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Wavelength Dependence of Photocurrent for Organic Phototransistors Featuring Bulk Heterojunctions

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Abstract

Organic phototransistors (OPTs) are considered a promising photodetector for its large photocurrent. Bulk heterojunctions (BHJs) are often introduced in OPTs due to its fast response time. However, the photocurrent dependency against wavelength of light remains unclear Here we report a wavelength dependency of photocurrent of OPT using BHJ while amplifying the photocurrent. The result suggests that both donor and acceptor absorb and contributes to the photocurrent amplification which differs from the result when OPTs are derived at non-amplification mode.

1. Introduction

Organic photodetectors are believed to be promising candidates for future application for their ability to detect a broad range of wavelengths, solution processability, and flexibility [1–4]. Interesting applications have been reported featuring these benefits, such as photonic skin [1,2], image sensor arrays [3], and flexible near-infrared sensor arrays [5]. While these applications uses organic photodiodes (OPDs) [1,2], another organic photodetector which are organic phototransistors (OPTs) have attracted interest for their large photocurrent and wide dynamic range [6,7].

OPTs are transistors where their drain current increases by exposing the channel area to light. In order to achieve maximum photocurrent, OPTs are derived at what is called the photovoltaic mode where the photocurrent gets amplified. In photovoltaic mode the photoexcited charges acts as a charge trap inside the channel of OPTs where they shift the threshold voltage of the OPT resulting in increase of drain current [8]. The degree of detectivity of light in OPTs are commonly referenced by the responsivity (R) which is defined equation (1).

$$R = \frac{\Delta I_d}{P} = \frac{I_{d\_light} - I_{d\_dark}}{P} \quad (1)$$

I_{d_light} and I_{d_dark} are the drain currents measured under light and dark, respectively. P is the power density of the light source. OPTs utilizing a bulk heterojunction (BHJ) in the active layers are considered as promising candidates. The BHJ helps the charge separation [9], and donor/acceptor in BHJ can work as the controlled traps to produce gains [10–12]. The OPTs featuring BHJs also show relatively fast response time (~65 μs) [9–12]. For OPTs recently it has been reported that the mobility of the major carrier is the dominant factor in achieving the optimal photocurrent [12]. Other report have compared the mobility and external quantum efficiency (EQE) against the donor-acceptor ratio when the OPT is derived in non-amplifying mode (EQE<100%) [13].

However, the dependency of OPTs photo amplification against wavelength has not yet been established. While many OPTs are still air unstable, it has been difficult to use a monochromatic light source that could change its wavelength continuously.

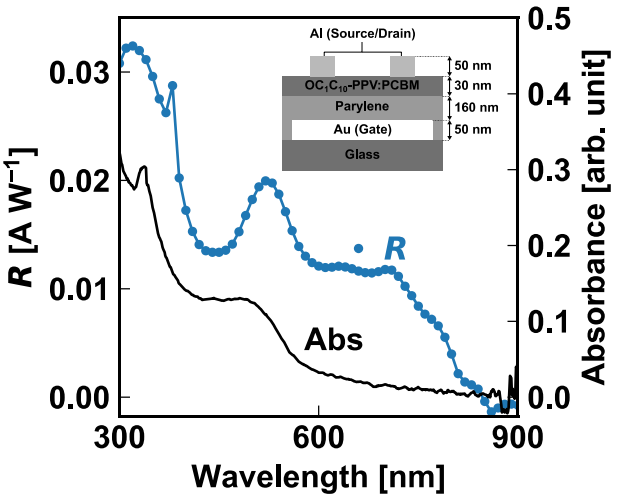
Here we measured the responsivity as a function of the wavelength of light. By encapsulating the OPT using glass we were able to use the light source used to measure the external quantum efficiency of OPDs. It is very important to understand, whether it is the donor or acceptor that is absorbing light and contributing to the amplification of photocurrents.

2. Experiment

An OPT was fabricated on glass using a bottom-gate and top-contact structure. 50 nm-thick Au was used as a gate electrode with 2 nm-thick Cr as an adhesion layer beneath it. Parylene (diX-SR) was formed by chemical vapor deposition (CVD), with the thickness of 160 nm as a dielectric layer. poly[2-methoxy-5-(3',7'-dimethyloctyloxy)-*p*-phenylene vinylene] (OC_1C_{10}-PPV) and [6,6]-Phenyl-C_{61}-Butyric Acid Methyl Ester (PCBM) blend was chosen as the active layer. A mixture of OC_1C_{10}-PPV and PCBM with PCBM content of 80 wt% was disolved in chlorobenzene. The concentration of the solution was 15 mg mL^{-1}. This solution was spin coated at 3000 rpm in N_2 which gives 30 nm thick film. Al was chosen for both the source and drain electrode with 50 nm of thickness. Metal electrodes were patterned by shadow mask. Channel length (L) and width (W) was 38 μm and 700 μm, respectively.

The fabricated OPT was then encapsulated by glass and taken out in ambient air for measurement. Basic electrical characteristics were measured using semiconductor parameter analyzer. Afterwards the OPT were illuminated using monochromatic light and the drain current were recorded as a function of the wavelength of light.

Fig. 1 Dependence of responsivity (R) and absorbance of



OC_1C_{10}-PPV:PCBM film on wavelength of light. The blue line represents the responsivity and the black line represents the absorption. The inset figure shows the schematic of cross-sectional view of OPT.

3. Result

We first performed and basic transistor curve measurement on the OPT. By fitting the transfer curve, we obtained the field effect mobility of 1.8×10^{-2} cm^2 V^{-1} s^{-1} and a threshold voltage of -1.0 V. The transfer curve was measured in air under dark condition. These values are at the identical to the previous report using the same structured OPT [12].

We then measured the drain current of our OPT under various wavelength of light. 15 V were applied to the source and gate while the drain was grounded. **Figure 1** shows the dependency of responsivity, calculated using equation (1), on wavelength. The wavelength of our light source changed from 300 nm up to 900 nm. The optical power density of our light source was between 0.003 W cm^{-2} and 0.013 W cm^{-2}, varying on the wavelength. By comparing the responsivity curve with the absorption spectra of OC_1C_{10}-PPV:PCBM, we could see that the responsivity follows the trend of absorption. OC_1C_{10}-PPV:PCBM shows higher responsivity in the short wavelength regime. The maximum responsivity was 3.2×10^{-2} A W^{-1} which was observed at the wavelength of 320 nm. This peak is the same peak of PCBM [12]. Another peak of responsivity was found at 520 nm of wavelength which corresponds to the peak of OC_1C_{10}-PPV absorption. It is worth noting that the peak of responsivity at 520 nm is much larger compared to the absorption peak. This shows that, though OC_1C_{10}-PPV does not contribute to the electron transport, it still absorbs and introduces enough charge traps to amplify the photocurrent. From these results we could conclude that both donor and acceptor absorb the light and contributes to the photoresponse of OPT.

3. Conclusion

For the first time we evaluated the wavelength dependence of OPT responsivity while OPT was derived at saturation region. The responsivity shows that both donor and acceptor are contributing to the absorption and photocurrent in OPT. A similar trend could be seen in OPDs [14,15] while it differs from the result of OPT derived at non-amplification mode [13].

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