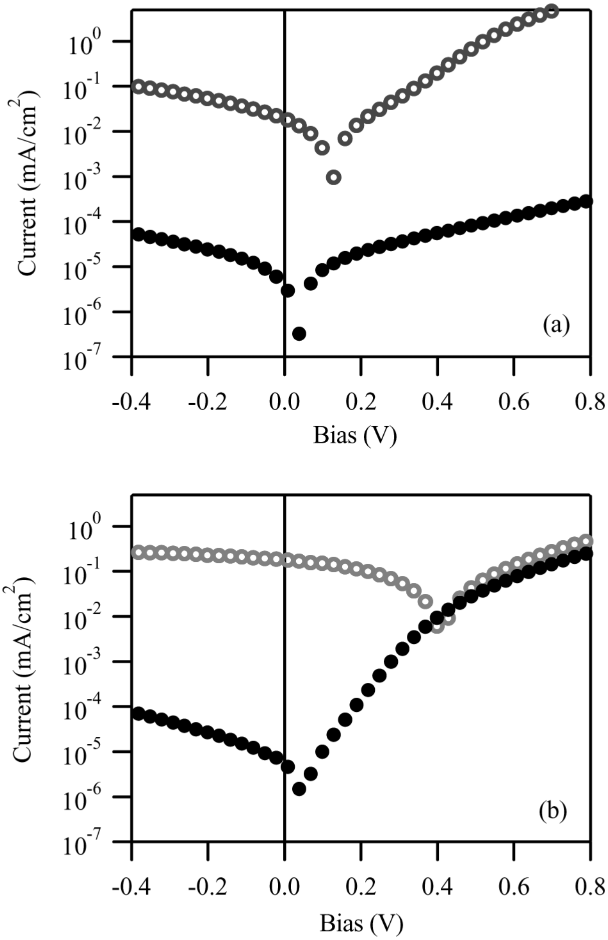


FIGURE 2 Plot of current density vs. voltage for devices made with (a) PTCDI-PhDTB and (b) PTCDI-C7.

photocurrent density differences between them. Therefore it can be concluded that the higher the electron mobility, the higher the current density and photoconversion efficiency. From this study, it is possible to conclude that the charge mobility of n-type semiconductor is one of the main factors influencing the performance of organic photovoltaic. We could not draw any relationship between mobility and photo-converted current density at this time, however, more research is underway.

REFERENCES

[1] Jenekhe, S. A. & Yi, S. (2000). *Adv. Mater.*, *12*, 1274.

[2] Rademacher, A., Märkle, S., & Langhals, H. (1982). *Chem. Ber.*, *115*, 2927.

[3] Kim, J. Y., Chung, I. J., Kim, Y. C., & Yu, J.-W. (2004). *Chem. Phys. Lett.*, *398*, 367.