# 용액형 유기반도체를 이용한 고성능 포토트랜지스터

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# High Performance Organic Phototransistors Based on Soluble Pentacene

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**Abstract** - A high performance organic phototransistor with dynamic range of 120 dB is demonstrated by employing soluble pentacene as a photo-sensing layer. The organic phototransistor used suspended source/drain (SSD) electrode structure, which provides a dark current level of ~ $10^{-14}$ A at positive gate bias. Under a steady-state illumination, the organic phototransistor exhibited a current modulation of $10^6$ compared to dark to give a dynamic range of 120 dB. These results suggest that the organic phototransistor based on TIPS pentacene can be a new promising candidate for low-cost and high-performance photo-sensing element for digital imaging applications.

## 1. Introduction

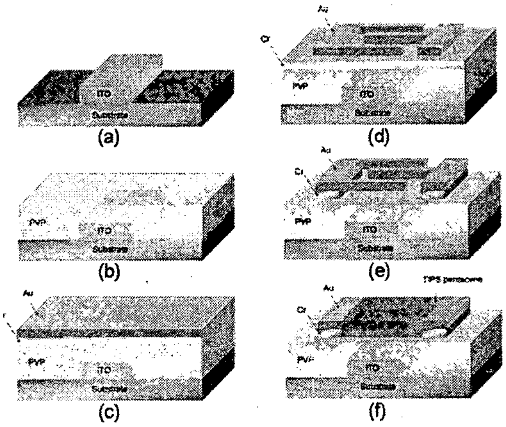
Organic thin-film transistors (OTFTs) based on polymers and small molecules have attracted a considerable attention in flexible electronics such as displays, photo sensors, pressure sensors and disposable radio-frequency identification tags (RF-IDs) due to their potential advantages of low-cost manufacturing, simple device architecture and compatibility to plastic substrates.[1,2] Most of the current researches on OTFTs are focused on realization of high-performance electrical switching devices as to integrate in flexible display panels such as liquid crystal displays, organic light-emitting diodes and electronic papers.[3]

The focus of this work is to investigate the effect of a steady-state light illumination on the electrical properties of ink-jet printed triisopropylsilyl (TIPS) pentacene phototransistors and to characterize the photo-electric properties of the phototransistors. With TIPS pentacene as a photo-sensing layer, an organic phototransistor with a current modulation up to six orders of magnitude was demonstrated. Also, we have characterized the effect of ultra-violet (UV) irradiation on the electrical properties of TIPS pentacene phototransistors to investigate the degradation caused by the UV exposure. After the UV irradiation the crystal structure of TIPS pentacene was significantly altered (showed a phase transition from polycrystalline to amorphous phase). As a consequence the electrical properties of TIPS pentacene phototransistor were significantly degraded. These results suggest that a proper UV-protective passivation layer is required for practical applications when employing TIPS pentacene phototransistor as a photo-sensing element.

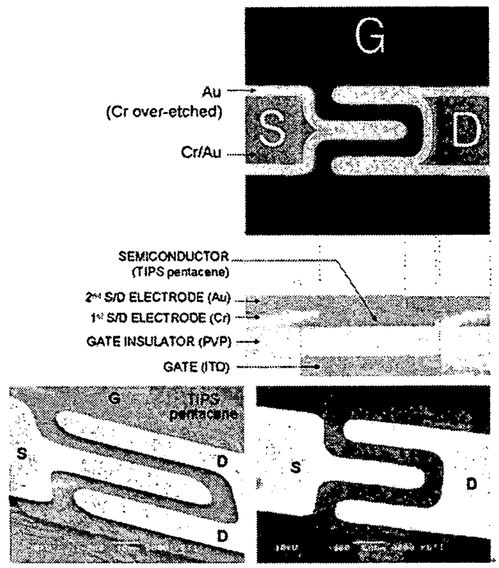
## 2. Results and Discussion

### 2.1 Structure and Fabrication

The organic phototransistors were fabricated as described in Fig. 1. The phototransistor consists of indium-tin-oxide as gate electrode, poly-4-vinylphenol as gate insulator and Cr/Au as source/drain electrode. To enhance the subthreshold characteristic of the phototransistor, suspended source/drain (SSD) electrode structure has been employed [4]. As a photo-sensing layer, triisopropylsilyl (TIPS) pentacene (a p-type semiconductor) was ink-jet printed. The fabricated device is shown on Fig. 2.



