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# Photoinduced characteristics of organic thin film transistor using π-conjugated dendrimer

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## ABSTRACT

*We fabricated OTFT device using soluble π-conjugated dendrimer, 4(HPBT)-benzene, and investigated photoinduced characteristics of the device. The OTFT device using 4(HPBT)-benzene as an active layer showed a carrier mobility as high as $6\times10^{-3}$ cm²/Vs in dark conditions and sensitive photoinduced characteristics even at low light intensity. We observed the shift of threshold voltage and saturation current in photoinduced field-effect transistor characteristic curves. Through the measurements of the photoinduced saturation current as a function of drain voltages, we estimated photoinduced charge density of the OTFT.*

## 1. INTRODUCTION

As the semiconductor industry dominated by silicon is nearing the limits of performance improvements, there are many researches for new semiconductor material that has outstanding properties. It is expected that devices using π-conjugated organic semiconductors can be a promising industry because of their competitive advantages such as lightness, flexibility, and easy and low-cost processing. Organic light-emitting diodes (OLEDs) were already commercialized and organic photovoltaic cells (OPVs) were intensively studied **[1, 2]**. Flat panel displays needs thin film transistors (TFTs) as an elementary drive circuit. However, photoinduced effect of OTFTs have been rarely known although the OTFTs have been used for optoelectronic devices. A few studies of photoinduced characteristics in OTFTs having low photo-sensitivity have been reported lately. In OTFTs using soluble active materials, Narayan et al. reported photoinduced characteristics of OTFT device using poly(alkylthiophene) as an active layer **[3]**. Here, we report on the photoinduced characteristics of newly synthesized star-shaped π-conjugated dendrimer based OTFT devices. Due to sensitive optical response of soluble dendrimer, we observed the increase of the current of the OTFTs by light with low intensity.

## 2. EXPERIMENT

The organic thin film transistor (OTFT) using soluble π-conjugated dendrimer, 4(HPBT)-benzene, was fabricated. The chemical structure of the 4(HPBT)-benzene is shown in Fig. 1(a). The core part of 4(HPBT)-benzene exhibit 2-dimensional planar geometry. Highly doped *p*-type Si wafer and thermally grown $SiO_2$ layer were used as a gate electrode and dielectric layer, respectively. The thickness and dielectric constant ($\varepsilon_r$) of the $SiO_2$ layer were ~250 nm and ~3.9, respectively. Using conventional photolithography, gold (Au) source and drain electrodes were patterned with the length and width on the active region as 5 μm and 1500 μm, respectively. For the adhesion, Ti layer with 20 nm was deposited before the deposition of Au. The active layer using planar π-conjugated dendrimer, 4(HPBT)-benzene, dissolved in chloroform solvent was dropped at 160˚C on hot plate and then annealed at 160˚C for 10 min. The schematic diagram of the OTFT device fabricated in this study is shown in Fig. 1(b). The current-voltage (*I-V*) characteristic curves of the OTFTs using four-armed star-shaped molecules were measured under vacuum condition below $10^{-2}$ Torr by using a Keithley 237 SMU. The wire bonder (Kunche & Sona 4524) was used for electrical contact from Au electrodes to a chip carrier for the OTFTs. The mercury-xenon lamp and monochromator were used for measurement of optical response of the OTFTs.

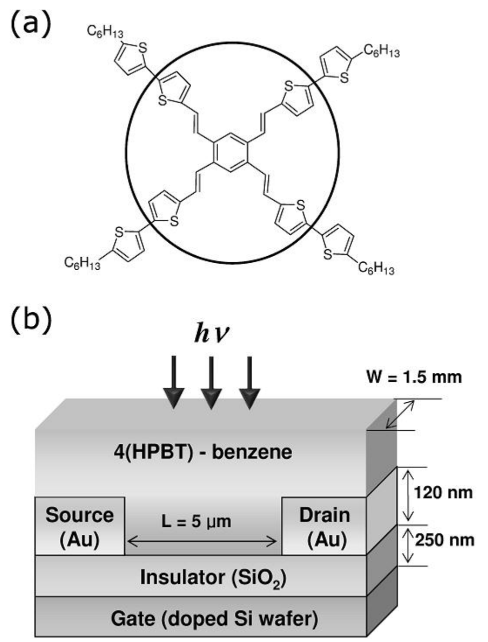


Fig. 1 (a) Chemical structure of 4(HPBT)-benzene with a planar (core part in circle) structure. (b) Schematic diagram of 4(HPBT)-benzene based OTFT device.

