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Effect of Illumination on Organic Polymer Thin-Film Transistors

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ABSTRACT

We have investigated the effects of white-light illumination on the electrical performance of organic polymer thin-film transistors (OP-TFTs). The OFF-state drain current is significantly increased, while the drain current in the strong accumulation regime is relatively unaffected. At the same time, the threshold voltage is decreased and the subthreshold slope is increased, while the field-effect mobility of the charge carriers is not affected. The observed effects are explained in terms of the photogeneration of free charge carriers in the channel region due to the absorbed photons.

INTRODUCTION

Organic polymer thin-film transistors (OP-TFTs) have shown promise for use in applications such as broad-area flat panel displays and photo-sensor arrays [1]. Since in these types of applications the device will either be integrated with light-emitting devices or will be used to detect light itself, it is important to understand the effects of illumination on the electrical performance of these devices. In this paper, we present the results of our investigation of the performance of our OP-TFTs under various levels of white-light illumination.

EXPERIMENTAL DETAILS

The structure of the device used in this study is shown in Figure 1. The device is an inverted, defined-gate, gate-planarized, co-planar thin-film transistor that has been previously described [2]. Indium tin oxide (ITO) was used for the source and drain contacts, amorphous silicon nitride (a-SiN:H) was used as the gate insulator, and chromium (Cr) was used for the patterned gate electrode. The organic semiconductor F8T2 (poly(9,9-dioctylfluorene-*co*-bithiophene) alternating copolymer from The Dow Chemical Corporation) was deposited by spin-coating from solution to provide a uniform film with an approximate thickness of 1000Å. To investigate the effect of illumination on the electrical performance of our devices, the devices were illuminated from the top with broadband white light from a 150W quartz tungsten halogen (QTH) lamp (Mitutoyo microscope lamp). Light from the QTH lamp is absorbed by the polymer in the range of wavelengths from approximately 475 to 525nn. The incident light intensity was controlled by a potentiometer connected to the QTH supply, providing sufficient control of the illuminance from 0 to 2370lux at the sample surface. The light was focused to a spot size approximately equal to the area of the device and the entire channel of the device was illuminated as shown in Figure 1.

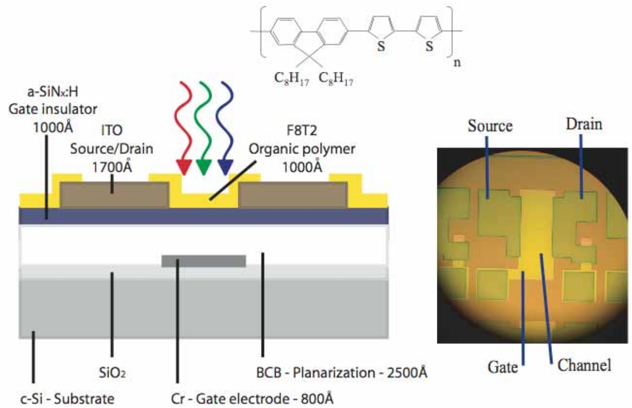

Figure 1. Device cross-section, chemical structure of F8T2, and picture of top-illuminated device.

We measured the OP-TFT transfer characteristics in the dark and under various levels of illumination at room temperature using a Karl Suss PM8 probe station, an HP4156 semiconductor parameter analyzer, and Interactive Characterization Software (Metrics). These devices exhibit p-channel field-effect transistor behavior as can be seen from the dark output characteristics (I_D vs. V_{DS}, drain current versus drain-to-source voltage). The linear regime field-effect mobility and threshold voltage were extracted from the linear regime transfer characteristics using the following equation, based on the MOSFET gradual channel approximation [3]:

$$I_D = -\mu_{FElin} C_{ins} \frac{W}{L} (V_{GS} - V_{Tlin}) V_{DS} \tag{1}$$

In this equation, $\mu_{FE\ lin}$ is the linear regime field effect mobility (cm^2/Vs), C_{ins} is the gate insulator capacitance per unit area (F/cm^2), W is the channel width of the device, L is the channel length of the device, V_{GS} is the applied gate to source bias, $V_{T\ lin}$ is the linear regime threshold voltage and V_{DS} is the applied drain to source bias. The subthreshold swing was extracted from the linear regime transfer characteristics, in the transition from the OFF-state to the ON-state, using the following equation:

$$S = \left(\frac{dLog(I_D)}{dV_{GS}} \right)^{-1} \tag{2}$$

In this equation S is the subthreshold swing (V/decade). The saturation regime field effect mobility and threshold voltage were extracted from the saturation regime transfer characteristics using the following equation, based on the MOSFET gradual channel approximation [3]:

$$I_D = -\mu_{FEsat} C_{ins} \frac{W}{2L} (V_{GS} - V_{Tsat})^2 \quad (3)$$

In this equation, $\mu_{FE\ sat}$ is the saturation regime field effect mobility (cm^2/Vs), $V_{T\ sat}$ is the saturation regime threshold voltage and the other parameters are the same as described above.

