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Dielectric and Photoinduced Absorption Spectroscopies for Characterization of Organic Photovoltaic Devices

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1. Introduction

In organic solar cells such as bulk-heterojunction solar cells based on a blend of poly(3-hexylthiophene) (P3HT) and [6,6]-phenyl-C61-butyric acid methyl ester (PCBM), excitons created by photoabsorption are efficiently dissociated into free carriers at the interface between P3HT and PCBM in spite of their large binding energy [1, 2]. In the subsequent transport process, the carriers travel from the interface to the electrodes under the influence of charge carrier recombination. The information concerning mobility and carrier lifetime is thus essential for optimizing device structures to maximize the power conversion efficiency.

Impedance spectroscopy (IS) is a powerful tool for measuring charge-carrier mobility and localized-state distributions [3-6]. IS has a number of advantages over conventional methods such as time-of-flight transient photocurrent technique as a mobility measurement. For instance, IS is truly spectroscopic; a wide range of mobilities, 10^{-14} – 10^{-2} cm^2/Vs in case of thickness L=100 nm and electric field E=10^4 V/cm, can be determined automatically. Both electron and hole mobilities can be determined simultaneously [6].

Photo-induced absorption (PIA) spectroscopy is a tool for measuring free carrier lifetime in organic solar cells [7, 8]. Free carrier lifetime can be determined from frequency dependence of PIA under the open-circuit condition of organic solar cells and charge carrier transit time is estimated under the short-circuit condition as well [8].

In this presentation, we demonstrate the determination of electron and hole mobilities and of hole lifetime using IS and PIA measurements in P3HT and PCBM bulk heterojunction solar cells.

2. Experiment

P3HT and PCBM solar cells were fabricated in a glove box filled with nitrogen gas and were encapsulated before bringing them into ambient atmosphere. An active layer was made by spin-coating the blends of P3HT and PCBM dissolved in chlorobenzene on surface of a layer of poly(ethylene dioxythiophene) doped with polystyrene sulfonic acid (PEDOT/PSS), which was predeposited on an indium tin oxide (ITO)-coated glass substrate. After the Al electrodes were deposited, the devices were annealed at 150 ^{o}C for 30 min. The thickness of the active layer was about 80 nm. The power conversion efficiency under simulated AM1.5G irradiation was 1-3 %.

The IS were measured with a Solartron 1260 impedance analyzer connected to a 1296 dielectric interface. The frequency range studied was from 10 mHz to 1 MHz, and the measurements were made in the temperature range from 100 to 340 K using a TTP4 prober station.

We carried out the cw-PIA measurements using reflection geometry; a probe beam was irradiated from the ITO side of a solar cell and a reflection from the Al electrode was detected by a silicon photodiode after being monochromated. This probe beam monitors an absorption band originating from the positive carriers (hole polarons) formed in P3HT that are generated by a pump beam. For a pump beam, we used a rectangular-shaped beam from a blue diode laser (405 nm). The small change of the probe beam synchronized to the pump beam was detected using a lock-in amplifier (Signal Recovery 7280). The lock-in amplifier can measure amplitudes of a signal component oscillating in-phase with respect to the modulated pump beam and a component oscillating with a 90^{o} phase shift (out-of-phase). We recorded both in-phase and out-of-phase components of the cw-PIA signal as a function of the probe beam photon energy and modulation frequency.

3. Results and discussion

Figure 1 shows the frequency dependence of $\omega\Delta G= \omega (G(\omega)-G(\infty))$, where $G(\omega)$ is the conductance of P3HT and PCBM bulk heterojunction solar cells at the frequency of ω. We observe one or two peaks in the frequency dependence of $\omega\Delta G$, from which we determine the charge carrier transit times. We stress that IS enables us to determine electron and hole drift mobilities simultaneously in the frequency spectra of $\omega\Delta G$ at 190 -210 K.

