Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp880-881

High-Mobility n-Channel Organic Transistor of Solution Processed Perylenediimide Derivative Single Crystals on PS/SiO_2 Dielectric

Somnath Mondal, Wei-Hsiang Lin, Yu-Chi Chen, Bo-Hsiang Chen, Te-Fang Yang*, and Ming-Yu Kuo*

Department of Applied Chemistry, National Chi Nan University, Nantou 54561, Taiwan
Tel: +886-49-2910960 ext.4146, Fax: +886-49-2917956, Email: tfyang@ncnu.edu.tw, mykuo@ncnu.edu.tw

Abstract

High performance single crystal organic field effect transistor (OFET) of perylenediimide derivative is demonstrated on PS/SiO_2 dielectric. The OFET exhibits high electron mobility of 1.2 cm^2/V.s with good $I_{ON/OFF}$ ratio of more than 10^5. Excellent operational ambient stability of more than 60 days is observed in this perylenediimide based OFET device.

1. Introduction

Solution processed organic field effect transistors are attractive because of their low cost and large area electronic applications as well as to understand fundamental charge transport properties in organic molecular solids. To date, greatest hole mobility as large as 40 cm^2/V.s is achieved [1], while electron mobility in OFETs are less developed and is not comparable with p-channel counterpart. The realizations of high electron mobility in combination with great ambient stability are challenging. Very limited works have been reported in single crystal OFETs with electron mobility exceeding 1 cm^2/V.s when measured in air ambient. The improved charge mobility in organic devices arise from well-ordered molecular packing enabled by strong intermolecular π−π interactions. This suggests that through proper designing and processing a molecular material, n-channel OFET may achieves or even exceeds the mobility of the best p-channel device. In this paper, a novel material of perylene-tetracarboxylic-diimide derivative (PTCDI-X, Fig. 1(a)) is designed and synthesized for high performance single crystal OFET applications.

2. Device Fabrication

The droplet pinning method for single crystal growth is illustrated in Fig. 1(b). Ribbon shaped crystals were formed on the substrates after the solvent slowly dried at room temperature. Schematic view of the fabricated single crystal OFET is illustrated in Fig. 1(c). Thermally grown SiO_2 and polystyrene (PS) treated SiO_2 were used for gate dielectric layer and Au source-drain was deposited by thermal evaporation method. Highly doped Si acted as gate electrode.

3. Results and Discussion

Despite the advantage of higher charge carrier mobility in single crystal organic molecular solid, development of single crystals organic electronics are limited due to manual fabrication process. The alignment of organic single crystals in predefined location from solution process is challenging. The droplet pinning method exhibited well aligned single crystals over a large area (Fig. 2). During solvent evaporation from substrate, crystals start to nucleate near the contact edge and grow along the receding direction, as shown in Fig. 2. The morphology and the crystalline structure were investigated. Very smooth surface of PTCDI ribbons indicates a good crystalline structure of the material. The crystallization was further confirmed by the HRTEM image of the ribbon (not shown here). SEM image of fabricated device was shown in Fig. 3. The channel width and length was measured for each device separately for evaluation of transistor parameters. Fig. 4 and Fig. 5 show the I-V characteristics of PTCDI-X based single crystal OFET device on bare SiO_2/Si substrate. All the measurements were carried out in air ambient. In spite of good crystallinity of the organic material, a low mobility and higher switch on voltage (V_{ON}) was observed in the device. This can be attributed to large amount of carrier trap at or near the semiconductor dielectric interface arising from the surface hydroxyl group on SiO_2 [2]. The influence of hydroxyl group on transistor performance was further investigated. It is reported that thermally cross-linked bilayer dielectric reduce the electron trap by eliminating the hydroxyl group from SiO_2 surface [3]. Improved I-V characteristics of single crystal OFET on bilayer dielectric are observed (Fig. 6 and Fig. 7). A high mobility of 1.2 cm^2/V.s, which is ~ 4-fold higher than bare SiO_2, is obtained. Moreover, near zero V_{ON} is also achieved on PS modified SiO_2 dielectric. This is believed due to the good single crystal nature of the organic material as well as the good electrical contacts at both the crystal−dielectric and the crystal−electrode interfaces. Table I shows comparative data for the PTCDI-X OFET for different dielectric layer. Additionally, the ambient stability is also an important parameter for realistic applications and the single crystal PTCDI-X OFETs on PS/SiO_2 exhibited high mobility even measured after 60 days. Therefore, the high mobility, and excellent air-stability in this single crystal OFET device has great potential for practical applications.

