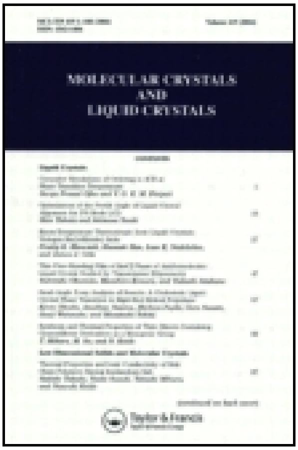


Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Characteristics and Fabrication of Vertical Type Transistor Using Solution-Processible Regioregular Poly(3-hexylthiophene)

Se Young Oh [a] [b] , Sun Kak Hwang [a] & Young Do Kim [a]
[a] Department of Chemical & Biomolecular Engineering, Sogang University, Seoul, Korea
[b] Interdisciplinary Program of Integrated Biotechnology, Sogang University, Seoul, Korea

Version of record first published: 22 Sep 2010

Mol. Cryst. Liq. Cryst., Vol. 470, pp. 207–213, 2007

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400701495609

Characteristics and Fabrication of Vertical Type Transistor Using Solution-Processible Regioregular Poly(3-hexylthiophene)

Se Young Oh
Department of Chemical & Biomolecular Engineering, Sogang University, Seoul, Korea; Interdisciplinary Program of Integrated Biotechnology, Sogang University, Seoul, Korea

Sun Kak Hwang
Young Do Kim
Department of Chemical & Biomolecular Engineering, Sogang University, Seoul, Korea

We have fabricated vertical type organic thin film transistor (OTFT) using solution-processible electrically conductive poly(3-hexylthiophene) (P3HT) as a p-type organic material. The layers of OTFT consisting of ITO/P3HT/Al gate/P3HT/Au were fabricated by vacuum evaporation and spin coating method onto the Indium Tin Oxide (ITO) coated glass. The effects of drain electrode and thermal annealing of P3HT on the current-voltage and on-off ratio of transistor were investigated. The vertical type OTFT using Au as drain electrode after the thermal annealing showed high current of -0.16 mA and on-off ratio of 16.0 at a low gate voltage of $+2.0$ V.

Keywords: drain electrode; P3HT; solution-processible; thermal annealing; vertical type transistor

INTRODUCTION

OTFT is expected for flexible displays, information tags, and e-papers etc. because of their large area coverage, structural flexibility and low

This work was supported by the Korean Research Foundation Grant (KRF-2006-005-J02301), the Basic Research Program of the Korea Science & Engineering Foundation (R01-2006-000-10196-0) and the second stage BK 21.

Address correspondence to Prof. Se Young Oh, Department of Chemical & Biomolecular Engineering, Sogang University, Sinsoo-dong, Mapo-gu, Seoul 121-742, Korea (ROK). E-mail: syoh@sogang.ac.kr

cost [1]. Recently, conventional OTFT using vacuum evaporated small organic molecules has been widely investigated. However, the conventional OTFT has some disadvantages such as current density, operation speed and processibility [2–5]. A solution to improve their problems is to use solution-processible materials and to change the device configuration.

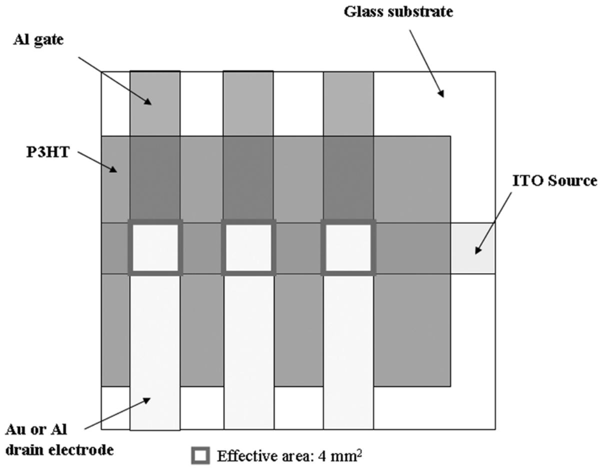
In this study, we have fabricated vertical type OTFT using solution-processible P3HT conducting polymer to improve the problems of conventional OTFT such as low speed, low power, relatively high operation voltage and processibility. OTFT using solution-processible polymer is easily fabricated by spin coating, spray coating and ink-jet printing. It should be noted that the solution process method for fabrication of organic molecular device exhibited the advantages such as simple processibility and low cost [5].