Figure 2 shows the temperature dependence of both electron and holes drift mobilities. Both mobilities exhibit thermally-activated behavior. We identify higher mobility as hole drift mobility; we estimate hole drift mobility from

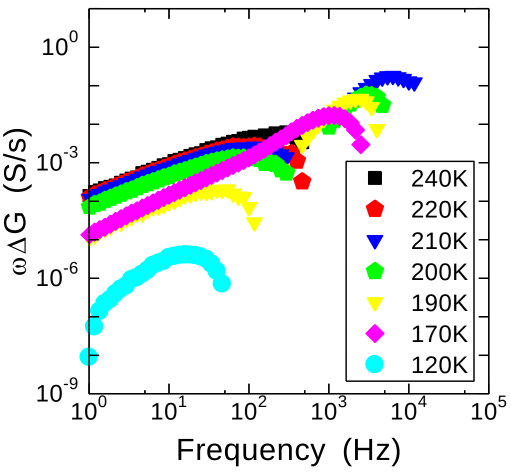

Figure 1. Frequency dependence of ωΔG in P3HT:PCBM solar cells at different temperatures. The charge carrier transit time can be determined from the frequency at the peaks. Two peaks are observed at 190, 200 and 210 K.

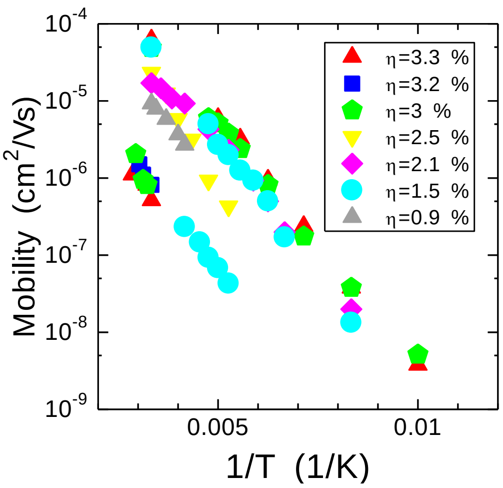

Figure 2. Temperature dependence of hole and electron drift drift mobilities in P3HT:PCBM solar cells. The higher mobility has been indentified as hole mobility .

PIA of delocalized hole polaron band in P3HT under the short circuit condition of P3HT:PCMB solar cells and the hole mobility estimated from PIA is in agreement with that of higher mobility in Fig. 2.

We show hole and electron drift mobilities, and hole lifetime, determined with IS and PIA measurements, respectively, as a function of power conversion efficiency of P3HT and PCBM solar cells in Fig. 3. The hole mobility determined with PIA under the short circuit condition of the solar cells is also shown. Although we do not estimate the lifetime of electrons, it is interesting to point out that the power conversion efficiency is not dependent on the electron mobility and hole lifetime but dependent on the hole mobility of P3HT:PCBM solar cells.

3. Conclusions

We have shown that drift mobilities and carrier lifetime

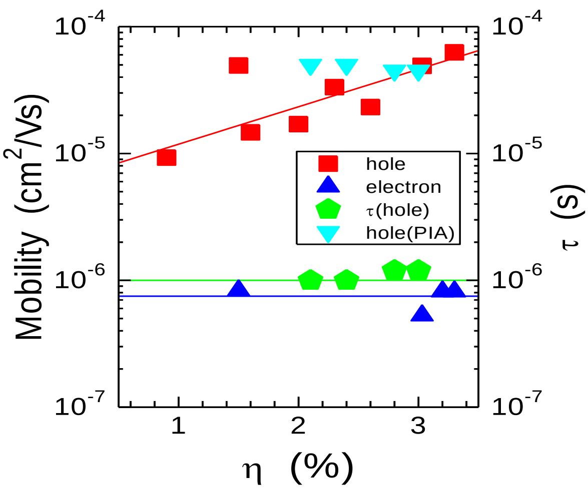

Figure 3. Hole and electron mobilities, and hole lifetime of P3HT:PCBM solar cells as a function of the power conversion efficiency.

have been determined by IS and PIA measurements in bulk heterojunction P3HT and PCBM solar cells. We find that the hole drift mobility correlates with the power conversion efficiency of the solar cells. Information shown here would be valuable to gain insight into device physics of organic solar cells and the physical quantities obtained here are useful as inputs for device simulation of the solar cells.

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