Investigation of Solvent Effect on the Electrical Properties of TIPS Pentacene Organic Thin-film Transistors

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Abstracts

In this paper, we investigated the effect of solvent on electrical properties of triisopropylsilyl (TIPS) pentacene organic thin-film transistors (OTFTs). The TIPS pentacene was spin coated by using chlorobenzene, p-xylene, chloroform and toluene as solvent. Fabricated OTFT with chlorobenzene showed field-effect mobility of 0.01 $cm^2/V\cdot s$*, on/off ratio* 4.3×10^3 *and threshold voltage of 5.5 V. In contrast, with chloroform the mobility was* 5.8×10^{-7} cm^2/Vs*, on/off ratio* 1.1×10^2 *and threshold voltage of 1.7 V.*

1. Introduction

Recently, there has been a growing interest in the fabrication of pentacene-based organic thin-film transistors (OTFTs) [1] due to their significant impact on low-cost, mass produced electronics using flexible substrates [2-3]. The development of simple, solution-phase processing methods to deposit semiconducting organic molecules would facilitate the development of new technologies such as large active matrix displays and inexpensive, mechanically flexible "plastic" electronics [4-7]. Pentacene has received special attention because single crystals [8] and thin films [9-10] exhibit high carrier mobilities. So we expect that OTFTs will have a ripple effect at portable device market. Many researchers have devoted their efforts to improve device performance parameters such as hole mobility, on/off current ratio, and threshold voltage, focusing on the relationships among the device structures, pentacene film morphology, gate dielectrics, chemical treatments on the surface of gate dielectric, and charge transport properties. Therefore, many remarkable achievements in device properties have occurred. In particular, a high hole mobility of ~3.3 cm^2/Vs and high on/off ratios over 10^6 were reported [11], and several inorganic and organic gate dielectric films have demonstrated to prove their feasibilities. However, despite these achievements, an in-depth research into the process-driven results has been absent. For example, the interface interaction between the pentacene channel and the gate dielectric was rarely studied despite its possible effect on the threshold voltage shift or control in thin-film transistors, which could be considered important aspects. In order to improve the performance of organic transistor, we investigated the electrical properties of TIPS pentacene OTFT using different solvent.

2. Results

First, We fabricated the device as the structure show in Fig 1. We deposited Al-Si (Si 1 wt%) with thickness of 100 nm on a cleaned glass substrate at room temperature by DC sputtering equipment with power of 400 W and deposition pressure of 6 mTorr. And we patterned the gate electrode with photolithography process. As a gate dielectric, Poly 4-vinylphenol (PVP) was deposited on the gate electrode by spin coating. The concentrations of curing agent of PVP, melamine-co-formaldehyde was fixed at 5 wt% and PVP was fixed at 10 wt%. We first put the sample in a convection oven set at 90°C for 5 minutes to remove the excess solvent in the film. Then, the PVP was thermally cured at 200°C for one hour to cross-link. More detailed results on the electrical properties of PVP can be found elsewhere [12]. For source/drain electrode, Cr/Au double layer was used. Cr was deposited the thickness of the Cr was 5nm on the PVP insulator to improve adhesion of Au and gate insulator by e-beam sputtering system and Au of 100 nm was deposited by thermal evaporator. Before spin coating TIPS pentacene, hexamethyldisilazane (HMDS) was spin coated for surface modification by spinner. The HMDS treatment has already been known to enhance the mobility of pentacene-based OTFTs [13].

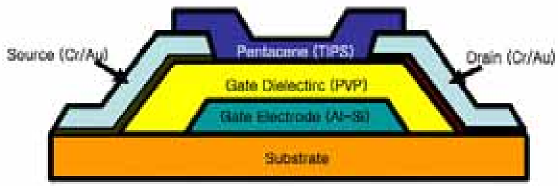

Figure 1. A schematic diagram of an OTFT device with bottom gate and bottom contact structure.

In our research, we used this treatment to examine its effects on the channel/gate insulator interface state. Finally, TIPS pentacene (1 wt%) with four different solvents, chlorobenzene, p-xylene, chloroform and toluene, was spin coated on source-drain electrode. The OTFT device had bottom gate and bottom contact type structure.

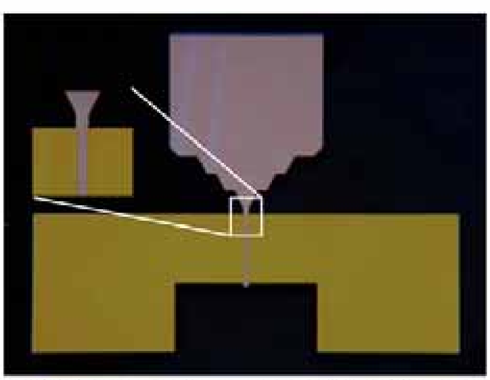

Figure 2. An optical image of OTFT device fabricated with TIPS pentacene as an active layer.

Figure 3 and Fig. 4 show the transfer and output characteristics of TIPS OTFT with chlorobenzene as a solvent, respectively. The calculated saturation field-effect mobility and on/off ratio were 1.6 x 10^{-2} cm^2/Vs and $10^{3.5}$, respectively.

