Photo-Leakage Currents in Organic Thin-Film Transistor

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Abstract

We report the light illumination effect on the performance of pentacene organic thin-film transistor (OTFT). The TFT performance with and without illumination were measured at various temperatures. The off-state currents increase linearly with light intensity in the region of gate voltage where the holes are majority carriers in the TFT channel. The minimum photocurrents of OTFT increase with increasing light intensity.

1. Introduction

Organic thin-film transistor (OTFT) is of increasing interest recently because they have potential applications to large-area devices with low cost, light-weight, and flexible such as smart card, RFID, electronic paper and display [1].

During the last several years, the performance of OTFT has been improved remarkably, so that its performance is at least the same as that of amorphous silicon (a-Si) TFT. Among many organic semiconductors, pentacene is the best material for a high-performance TFT. [2, 3].

In this work, we made a high performance OTFT with self-organized process and studied its characteristics under illumination. Especially we studied the performance at positive gate voltage to study the off-state currents under and after illumination. Light intensity and temperature were changed for the measurements.

Photosensitivity is important for the display applications such as liquid-crystal display (LCD) and organic light emitting diode (OLED). The band gap of pentacene is 1.7 eV so that the light absorption in the visible range is high. [4].

2. Experimental

Figure 1 shows the cross sectional view of an OTFT. The OTFT on polyethersulfone (PES) substrate with a bottom gate and bottom contact structure was fabricated. Al and Au/Cr electrodes patterned by photolithography were used for gate and source/drain, respectively. Cross-linked PVP was used as a gate insulator layer and its thickness was 450 nm. The spin coated cross-linked PVP layer was cured at 180 °C in vacuum oven. [5] Before pentacene growth, a monolayer of OTS was self-assembled on the PVP surface. Treating the surface with an OTS monolayer has been shown to noticeably improve the performance of pentacene TFT. [6]

The pentacene layer was deposited by organic vapor phase deposition (OVPD) on plastic substrates held at an elevated temperature. [7]

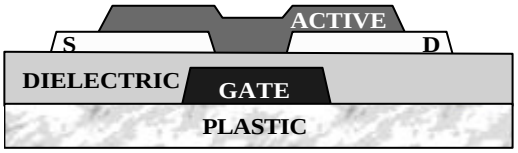

Figure 1. A cross-sectional view of an OTFT used in the present work.

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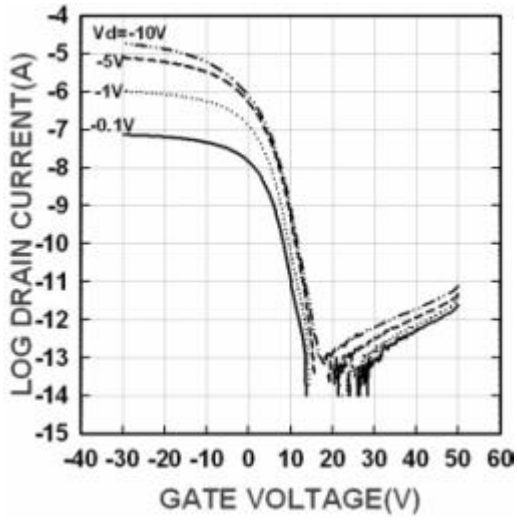


Figure 2. Transfer characteristics of an OTFT studied in the present work.