## 3. RESULTS AND DISCUSSIONS

Figure 2(a) shows typical source-drain current ($I_d$) characteristic curves with various gate voltages ($V_g$'s) for the 4(HPBT)-benzene based OTFTs in dark conditions. As the $V_g$ negatively increased, the $I_d$ negatively increased for the OTFT devices, implying *p*-type characteristics. Figure 2(b) shows $I_d$–$V_d$ characteristic curves as a function of $V_g$ for the OTFT devices using 4(HPBT)-benzene. The on/off current ratio ($I_{on/off}$) and threshold voltage ($V_{th}$) were ~$10^3$ and -10 V, respectively. The charge carrier mobility $\mu$ of the OTFT can be estimated by using the following equation in the saturation region of current:

$$I_{ds} = \frac{W\mu C_i}{2L}(V_g - V_{th})^2 \qquad (1)$$

where $W$ is the channel width, $L$ is the channel length, $\mu$ is the charge carrier mobility, and $C_i$ is the capacitance per unit area of the dielectric layer. The OTFT device using 4(HPBT)-benzene as an active layer showed a carrier mobility as high as $6\times10^{-3}$ cm$^2$/Vs calculated from the slope of the plot of $(-I_{ds})^{1/2}$ versus $-V_g$ in dark conditions, as shown in Fig. 2(a). The important factor of determining on/off current ratio and charge carrier mobility of the devices is chemical structure related to π-conjugation length of active organic molecules. Because π-conjugation paths of four-armed dendrimers were well-formed and core parts of the dendrimers exhibited 2-dimensional planar geometry, the charge carrier mobility of the devices was relatively higher than that of the previous report using soluble dendrimers bearing three conjugated arms.

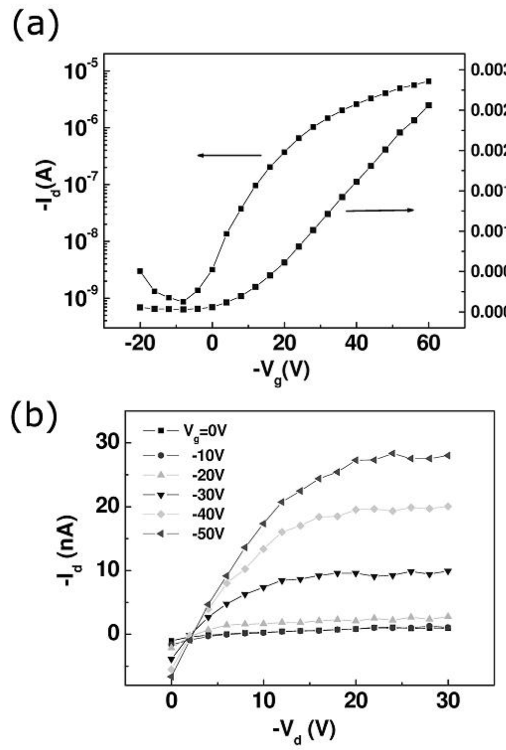


Fig. 2 I-V characteristics of 4(HPBT)-benzene based OTFT in dark conditions: (a) Transfer characteristics at $V_d$=−60V and (b) Output characteristics with various $V_g$'s.

