Investigation of carrier transit motion in PCDTBT by optical SHG technique

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Received 19 May 2014, revised 23 May 2014
Accepted for publication 29 May 2014
Published 5 August 2014

Abstract

We analyze the carrier transit behavior in poly[N-9’-heptadecanyl-2,7-carbazole-alt-5,5-(4’,7’-di-2-thienyl-2’,1’,3’-benzothiadiazole)] (PCDTBT), which has been reported as a donor material for efficient bulk heterojunction photovoltaic devices. The transfer and transient carrier mobilities in the PCDTBT thin films have been measured and analyzed. The transfer mobility has been measured by the transfer curve of the OFET, whereas the transient mobility is recorded using a time-resolved electric field-induced optical second harmonic generation (TRM-SHG) technique. Using the TRM-SHG technique, the dynamic motion of the charge carriers in the PCDTBT thin films has been directly visualized. We anticipate that the analysis of the carrier motion by TRM-SHG will be effective for the understanding of carrier behavior in PCDTBT thin film and will help to make further improvements in the efficiency of the PCDTBT-based photovoltaic devices.

Keywords: PCDTBT, optical second harmonic generation, charge transport, photovoltaics

(Some figures may appear in colour only in the online journal)

1. Introduction

The studies of organic-based electronic devices have received much attention because of their physical flexibility (Fabretto et al 2012, Kim and Graham 2013), potential tailored properties (Krucaite et al 2012, Teichler et al 2013), and their ability for commercialization (Yang et al 2012). This emerging technology can be seen in the use of color displays, flexible solar cells, and non-volatile memories. The selection of materials for such applications depends on their fundamental purpose and the charge transport behavior in these materials. The carrier transit behavior can be analyzed by means of several techniques such as current–voltage (I–V) characteristic (Sessler and Gerhard-Multhaupt 1998), time-of-flight (ToF) method (Kepler 1960), charge extraction by linearly increase voltage (CELIV) technique (Juška et al 2013), and by a recent technique developed by Manaka et al (2007) called time-resolved electric field-induced second harmonic generation (TRM-SHG). The TRM-SHG approach gives information about the charge transport motion without considering the effect of the electrode injection process. It is free from the issues of contact resistance and potential decline at the metal–organic interfaces. This technique allows selective and direct probing of dynamic carrier motion in organic semiconductor materials. TRM-SHG technique reveals the dynamic changes in SHG intensity profiles. The TRM-SHG images can be directly visualized using a CCD camera.

Over the past decade, high-performance bulk heterojunction solar cells have been reported using a blend of P3HT and PCBM. Alternatively, polymer materials consisting of poly(2,7-carbazole) derivatives also seem to be interesting for photovoltaic applications. These compounds are allowed to have a better charge transfer from an electron-rich unit to an electron-deficient moiety within the repeated unit (Park et al 2009), whereas the deeper HOMO of the carbazole gives the larger value of $V_{OC}$ (Blouin et al 2008). In the present study, we chose a poly(2,7-carbazole) derivative,
the contacts injection process is not taken into account and only probed carrier motion is recorded along the channel. Therefore, the TRM-SHG technique allows us to measure the intrinsic carrier mobility in the thin films.

Figure 5 shows that the carriers are moving through the OFET with the relation between \( x \) and \( t^{1/2} \). So, according to a previous study (Weis et al. 2010), it could be easily explained that this square root dependence of the carrier transit time by assuming an interface charge propagation can be described by the Maxwell–Wagner model and the ladder RC-circuit model as well. The carrier migration in our current study should be either moved between the source–drain by the carrier drift between the source and drain electrodes (which is proportional to \( V_{ds} \)) or moved by the field between the gate and source electrodes (which is proportional to \( V_{gs} \)). This is in accordance with the SHG experiment, in which the injected carriers keep moving even though the source and drain are electrically shorted, as shown in figure 5(b). The TRM-SHG images also show that the charge motion is almost symmetric from both electrodes when the source and drain electrodes are at the same potential. Actually, no drift field between source–drain exists under the drain source short circuit condition; therefore, the carrier propagation does not occur because of the diffusion of the carriers but rather because of the phenomenon of the interface charging (Burgi et al. 2003).

4. Conclusions

We recorded the TRM-SHG images to study the carrier motion in the PCDTBT thin films. The motion of the holes has been visualized. Further, the time-resolved images have been used for the calculation of intrinsic mobility of holes in the PCDTBT-based OFETs, which is found to be 2.33 times higher than the transfer mobility. The time-resolved images of the carrier’s distribution could also be useful for the modeling of the electronic devices based on PCDTBT. Furthermore, the EFISHG is material-dependent and is generated in proportion to the \( \chi^3 \) parameter. This study shows that by choosing the appropriate laser beam wavelength, we can investigate carrier path and carrier lifetime in the PCDTBT-based bulk heterojunction thin films.

Acknowledgement

This research is supported by High Impact Research MOE Grant UM.S/625/3/HIR/MoE/SC/26 from the Ministry of Education Malaysia. Part of this work was also financially supported by a grant-in-aid for Scientific Research (S) (No. 22226007) from the Japan Society for the Promotion of Science (JSPS). This study was performed at the Tokyo Institute of Technology, Japan. We also acknowledge our colleagues
Mr Qayyum Zafar and Mr Karwan Wasman Qadir for their assistance in measuring the PL and UV/Vis.

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