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Reliability Enhancement of Air-Stable Organic Vertical Transistor

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Abstract

In this paper, the difference of bias stress effect reliability of vertical transistor (space charge limited transistor, SCLT) and organic field effect transistor (OFET) is investigated. A novel air-stable polymer, PNTz4T, is used as the active layer. We demonstrate that PNTz4T-SCLT demonstrate small threshold voltage shift (-0.11 V) after 5000-s negative bias stress and shows stable performance after placing in the air ambient for 100 days.

1. Introduction

In recent year, active matrix organic light emitting diodes (OLED) displays have attracted lots attentions. The reliability of driving transistor is one of critical issues for development [1]. In our previous work, we had demonstrated that space charge limited transistor (SCLT) is a promising vertical transistor which can deliver high output current density and better bias stress reliability if the device was treated with octadecyltrichlorosilane (OTS) monolayer [2, 3]. However, the material we used as the active layer was poly(3-hexylthiophene) (P3HT) which is not stable in the air ambient. SCLT is like the solid-state triode tube. Holes of p-type material are injected from emitter electrode into vertical channel and arrive at collector electrode. The potential profile inside the openings can be modified by the porous base electrode. As a result, the on-state and off-sate of the vertical channel is controlled. PNTz4T is an air-stable polymer exhibiting good carrier mobility of 0.56 cm^2/ (Vs) [4]. Nakayama et al. demonstrated that PNTz4T transistor with vertical channel structure showed better mobility reliability than the organic filed effect transistor (OFET) with planer structure [5]. However, bias stress effect of PNTz4T based transistors has still not been investigated. In this paper, we investigate and compare the bias stress effect of PNTz4T-SCLT and PNTz4T-OFET. With the electrode covering on the top of structure, PNTz4T-SCLT showed much better bias stress reliability than PNTz4T-OFET. Finally, no significant degradation was observed for PNTz4T-SCLT after operating in the air for 100 days.

2. Experimental Setup

The air-stable material we used to serve as the active layer was a synthesized novel NTz-based semiconducting polymer, PNTz4T. The chemical structure of PNTz4T is shown in Fig. 1(a). Schematic diagram of OFET and SCLT are shown in Fig. 1(b) and (c), respectively. For SCLT, indium tin oxide (ITO) glass substrate was used as the collector electrode (C). Poly(4-vinyl phenol) (PVP) was then deposited on collector electrode to form an insulating layer. After grid-like Al metal serving as the base electrode (B) was deposited, the active layer was spin coated on the substrate. Finally, a top electrode containing thin molybdenum oxide (MoO3) and Al was evaporated to serve as the emitter (E). For OFET, a highly doped p-type silicon wafer was used as the gate electrode and 100-nm-thick SiO_2 as the gate insulator, respectively. The substrate was then treated with OTS. After PNTz4T being depositing on the substrate, Au was deposited on the substrate to serve as the source and drain electrode.

All the electrical measurement for devices coating with PNTz4T were carried out in ambient. We used Agilent E5270B semiconductor parameter analyzer to measure the electric characteristics of and the bias effect of SCLT. Negative bias (V_{BE} = -1.0 V for SCLT, V_{GS} = -40 V for OFET) and positive bias (V_{BE} = 1.0 V for SCLT, V_{GS} = 40 V for OFET) were applied for 5000 seconds. During this time, other electrodes were all biased at 0 V.

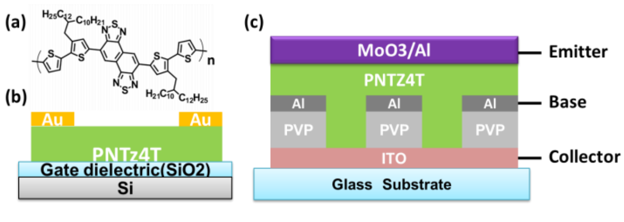

Fig. 1 Schematic diagram of (a) OFET and (b) SCLT

3. Results and Discussion

Fig. 2 shows the transfer characteristics with various bias stress time of PNTz4T-OFET and PNTz4T-SCLT. After biasing at V_{BE} = -1 V for 5000 s, PNTz4T-SCLT shows almost no threshold voltage shift shown in Fig. 2(a). On the other hand, in Fig. 2(b), PNTz4T-OFET shows larger threshold voltage shift (△Vth) after a 5000-s negative bias stress (V_{GS} = -40 V).

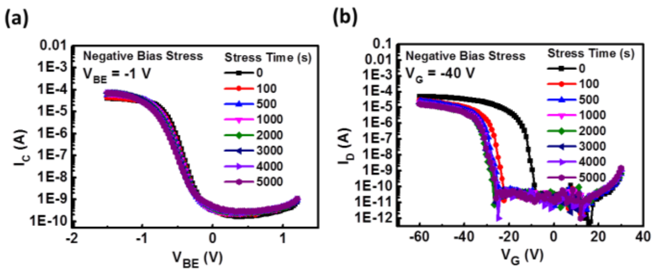

Fig. 2 Transfer characteristics with various bias stress time of (a) PNTz4T-SCLT and (b) PNTz4T-OFET.

