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## Fabrication of Air-Stable High-On/Off-Ratio Organic Static-Induction Transistor with Nano-Triode Array

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### 1. Introduction

In recent years, organic thin-film transistors (OTFTs) have been intensively studied to apply them to flexible electronic devices. Among many types of transistor structures, organic static induction transistors (OSITs) have great advantages in decreasing on-state resistance and operation voltage because the carrier runs through the small distance over wide sectional area. We have reported that a high performance can be obtained by the OSITs with nano-triode array which is fabricated by colloidal lithography [1]. In the previous report, copper-phthalocyanine (CuPc) or pentacene was used as an active material. However, these materials had a practical disadvantage: a number of acceptors are generated in air and, as a result, the device characteristics change remarkably. To obtain air-stable devices, we need to use more inert semiconducting materials against oxygen and water.

In this paper, we have therefore selected 2,7-diphenyl[1]benzothieno[3,2-b][1]benzothiophene (DPh-BTBT) [2] as an active material for the OSIT. DPh-BTBT is known to show a high carrier mobility and the stability against air because of its high ionization potential (IP). The high IP however has a negative side effect, that is a relatively large carrier-injection barrier from the source electrode. To solve this problem, we have screened acceptor molecules, which effectively form a heavily p-type doped carrier-injection layer, by comparing the electrical conductivity of the doped DPh-BTBT films. Then, we have confirmed that an OSIT with DPh-BTBT and the acceptor material shows superior and air-stable device characteristics.

### 2. Experimental

For comparison of the activation rates of acceptor molecules, DPh-BTBT and each acceptor material { N, N'-dioctyl-3,4,9,10-perylene tetracarbox diimide (PTCDI), 7,7,8,8-tetracyanoquinodimethane (TCNQ), copper-hexadecafluoro-phthalocyanine (F16CuPc), tetrafluoro-tetracyanoquinodimethane (F4TCNQ), and perfluorofullerene (C60F36)} were co-deposited on a glass substrate for 50 nm with the volume ratio of 9:1. Au

parallel electrodes, where the length and width of the conduction channel were 20  $\mu\text{m}$  and 5 mm, respectively, were deposited on the films. The electrical conductivity of the film was estimated from current-voltage characteristics.

For the fabrication of OSIT, polystyrene (PS) particles (200 nm in diameter) were first adsorbed onto a glass substrate from the water dispersion. Pt (20 nm), SiO<sub>2</sub> (100 nm), and Al (20 nm) layers were deposited on the substrate as a drain electrode, a insulating layer and a gate electrode, respectively. Then, the particles were selectively removed by an adhesive tape. After the particles were removed, a large number of nano-holes were formed [3]. A DPh-BTBT active layer (250 nm) and a doped carrier-injection layer (150 nm) were deposited on the porous electrodes, and finally, a Au source electrode was deposited on top. The active device area of the OSIT was 2x2 mm<sup>2</sup>. The device characteristics were measured after the two-day storages of the device in N<sub>2</sub>, O<sub>2</sub> and air, successively.

### 3. Results and Discussion

Figure 1 shows the comparison of the conductivity of DPh-BTBT films with various acceptor molecules. The improvement of the conductivity is obvious only when F4TCNQ or C60F36 is doped. As is evident from Fig. 2, these effective acceptor materials have approximately the

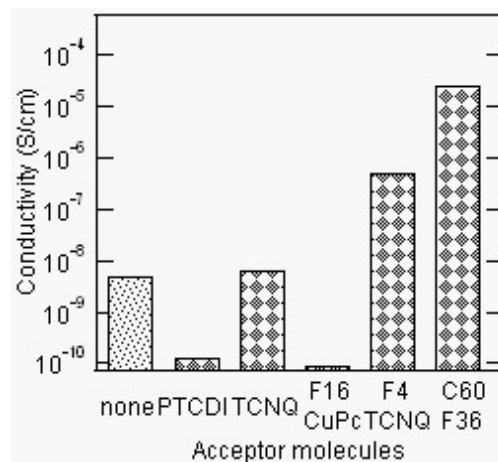


Fig. 1 Comparison of the conductivity of DPh-BTBT films doped with various acceptor molecules.