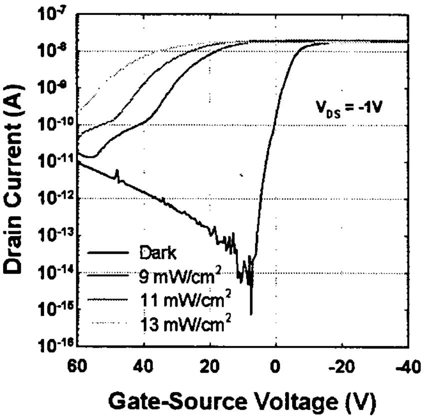

**<Fig. 1> Fabrication process of TIPS pentacene phototransistors with SSD electrode. (a) Gate electrode deposition/pattern, (b) Gate insulator coating, (c) S/D metal (Cr/Au) deposition, (d) Au pattern, (e) Cr pattern (over-etch), (f)TIPS pentacene ink-jet printing.**



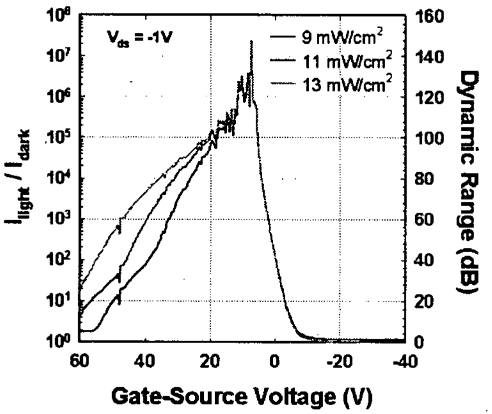

**<Fig. 2> (Top) The optical microscope image of TIPS pentacene phototransistor viewed from the substrate side. (Bottom) The scanning electron microscopy images of the phototransistor with ink-jet printed TIPS pentacene.**

### 2.2 Photo-electrical Characterization

The transfer characteristics of a TIPS pentacene phototransistor measured at dark condition and with a steady-state light illumination are shown in Fig. 3 (at $V_{ds}$ = -1 V). The increased drain current by light illumination is due to the photogenerated excitons and localized heating by absorption and rapid thermalization of light [5]. The current modulation of the phototransistor which is defined as $I_{light}/I_{dark}$ was $10^6$ at a gate bias of 10 V to give a dynamic range of 120 dB (Fig. 4). With a gate bias of 30 V, the dynamic range varied from 70 - 90 dB depending on the light power density. The dependency of dynamic range (or the current modulation) on gate bias and light power density can be explained by the photofield effect model and movement of quasi-Fermi levels (QFLs) which were developed for a-Si:H TFTs [6,7]. According to this model, when light is illuminated on the semiconductor, a redistribution of space charge in localized donor- and acceptor-like states takes place and relaxes the band bending of conduction and valence bands [6]. Also, under illumination the semiconductor is at a non-equilibrium steady-state and QFLs for trapped electrons and holes are created [7]. The QFLs are separated from the equilibrium Fermi level (Fermi level at dark) by $\Delta E_f$ and the $\Delta E_f$ depends on the intensity of the illumination. However, when charges (electrons or holes) are accumulated near the semiconductor/insulator interface, the movement of QFLs is opposed by the band bending and the photocurrent becomes less dependent on the intensity of the illumination. This explains the low current modulation and dynamic range observed at high negative gate bias in Fig. 4.



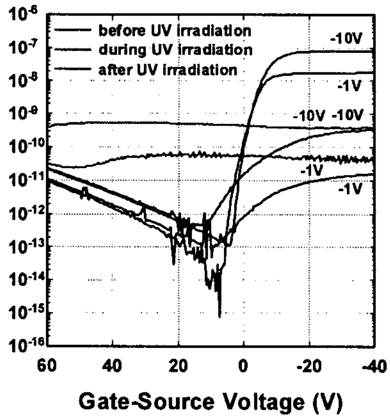

**<Fig. 3> The transfer characteristics of TIPS pentacene phototransistor measured at dark condition and with a steady-state light illumination.**




**<Fig. 4> The dependency of dynamic range of TIPS pentacene phototransistor on illuminated light power density and gate bias.**

**2.3 Degradation of Organic Phototransistors by Light Illumination**

Figure 6 shows the effect of UV irradiation on the transfer characteristics of TIPS pentacene phototransistor. The transfer curves were measured before, during and after the UV irradiation. Dissimilar to halogen light illumination, the on current level is reduced by 2 - 3 orders of magnitude compared to a fresh device and no gating effect was observed with UV irradiation. Even after the UV source is turned off, the on current level remains very low but gating effect is observed. During UV irradiation, photogenerated excitons are formed thereby increasing the drain current in off-state. However, simultaneously the UV ray destroys the crystallinity of TIPS pentacene which was confirmed by X-ray diffraction study (not shown here). Compared to as-coated TIPS pentacene films, the UV exposed film showed very weak (001) peak. Since most of the light sources emit UV ray including the solar ray, a proper UV-protective passivation must be integrated in the array to enhance its reliability when employing TIPS pentacene as a photo-sensing layer.




**<Fig. 5> Effect of UV irradiation on the transfer characteristics of TIPS pentacene phototransistors. The transfer characteristics were measured before, during and after UV irradiation.**

## 3. Conclusions

We demonstrated a high performance organic phototransistor by employing TIPS pentacene and SSD electrode structure. Under a steady-state illumination, the organic phototransistor showed high current modulation and dynamic range which suggests that the phototransistor based on TIPS pentacene can be a new promising candidate for low cost and high performance photo-sensing element for digital applications. Also, by examining the influence of UV irradiation on the electrical properties and crystalline structure of TIPS pentacene phototransistors, a proper UV-protective passivation layer must be integrated in the phototransistor to enhance its reliability.

## [References]

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