Enhanced Performance of Solution-Processed n-channel Organic Thin Film Transistor with Electron-Donating Injection Layer

Sung Hoon Kim1,2, Sun Hee Lee1,2, Seung Hoon Han1,2, Min Hee Choi1,2, Yong Bin Jeong1,2 and Jin Jang1,2

1Advanced Display Research Center, Kyung Hee University
2Dept. of Information Display, Kyung Hee University
Tel.: 82-2-961-0270, E-mail: jjang@khu.ac.kr

Keywords: TFT, OTFT, Flexible devices, Organic electronics

Abstract

We obtained high performance of n-type organic thin film transistors (OTFTs) using a solution process. N, N' bis-(octyl-)-dicyanoperylene-3,4:9,10-bis(dicarboximide) (PDI-8CN2) in ambient air: Low work function interlayer on source/drain is needed to enhance the electron injection to low LUMO level of n-type organic semiconductor. By using self-assembled monolayer (SAM) the field-effect mobility of 0.33 cm2/Vs was achieved.

1. Introduction

Solution-processed electronic devices such as ink-jet printing, spin-coating, roll-to-roll printing have advantages of low-cost, large-area circuits, flexible display.[1-4] In the organic thin film transistor (OTFT) fields, the performance of p-channel OTFTs such as field-effect mobility, stability on-off current ratio were remarkably improved.[5] Along with these outstanding performances of p-channel OTFT, high performances of n-channel devices are necessary for flexible, inexpensive complementary circuits (CMOS).[6]

Recently, high field-effect mobility, air-stable n-channel materials were reported and that could operate CMOS circuit sufficiently.[7] However, the field-effect mobility and on-off current ratio of solution-processed devices had lower performance than that of vacuum evaporation devices. [8].

Especially, n-channel organic thin film transistors need to low work-function metal or electron injection layer for reducing electron injection barrier. However, most low work-function metal can be oxidized easily such as Ca, Mg. [9] Therefore, we treated source and drain electrodes with SAM layer of electron-donating group that helps to electron injection between the electrodes and n-channel organic semiconductor. Reducing the injection barrier, we enhanced performance of n-channel organic thin film transistor.

2. Experimental

Figure 1(a) shows cross-sectional view of bottom-gate bottom-contact structure of n-channel organic thin film transistor and molecule structure of N,N' bis-(octyl)-dicyanoperylene-3,4:9,10-bis(dicarboximide) (PDI-8CN2)(Active InkTM, Polyera) was described in Figure 1(b). The AlNd (100 nm) as gate electrode was deposited by sputtering and patterned by photolithography method on the glass substrate. And the poly(4-vinylphenol) (PVP) with cross-linking agent was spin-coated as dielectric layer that was cured in vacuum oven at 180 ℃ for 4 hour (550 nm). After the curing process, Cr (5 nm) and Au (500 nm) was deposited by sputtering as the source and drain electrodes and patterned by photolithography. To pattern of active layer, photosensitive poly(vinyl

Keywords: TFT, OTFT, Flexible devices, Organic electronics
5-2 / S. H. Kim

Fig. 1. (a) A cross-sectional view of n-channel OTFT (b) Chemical structure of PDI-8CN₂

Fig. 2. Chemical structure of (a) β-PTS (b) PFBT (c) TP

alcohol) (PVA) was spin-coated and patterned by photolithography and cured at 180 °C for 1 hour. Figure 2 describes structure of SAM layer. To passivate hydroxyl groups on the PVP gate dielectric surface, all samples were immersed in 10 mM β-phenethyltrichlorosilane (β-PTS) solution that dissolved in toluene (Fig. 2(a)). After the gate insulator treated, each sample was dip into 10 mM of pentafluorobenzenethiol (PFBT) (Fig. 2(b)) and thiophenol (TP) (Fig. 2(c)) solution that are dissolved in ethanol, respectively. The n-channel material, 3 mg/mL of PDI-8CN₂ was dissolved in 1,2-dichlorobenzene that have high boiling point (174 °C) helps to better molecular ordering compare with low boiling solvent such as chloroform. The solution was spin-coated on the each sample and these were annealed at 80 °C in N₂ oven for 30 minutes.

3. Results and discussion

Figure 3 shows transfer and output characteristics of TP treated n-channel OTFT. We achieved field-effect mobility (μₑₑₑ) of 0.33 cm²/Vs, threshold voltage (Vₜₜₜ) of -1.1 V, with on-off current ratio (Iₒₒₒ/Iₒₒₒ) of 10⁵ in ambient condition. These enhanced performances were originated by reduction of injection barrier between Au electrodes and organic semiconductor.

We summarized performances of n-channel OTFTs with difference SAM treatments (Table 1). Clearly, TP as electron-donating SAM treated n-channel OTFT had highest on and off current ratio and field-effect mobility.

The PFBT treatment as electron-withdrawing group helps to lower the Au work-function. Despite of n-channel OTFT with PFBT treatment had high electron injection barrier, PFBT treated device had higher on-current and mobility than that of without SAM treated n-channel OTFT. Because the PFBT formed organic dielectric layer on the contact region that improved interface between organic semiconductor and electrodes.[11]

Table 1. Summary of SAM treated n-channel OTFT (W/L=200 µm/8 µm, V₀=20 V)

<table>
<thead>
<tr>
<th></th>
<th>Mobility (cm²/Vs)</th>
<th>Iₒₒₒ/Iₒₒₒ</th>
<th>Vₜₜₜ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without SAM</td>
<td>0.008</td>
<td>-10⁴</td>
<td>1.8</td>
</tr>
<tr>
<td>PFBT</td>
<td>0.03</td>
<td>-10³</td>
<td>-0.7</td>
</tr>
<tr>
<td>TP</td>
<td>0.33</td>
<td>-10⁵</td>
<td>-1.1</td>
</tr>
</tbody>
</table>

To confirm the TP treatment reduced electron injection barrier, we calculated contact resistance of n-channel OTFTs. The contact resistance was extracted by transmission line method.[12] We obtained contact resistance of 654 kΩ (V₀=40 V) without treated n-
channel OTFT, 27 k cm (V \text{gs}=40 V) of PFBT treated n-channel OTFT and 17 k cm (V \text{gs}=40 V) of TP treated n-channel OTFT. In these results, we reduced the contact resistance of n-channel OTFT that have almost 36% low of contact resistance, compare electron-donating SAM with electron-withdrawing SAM.

4. Summary

We achieved high performance of solution-processed n-channel OTFT with electron-donating SAM in ambient condition. Our n-channel OTFT had 0.33 cm²/Vs of field-effect mobility, 10⁵ of on-off current ratio and -1.1 V of threshold voltage. Therefore, we reduced contact resistance of n-channel OTFT.

Acknowledgement

This research was supported by the Knowledge Economy of Korean Government.

5. References