3. Conclusion

In summary, a solution processed and perylene diimide derived single crystal OFET on PS/SiO_2 dielectric is demonstrated. The device exhibited high electron mobility of 1.2 cm^2/V.s in air, near zero V_{ON} and $I_{ON/OFF}$ higher than 10^5. The excellent performance is due to the proper molecular design as well as to the formation of good single crystal by their strong intermolecular interaction.

References

[1] H. Li, et al., *J. Am. Chem. Soc.*, vol. 134, p. 2760, 2012.
[2] T. D. Anthopoulos, et al., *Appl. Phys. Lett.*, vol. 89, p. 213504, 2006.
[3] T. Takahashi, et al., *Appl. Phys. Lett.*, vol. 88, p. 033505, 2006.
[4] A. S. Molinari, et al., *J. Am. Chem. Soc.*, vol. 131, p. 2462, 2009.

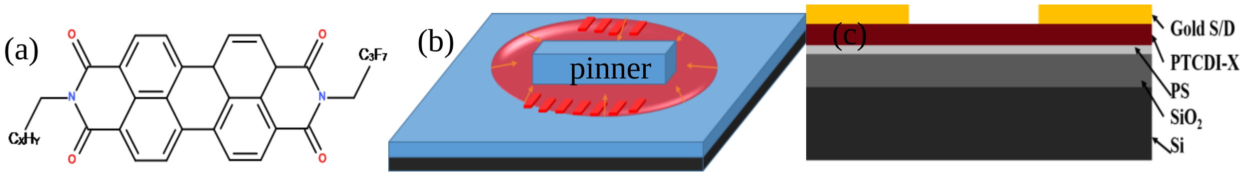

Fig. 1 (a) Molecular structure of perylene-tetracarboxylic-diimide derivative. (b) Schematic presentation of crystal growth method by droplet pinning. (c) Schematic structure of PTCDI-X single crystal OFET on bilayer dielectric.

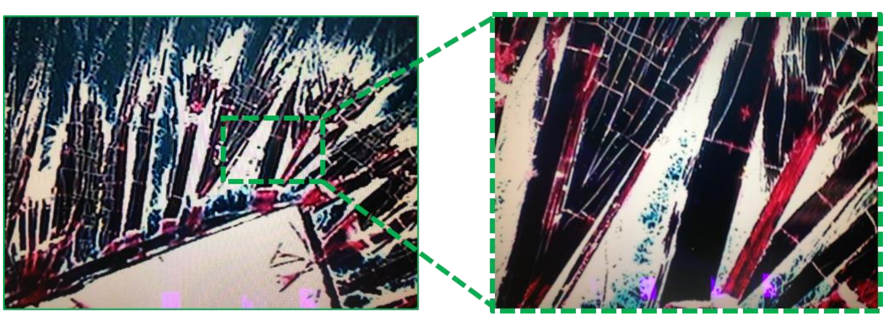

Fig. 2 Optical camera image of as grown single crystal by droplet pinning method. Highly oriented ribbon shaped single crystals are obtained.

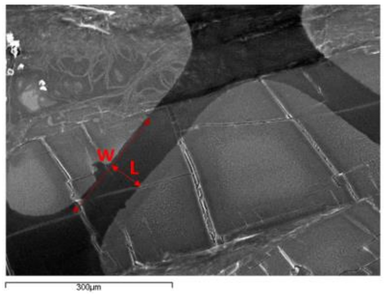

Fig. 3 SEM micrograph image of PTCDI-X single crystal OFET on SiO_2 dielectric.