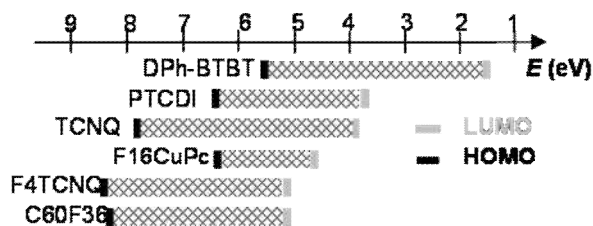


Fig. 2 HOMO and LUMO levels of the materials used in this work [4,5].

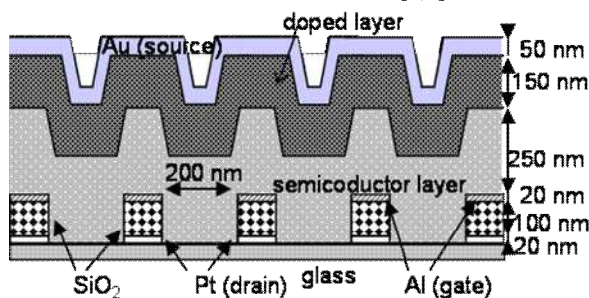


Fig. 3 Structure of the OSIT with nano-triode array.

same level of LUMO as the HOMO of DPh-BTBT, which is reasonable by considering the charge transfer between these levels. From the conductivity measurements, we selected C60F36 as the most active acceptor against DPh-BTBT, and fabricated OSITs with the charge-injection layer of which device structure is shown in Fig. 3.

Figure 4(a) shows transfer characteristics of the DPh-BTBT OSIT measured in  $N_2$ ,  $O_2$  and air ambients. For comparison, those of the conventional CuPc OSIT are shown in Fig. 4(b). It is evident that the OSIT with a DPh-BTBT active layer is far more stable against both oxygen and water vapor than that with CuPc. When we fabricated a DPh-BTBT OSIT without the carrier-injection layer, no effective drain current was observed in any ambience. In contrast to DPh-BTBT, a CuPc OSIT works fine even without a carrier-injection layer when it is doped by the oxygen exposure. These results indicate that the carrier-injection layer is necessary in the cases of high IP materials.

The on/off ratio of the output current shown in Fig. 4(a) is approximately 2500, which is higher than that of the conventional CuPc OSITs [1]. A considerable cause of the previous poor on/off ratio is the acceptor formation in the channel region also by the ambient gases. Oxygen and water molecules gradually diffuse into the active layer and form high-density acceptor levels [6]. They acts as a space charge to screen the gate electric field and the device become less sensitive to the gate voltage. This must be another advantage of the DPh-BTBT's insensitivity against ambient gases.

#### 4. Conclusion

Various acceptor molecules were examined to be used in the carrier-injection layers of DPh-BTBT OSITs. F4TCNQ and C60F36 were found to exhibit high dopant activation rate in DPh-BTBT. By using C60F36-doped

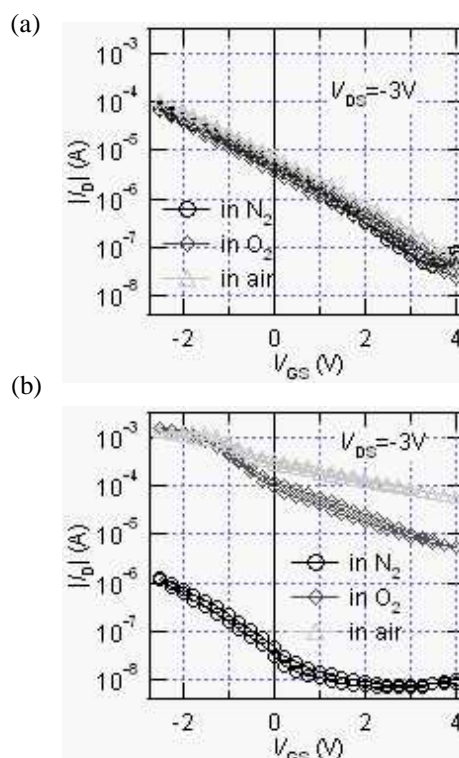


Fig. 4 Transfer characteristics of OSITs with (a) DPh-BTBT and (b) CuPc as active materials.

carrier-injection layer, an air-stable DPh-BTBT OSIT having ~2500 on/off ratio was successfully fabricated.

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