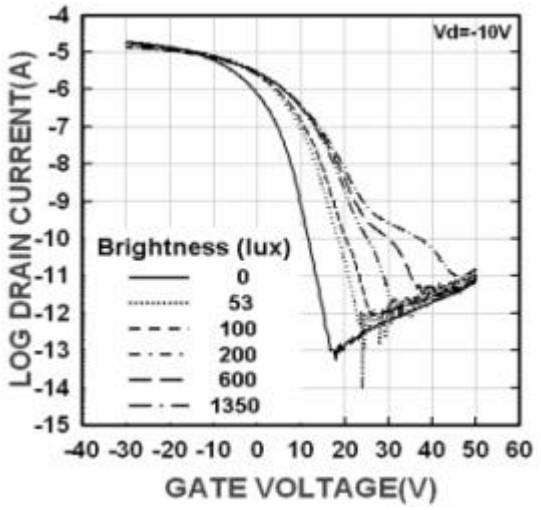
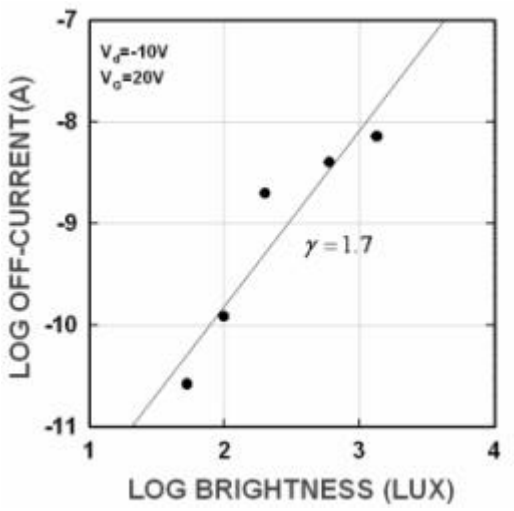


Figure 3. Transfer characteristics under illumination for an OTFT.

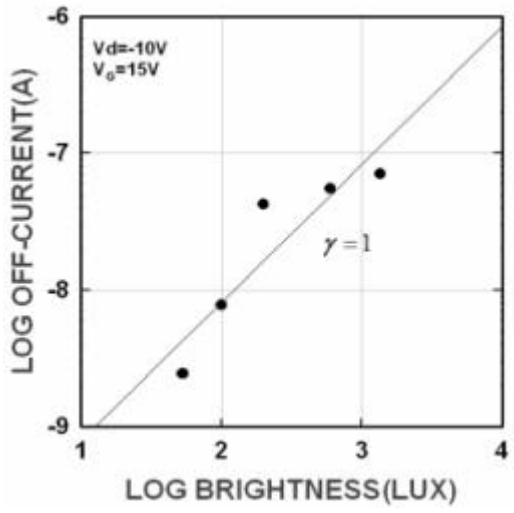
The performance of the OTFT was measured under light illumination and also after illumination. The light source was a CCFL backlight unit for LCD, illuminating white. The performances of OTFTs were measured using a semiconductor parameter analyzer (HP 4156 B).

3. Result and discussion

Figure 2 shows the transfer performance of OTFT under dark. The ratio of channel width to length of the TFT was 236 μm / 6 μm. The OTFT exhibited the field-effect mobility of 0.7 cm^2/Vs in saturation region and threshold voltage (V_{TH}) of -7 V. The TFT has the minimum off-state currents of less than 0.1 pA and the on-currents are ~10 μA, therefore the on-off ratio is around 10^8.



(a)



(b)

Figure 4. The off-state drain currents as a function of brightness at Vg = 20V(a) and Vg = 15V (b).

Figure 3 shows the transfer characteristics of the OTFT under light illumination. The minimum drain currents increase with increasing light intensity, especially the subthreshold region currents increase significantly and thus the slope decrease. The electron-hole pairs generated by light absorption increase the off-state currents significantly. This affects the position of the quasi-Fermi-level and the carrier density in the valence band.

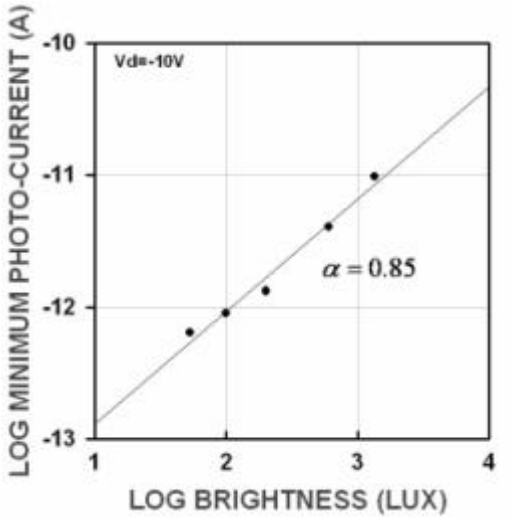


Figure 5. The minimum photo-current as a function of brightness.