DISCUSSION

The linear regime transfer characteristics (I_D vs. V_{GS}, drain current versus gate-to-source voltage) of a typical device in the dark are presented in Figure 2. We find values of the linear regime field-effect mobility, threshold voltage, and subthreshold swing to be 4×10^{-3} cm^2/Vs, -25V, and 3.0V/decade respectively.

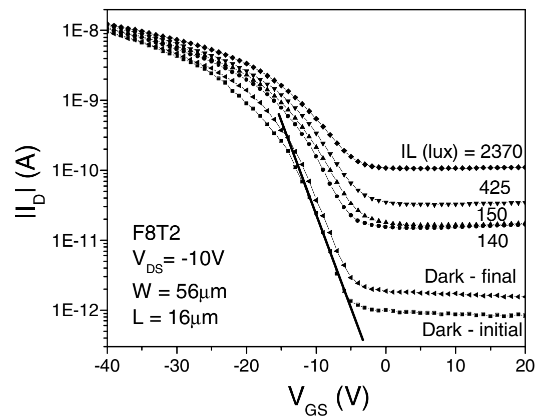

Figure 2. OP-TFT linear regime transfer characteristics in the dark and under various levels of white-light illumination.

We have observed very strong effects of broadband illumination on the electrical performance of our OP-TFTs. The effects are evident when we compare the linear regime transfer characteristics of a device in the dark to those of the same device under illumination as in Figure 2. From this figure, we can see that the drain current in the OFF-state is significantly increased by several orders of magnitude, while the drain current in the strong accumulation regime is relatively unaffected. The significant increase of drain current in the OFF-state, when the device is under illumination, can be attributed to the enhancement of the free carrier density in the channel of the device due to the photo-generation of carriers in the polymer. Whereas, in the strong accumulation regime, the relatively unaffected drain current can be explained by the overwhelming effect of the gate voltage on the concentration of accumulated carriers in the channel of the device, even when the device is illuminated. From Figure 2, we can also see that OFF-state drain current under illumination is not a strong function of V_{GS}. This non-dependence may be a useful characteristic of the device if it is to be used to detect light.

We have also investigated the effect of the level of illumination. Figure 2 shows the linear regime transfer characteristics of our device in the dark and under various levels of illumination up to approximately 2370 lux. From this figure, we can see that the OFF-state current is strongly dependent on the level of illumination. Figure 3 shows the dependence of $I_{D\ illum}$ on V_{GS} for several values of illumination. We can see that as expected, $I_{D\ illum}$ increases with increasing illuminance. In fact, $I_{D\ illum}$ exhibits a power law dependence on the illumination according to the following equation:

$$I_{Dillum} \propto IL^{\gamma} \tag{4}$$

In this equation, IL is the illuminance and γ is a constant. In the case of our devices, γ has a value of approximately 0.7; slightly less than one, which would give a linear dependence on the illumination.

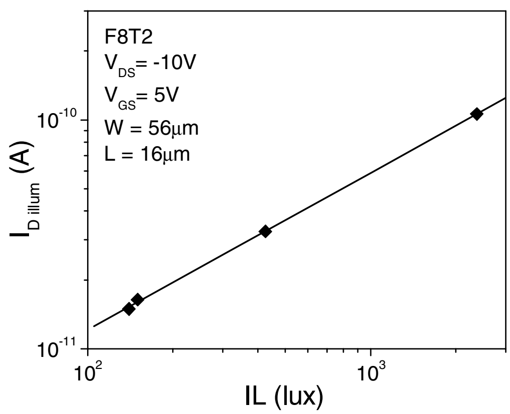

Figure 3. Dependence of OFF-state drain current on level of illumination.