EXPERIMENTAL

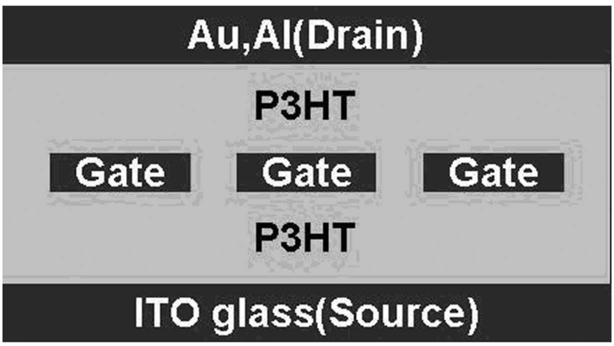
The vertical type OTFT consists of a buried grid type Al gate electrode in P3HT film, drain electrode and ITO source electrode as shown in Figure 1. Regioregular P3HT (Mw = 87000, RR $\approx$ 98.5%) used in the present work was purchased from Aldrich Co.Ltd. Firstly, P3HT layer was spin-coated from chloroform solution (2 wt%) at a speed of 3000 rpm for 60 sec on ITO glass with sheet resistance less than 20 Ω. The chloroform solution of P3HT was used after filtering with a 0.20 μm pore size PTFE membrane syringe filter. Secondly, a grid type Al gate electrode was deposited on the P3HT film by shadow thermal evaporation technique under a vacuum of 10^{-6} torr. Thirdly, the second layer of P3HT was spin-coated in the same method of a first layer of P3HT. Finally, the drain electrode (Au or Al) was deposited by thermal evaporation. In order to explore the effect of thermal heat treatment of P3HT, the device was annealed for 20 min at 200°C under N_2 atmosphere. X-ray diffraction (XRD) measurements of before and after annealing of spin coated P3HT film were performed using Rigaku diffractometer (Miniflex). Current–voltage (I–V) characteristics of vertical type OTFT were investigated using sourcemeter (KEITHLEY-2400, 237). I–V measurements were carried out under N_2 atmosphere at room temperature.

RESULTS AND DISCUSSION

Figure 2(a) showed I–V characteristics of vertical type OTFT using P3HT. The drain-source current (I_{DS}) at a constant drain-source



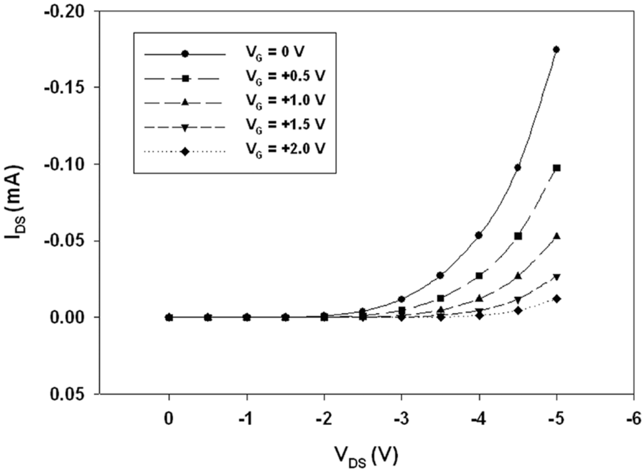
(a)



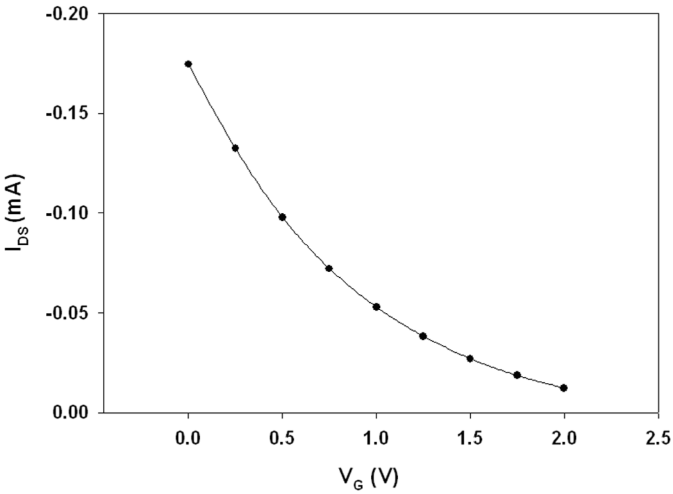
(b)

FIGURE 1 Schematic illustrations of (a) the front side and (b) the lateral face of vertical type OTFT using P3HT.

voltage (V_{DS}) was decreased with increasing gate voltage like the depletion mode of conventional OTFT. However, no saturation of I–V characteristics was occurred in the vertical type OTFT because the series channel resistance is sufficiently small [1,6]. Figure 2(b) showed I_{DS}-gate voltage (V_G) curve at a V_{DS} of $-5.0\,V$. The current is controlled by relatively small V_G and a typical characteristic of p-type vertical transistor was obtained [6]. The on-off ratio ($V_{DS} = -5.0\,V$) was 14.5. The operation principle of vertical type OTFT using P3HT can be explained by following. P3HT shows p-type semiconducting properties [7,8] and forms a schottky barrier contact with the Al gate electrode as shown in Figure 3. The injected hole