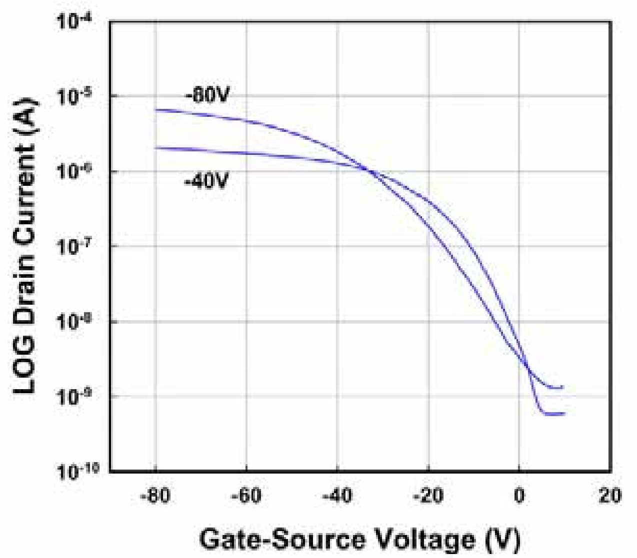

Figure 3. The transfer curves of an OTFT device fabricated with TIPS pentacene. The source-to-drain voltages were -40 V and -80 V.

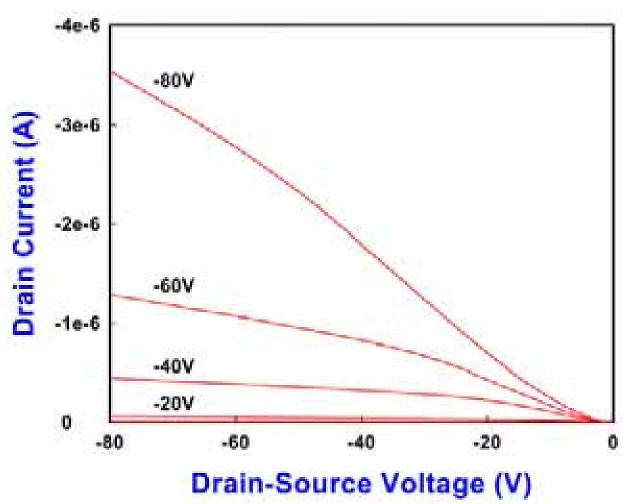

Figure 4. Output curves of an OTFT device fabricated with TIPS pentacene. The gate-to-source voltages were changed from 0 V to -80 V with -20 V step.

The field effect mobility, μ and the threshold voltage, V_{th} were extracted from saturation region of the transfer characteristic using the following equation.

Table 1.Electrical properties of OTFTs fabricated with different solvents.

Solvent	Boiling point (˚C)	mobility (cm^2/Vs)	I_{on}/I_{off}	Threshold Voltage (V)
Chlorobenzene	239~240	0.01	4.3×10^{3}	5.5
Chloroform	60.5~61.5	5.8×10^{-7}	1.1×10^{2}	1.7
p-Xylene	138~139	1.2×10^{-3}	1.4×10^{3}	-0.8
Toluene	110	6.6×10^{-4}	3.4×10^{2}	5.4

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

where I_{ds} is the drain current, L is the channel length, W is the channel width, C_i is the capacitance per unit area of the insulating layer, V_{gs} is the gate voltage and V_{th} is the threshold Voltage. The insulator capacitance C_i= 6.5 nF/cm^2 is a 600 nm thick insulator. The electrical characteristics of OTFT device made with different solvent are listed in Table 1.

In Fig. 5, the transfer characteristics of TIPS pentacene OTFTs fabricated with various solvents are shown. It can be noticed that the electrical properties of the transistors have significant dependence on what kind of solvent used in the coating process.

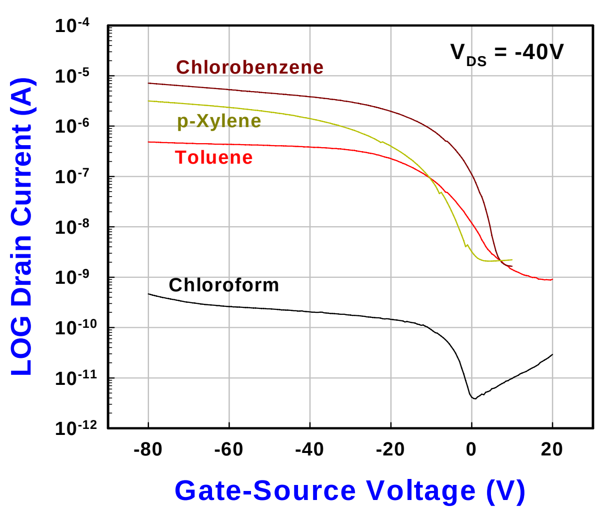

Figure 5. Transfer characteristics of TIPS pentacene OTFTs fabricated with different solvents.

3. Conclusion

We investigated the effect of solvents on the electrical properties of OTFT by using various solvents with different boiling points. It can be concluded that a solvent with a higher boiling point is preferable in obtaining high performance organic transistors. A solvent with low boiling point such as chloroform had the problems in uniformly coating TIPS pentacene film and also exhibited extremely low performance.

4. References

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