The threshold voltage shift against the bias stress time with negative base bias stress is shown in Fig. 3(a). After biasing for 5000 s, PNTz4T-OFET exhibits much larger threshold voltage shift (-13.25 V) than PNTz4T-SCLT. In order to show clearly curves, smaller scale of Fig. 3(a) is shown in Fig. 3(b). We can observed that threshold voltage shift of PNTz4T-SCLT is nearly -0.11 V.

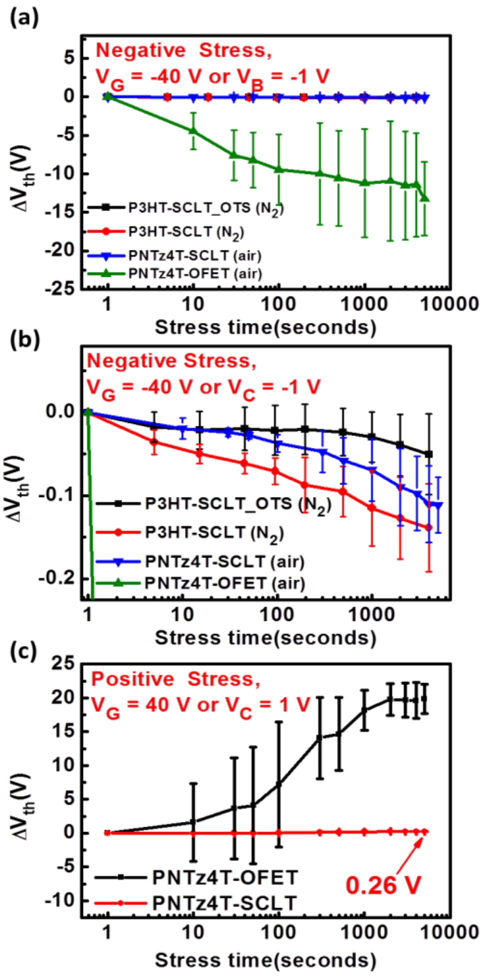

Fig. 3 Threshold voltage shift versus stress time under (a) negative base stress and (b) positive base stress. (c) The smaller scale figure of (a).

Furthermore, we also compared the ∆Vth with SCLT fabricated by P3HT. P3HT-SCLT cannot be operated in the air ambient for long time. As the result, the measurement was made in the glovebox with N_2 environment. In our previous work, P3HT-SCLT with OTS treatment showed better bias stress stability. Here PNTz4T-SCLT shows smaller threshold voltage shift than P3HT-SCLT without OTS treatment (-0.14V). Although P3HT-SCLT with OTS treatment had smaller threshold voltage shift, P3HT is not an air-stable material which is a disadvantage for further applications. Fig. 3(c) shows the ∆Vth against stress time under positive bias stress. After biasing for 5000 s, ∆Vth is only 0.26 V of PNTz4T-SCLT which is much smaller than 19.8 V of PNTz4T-OFET. We speculate that the better reliability of PNTz4T-SCLT is due to the emitter electrode covering the whole device. The effect is probably similar to the OFET with top gate structure covered by top gate dielectric layer [6]. The specific reason should be further investigated in the future.

Finally, we continuously measured the output current of PNTz4T-SCLT for more than 100 days which was placed in the air ambient. As shown in Fig. 4, no significant degradation of On-current density and Off-current density was observed. Furthermore, the output current is high enough to drive the OLED.

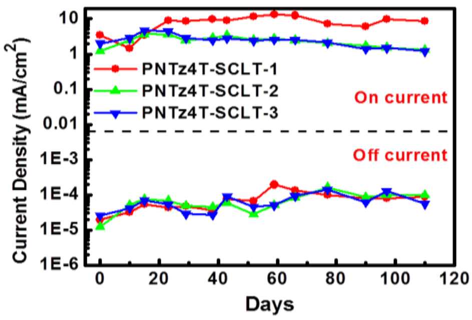

Fig. 4 Output current density against days of 3 PNTz4T-SCLTs.

4. Conclusions

We successfully demonstrated an air-stable organic vertical transistor with high bias stress reliability. After a 5000-s bias stress, the threshold voltage shift of PNTz4T-SCLT under negative stress was -0.11 V which was much lower than the one of PNTz4T-OFET. For SCLT, no significant degradation of performance was observed after 100 days. With high enough output current, better reliability and air-stable performance, SCLT might be used for further application like OLED driving in the future.

Acknowledgements

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