(a)



(b)

FIGURE 2 I–V characteristics of vertical type OTFT consisting of Au/P3HT/Al gate/P3HT/ITO. (a) Plots of I_{DS} versus V_{DS} at various V_G and (b) Plot of I_{DS} versus V_G at constant V_{DS}.

carriers from source electrode flow through the potential barrier near Al gate. The potential barrier height depending on Al gate voltage controls the hole carrier flow. Abdou et al. reported that the thermal annealing of P3HT layer increased I_{DS} and the on-off ratio of conventional OTFT device [7,8]. The annealing of P3HT conducting polymer can help in reducing the free volume in the polymer layer and the removal of residual solvent, thus leading to more compact and ordered film [8]. The prepared organic transistor was annealed for 20 min at 200°C under N_2 atmosphere to explore the effect of heat treatment on the performance of vertical type OTFT. The XRD result of the heat-treated P3HT film was shown in Figure 4. After the thermal annealing of P3HT, the intensity of (100) peak was increased, which implies that the crystalline order of P3HT was improved. Table 1 showed the device properties of before and after the heat treatment. The vertical type OTFT using Au as drain electrode showed high I–V characteristics compared to the Al drain electrode. It may be argued that the result is mainly due to the ohmic contact between P3HT polymer and Au electrode [9,10]. Figure 5 showed the result of I_{DS} versus V_{DS} of before and after the heat treatment of device. After the heat treatment of device, I_{DS} was increased from 0.17 mA to 0.33 mA at V_{DS} of -5.0 V like conventional type OTFTs. Especially, I–V characteristic of the heat-treated device was shifted significantly to lower voltages. The thermal annealing of P3HT increases hole carrier density because the heat treatment leads to more compact and ordered P3HT film as shown in XRD result. Thus, the heat-treated device showed higher current than the device before thermal annealing. I_{DS} and on-off ratio of the heat-treated device were similar to the

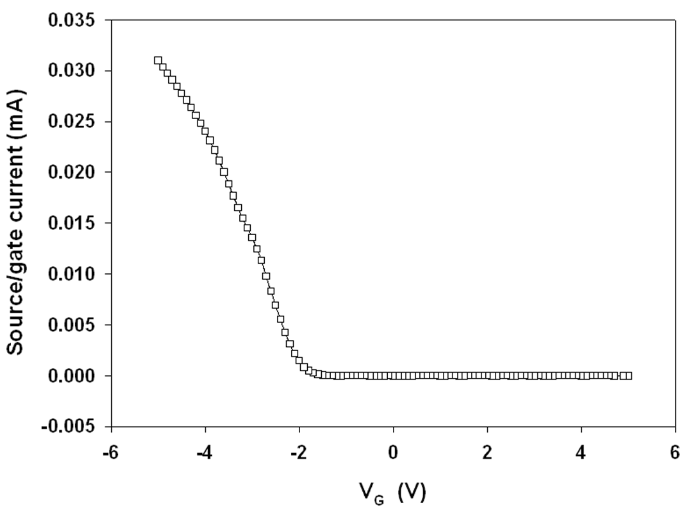


FIGURE 3 Gate/source current-V_G characteristic of device consisting of Au/P3HT/Al gate/P3HT/ITO.

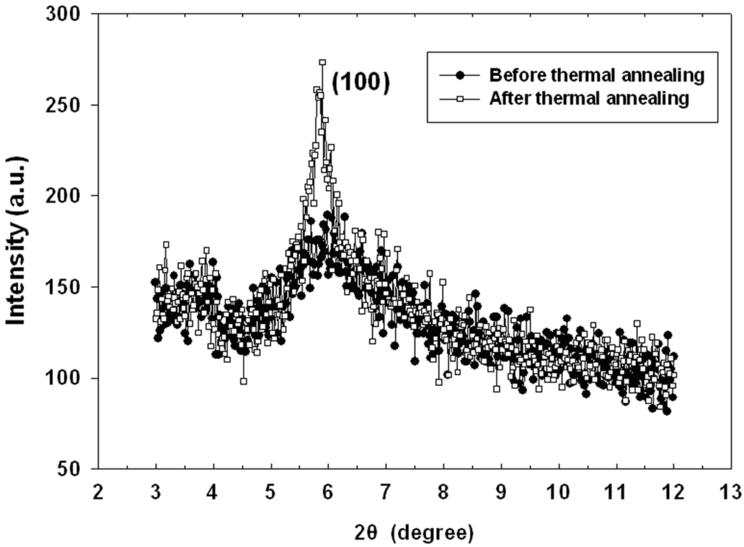


FIGURE 4 XRD data of P3HT film spin coated on glass substrate, (a) before and (b) after thermal annealing.

device before thermal annealing at a low voltage, which is mainly attributed to the decrease of operation voltage.