We can also see that, as the illumination level is increased the subthreshold swing is increased (i.e. lower slope) as shown in Figure 4.

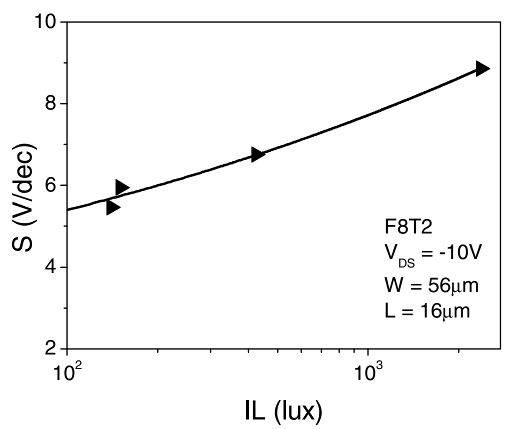

Figure 4. Variation of subthreshold slope with illumination.

The linear plots of the linear regime transfer characteristics are presented in Figure 5. In these plots, we see that the slopes, and therefore the field-effect mobilities, of all the characteristics remain unaffected by the illumination. While, as shown in Figure 6, the threshold voltage is reduced as the level of illumination is increased.

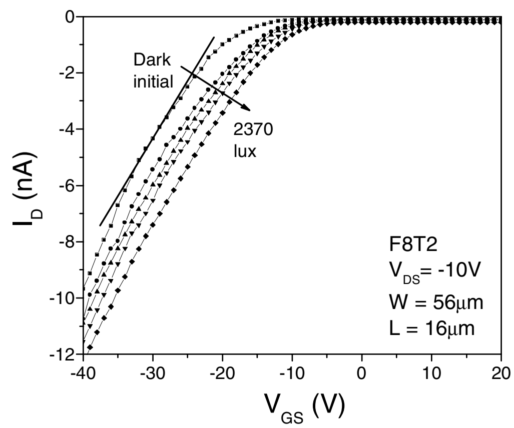

Figure 5. OP-TFT linear regime transfer characteristics in the dark and under various levels of illumination.

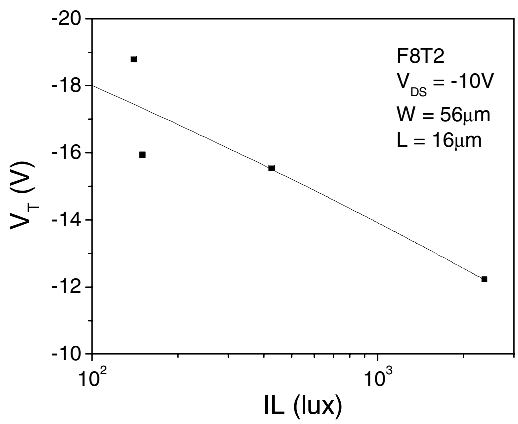

Figure 6. Variation of threshold voltage with illumination.

It should be noted that the device undergoes full recovery and relaxes back to its original state (i.e. significantly lower OFF-state drain current) after the illumination is removed. This effect can be seen in Figure 2 where $I_{D\ Final}$ has returned to $I_{D\ Initial}$. This recovery takes several minutes, in some cases, when the device is in the air at room temperature.

CONCLUSIONS

We have studied the electrical performance of our OP-TFTs under white-light illumination. We have shown that the OFF-state drain current is significantly increased due to the illumination, while the drain current in the strong accumulation regime is relatively unaffected. The effects of the level of illumination on the response of the device have also been investigated. It has been shown that the effects of the illumination increase as the illumination is increased. In the OFF-state, the response of the device to the illumination is effectively independent of the gate voltage. Therefore, when operated in the OFF-state, this device could be used as a low power photosensor, to detect and quantify the number of incident photons. However, if this device were to be used in display applications in which it would be subject to visible light in the range of 400nm to 500nm, a decrease in the ON/OFF ratio would result if the device were not shielded properly. We have also observed full recovery of the device after the illumination is removed.

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REFERENCES

[1] K.S. Narayan, A.G. Manoj, Th.B. Singh, A.A. Alagiriswamy, *Thin Sol. Films* **417**, 75 (2002).
[2] S. Martin and J. Kanicki, *J. of Elec. Mat.* **31**, 512 (2002).
[3] R.F. Pierret, *Semiconductor Device Physics*, (Addison-Wesley, Reading, 1996) p. 620.