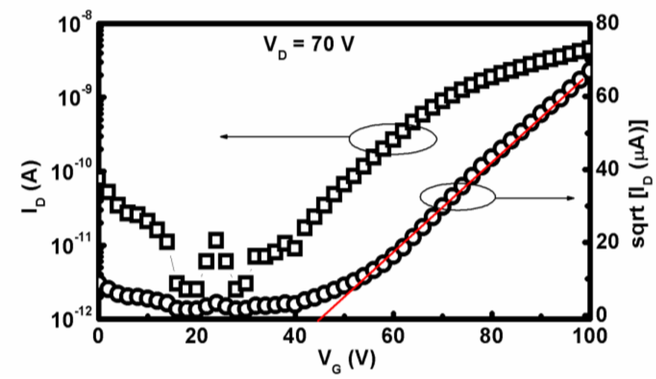

Fig. 4 Input current-voltage (I-V) characteristics of the PTCDI-X single crystal OFET on SiO_2 dielectric.

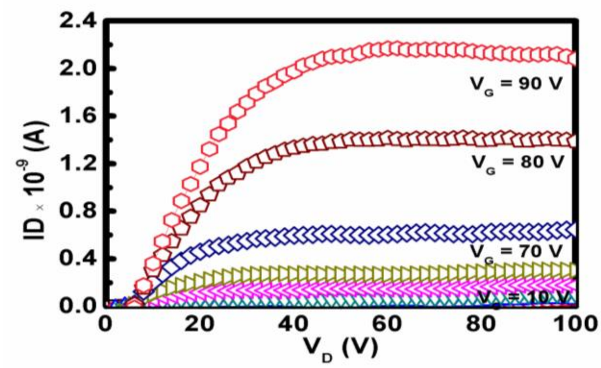

Fig. 5 Output current-voltage (I-V) characteristics of PTCDI-X single crystal OFET on SiO_2 dielectric.

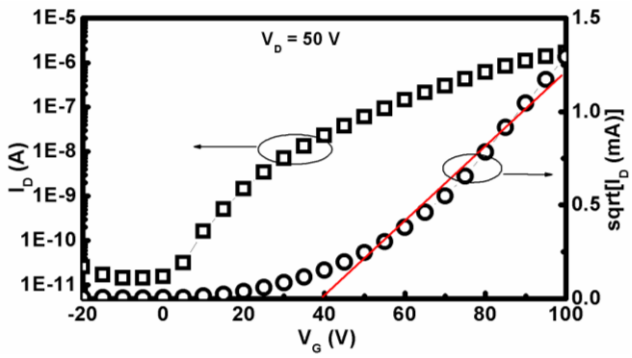

Fig. 6 Input current-voltage (I-V) characteristics of the PTCDI-X single crystal OFET on PS/SiO_2 dielectric.

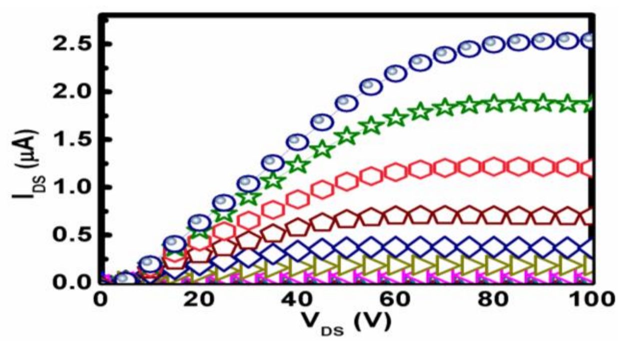

Fig. 7 Output current-voltage (I-V) characteristics of PTCDI-X single crystal OFET on PS/SiO_2 dielectric.

Table I Comparison of PTCDI single crystal OFET for different dielectric.

	PS modified SiO_2	**Bare SiO_2**
Saturation Mobility (cm^2/V.s)	1.2	2.93×10^{-4}
Threshold voltage (V)	40	45
$I_{ON/OFF}$	$\approx10^5$	$\approx10^3$
V_{ON} (V)	2	35

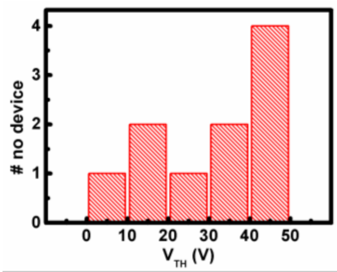

Fig. 8 Threshold voltage distribution of PTCDI-X single crystal OFET on PS/SiO_2 dielectric.