CONCLUSIONS

OTFTs using small molecules such as NTCDA (1,4,5,8-naphthalene-tetracarboxylicdianhydride), F16CuPc (copper hexadecafluorophthalo-cyanine) and pentacene have disadvantage in device fabrication compared to the solution-processible conjugated polymer. It should

TABLE 1 I_{DS} and On-off Ratio of Before and After P3HT Thermal Annealing in the Vertical Type Polymer Transistor

Sample			I_{DS} (mA)	On-off ratio
Al (drain electrode)	Before annealing	$V_{DS} = -5.0\,V$	On current: –0.080 (at $V_G = 0\,V$) Off current: –0.014 (at $V_G = +2.0\,V$)	5.7
	After annealing	$V_{DS} = -4.0\,V$	On current: –0.088 (at $V_G = 0\,V$) Off current: –0.013 (at $V_G = +2.0\,V$)	6.8
Au (drain electrode)	Before annealing	$V_{DS} = -5.0\,V$	On current: –0.174 (at $V_G = 0\,V$) Off current: –0.012 (at $V_G = +2.0\,V$)	14.5
	After annealing	$V_{DS} = -3.5\,V$	On current: –0.160 (at $V_G = 0\,V$) Off current: –0.010 (at $V_G = +2.0\,V$)	16.0

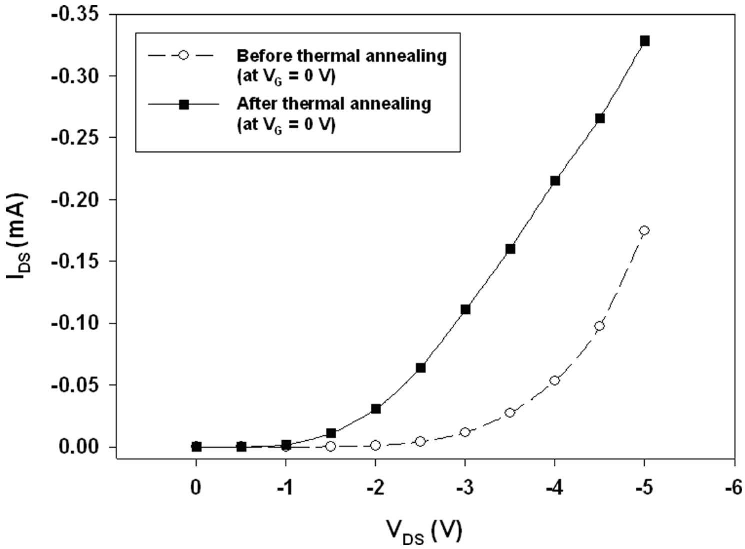


FIGURE 5 Plots of I_{DS} versus V_{DS} of before and after the heat treatment of device.

be emphasized that it is possible to fabricate vertical type OTFT using P3HT conducting polymer. Also, it was demonstrated that heat-treated vertical type transistor showed low operation voltage of −3.5 V. The vertical type OTFT after the thermal annealing showed high I_{DS} of −0.16 mA and on-off ratio of 16.0 at V_{DS} of −3.5 V. Especially, the on-off ratio was obtained at a low gate voltage of +2.0 V.

REFERENCES

[1] Sirrighaus, H. (2005). *Adv. Mater.*, *17*, 2411.
[2] Kudo, K., Iizuka, M., Kuniyoshi, S., & Tanaka, K. (2001). *Thin Solid Films*, *393*, 362.
[3] Tanaka, S., Yanagisawa, H., Iizuka, M., Nakamura, M., & Kudo, K. (2004). *Electrical Engineering in Japan*, *149*, 43.
[4] Oh, S. Y. & Lee, J. Y. (2006). *Mol. Cryst. Liq. Cryst.*, *444*, 211.
[5] Bao, Z., Dodabalapur, A., & Lovinger, A. J. (1996). *Appl. Phys. Lett.*, *69*, 4108.
[6] Nishizawa, J., Terasaki, T., & Shibata, J. (1975). *IEEE Trans. Electron Devices ED-22*, 185.
[7] Wang, G., Swensen, J., Moses, D., & Heeger, A. J. (2003). *Appl. Phys. Lett.*, *93*, 6137.
[8] Abdou, M. S. A., Lu, X., Xie, Z. W., Orfino, F., Deen, M. J., & Holdcroft, S. (1995). *Chem. Mater.*, *7*, 631.
[9] Chirvase, D., Chiguvare, Z., Knipper, M., Parisi, J., & Dyakonov, V. (2003). *Appl. Phys. Lett.*, *93*, 3376.
[10] Tomozawa, H., Braun, D., Phillips, S., & Heeger, A. J. (1987). *Synth. Met.*, *22*, 63.