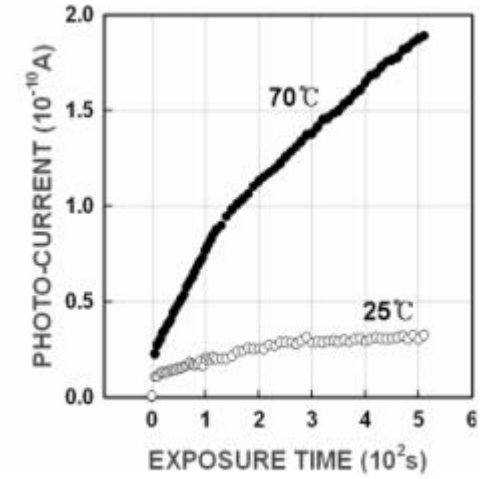


Figure 6. The photo-currents of OTFT measured at Vg = 4V and Vd=-10V at 25 and 70℃.

Figure 4 shows the off-state drain currents at Vg = 20V (a) and 15V (b). From Fig.3, the holes are the major carriers when Vg = 15V even though the electrons are induced in the channel. However, the electrons can affect significantly the currents because the dark current at Vg=20V is higher than the minimum current as shown in Fig. 3.

The currents in Fig. 4(b) increase with light intensity because the photo-generated carrier density increases with the incident light intensity. However, the currents increases super-linearly with increasing the incident light intensity in Fig. 4(a) because the

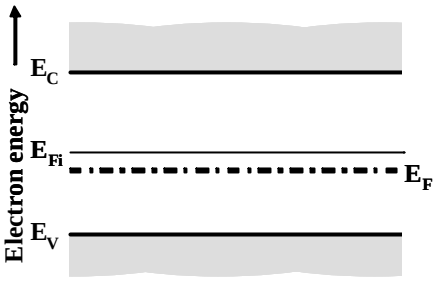


Figure 7(a). Thermal-equilibrium energy-band diagram

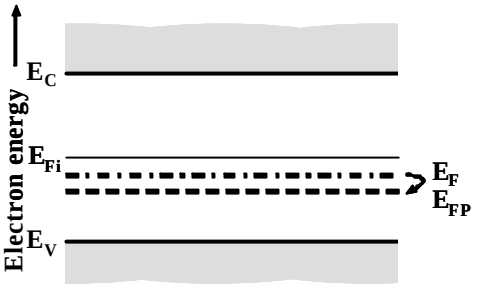


Figure 7(b). Quasi-Fermi level for holes

contribution of electrons is significant. The recombination of photo-generated electron-holes with the induced carriers can give super-linear light intensity dependence [8] .

Figure 5 shows the plot of minimum photo-current as a function of brightness in *log-log* scale. We got a straight line with a slope of 0.85. The minimum current appears at the border line where the hole current changes into electron current. Under the illumination more holes contribute to the conduction so that the minimum current increases with increasing illumination intensity.

Figure 6 shows the photocurrents as a function of exposure time under light illumination at room temperature and at 70℃. The currents were measured at Vg = 4V and Vd = -10V. It is interesting that the current increases with time. The currents increase significantly at 70°C. This means that under the non-equilibrium condition, the quasi-Fermi level shifts to the valence band by extending the exposure time, which appears to be due to the accumulation of holes in the channel.

Figure 7(a) and (b) show the thermal-equilibrium Fermi level (E_F) and quasi-Fermi level(E_{FP}) for holes, respectively. After illumination, the quasi-Fermi level shifts toward the valence band edge. This is true at

room temperature and at 70°C, but the shift is higher at 70°C. The quasi-Fermi level approaches toward the valence band edge with increasing the illumination time.

The relaxation of the carriers in the channel takes a long time. This is due to the deep electron traps which might attract the holes in the channel. The electron traps can be in the grain boundaries between the polycrystalline pentacene grains. With extending the exposure time more electrons can be trapped in the grain boundaries, resulting in more holes in the channel.

4. Conclusion

We fabricated a high performance OTFT and studied the light illumination effects on the OTFT performance. The off-state photo-currents increase linearly with light intensity when the carriers in the channel are holes, but they increases super-linearly when the electrons are majority carrier in the channel. It is also found that the quasi-Fermi level in the channel shifts toward the valence band edge with extending the exposure time. This is due to the electron traps in the grain boundaries in the pentacene polycrystalline film.

5. Acknowledgement

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6. References

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