In light ($\lambda_{ex}$ = 405 nm, ~0.5 mW/cm$^2$) conditions, $I_d$-$V_d$ characteristic curves of 4(HPBT)-benzene based OTFT device were dramatically changed. When light was incident on the active layer, bulk conductivity in active layer increased as trapped charge carriers were excited to band by the absorption of light. Therefore, both accumulated channel charges by gate voltage ($V_g$) and excited charges induced by light contributed to charge transport in active layer. In output characteristic curves in Fig. 3, the saturation region was not observed in light conditions, compared with in dark conditions. We could also observed threshold voltage ($V_{th}$) shift from -10 V to +20 V, and saturation current originated by bulk conductivity dramatically increased at large $-V_g$, in light conditions as shown in Fig. 3. The shift of $V_{th}$ means that bulk conductivity was suppressed as $V_g$ positively increased.

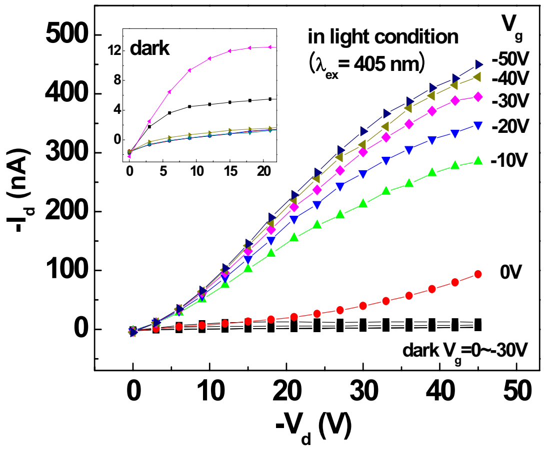


Fig. 3 $I_d$-$V_g$ characteristics with various $V_g$'s of 4(HPBT)-benzene based OTFT device in light conditions ($\lambda_{ex}$=405 nm, ~0.5 mW/cm$^2$)

Figure 4 shows photocurrents of the OTFT devices using 4(HPBT)-benzene between source and drain electrodes with various $V_d$'s as a function of time. As soon as light was given on active layer the photocurrents immediately increased and saturated in 2-3 seconds. The saturated photocurrent varies according to magnitude of $V_d$'s. From the saturated photocurrent, we can estimate a total number of carriers P(t) that is given by Eq. (2).

$$P(t) = \frac{I(t)L^2}{e\mu V} \quad (2)$$

where $I$ is the photocurrent, $L$ is the interelectrode distance, $e$ is the unit charge, $V$ is the applied voltage, and $\mu$ is the hole mobility [4]. When strong light (436 nm, ~1 mW/cm$^2$) was emitted, as a result of calculation, photoinduced total number of carriers was about $1.5\times10^7$ and this value was similar to all of $V_d$'s except for small $V_d$ (at about 0~−20V).

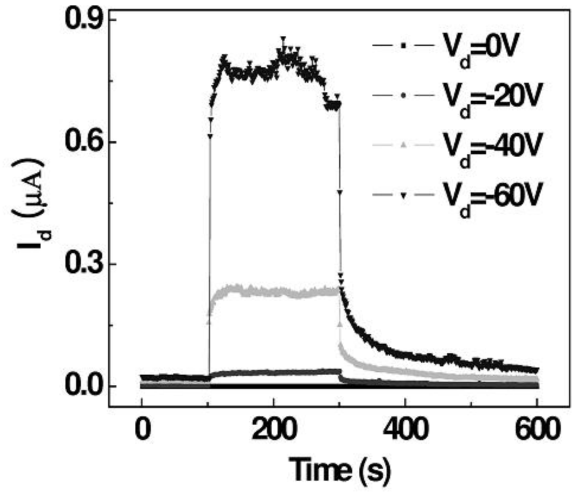


Fig. 4 Photocurrents of 4(HPBT)-benzene based OPT device between source and drain electrodes with various $V_d$'s

## 4. CONCLUSION

We fabricated 4(HPBT)-benzene based OTFT device and investigated photoinduced characteristics of the device. In our observation, the bulk current induced by incident light and channel current induced by gate bias coincidently affected in I-V characteristic curves of OTFT device. We also observed shift of threshold voltage and different saturation bulk current according to drain voltages. Because of highly photo-sensitive characteristics of 4(HPBT)-benzene molecules, the photocurrent dramatically increased even in small optical powers.

## 5. REFERENCES


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