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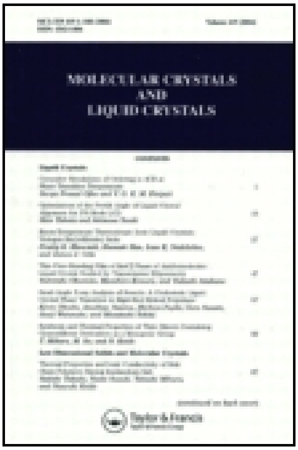

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Characteristics of Vertical Type Organic Transistor Using N-Type Material and its Application for OLED

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Characteristics of Vertical Type Organic Transistor Using N-Type Material and its Application for OLED

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We have fabricated static induction organic transistor of vertical type in order to improve the problems of conventional organic thin film transistor (OTFT). The vertical type organic transistors were fabricated by using n-type organic semiconductor materials such as F16CuPc, NTCDA and PTCDI C-8. The effects of carrier mobility of organic active materials, the thickness of thin film and gate structure on current–voltage (I–V) and transistor characteristics were investigated. The vertical type organic transistor using PTCDI C-8 exhibited low operation voltage and high on–off ratio. In addition, we have examined the feasibility of application in organic light emitting transistor using a light emitting polymer.

Keywords: light emitting transistor; n-type organic semiconductor materials; on–off ratio; operation voltage; OTFT; vertical type

INTRODUCTION

Recently, organic semiconductor materials have attracted much attention due to their attractive applications in organic molecular devices such as OTFTs [1–2], organic light emitting diodes (OLEDs) [3–5] and organic solar cells. OTFTs can be used for application of requiring large area coverage, structural flexibility, low temperature processing and especially low processing cost, such as screen printing or an ink jet process. In particular, pentacene showed a remarkably high mobility

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and on–off ratio [3]. However, the conventional configuration of organic field effect transistor (FET) has weak points such as low speed, low power and relatively high operation voltage due to the long channel length between drain and source electrodes. It is well-known that vertical type static induction transistor (SIT) using inorganic semiconductors is a promising device configuration to improve the problems [6–11].

In this work, we have fabricated organic SITs with a vertical structure using n-type organic semiconductor materials such as NTCDA (1,4,5,8-naphthalenetetracarboxylicdianhydride), F16CuPc (copper hexadecafluorophthalocyanine) and PTCDI C-8 (N,N-dioctyl-3,4,9,10-perylenetetracarboxylic diimide). The vertical type organic transistors show short channel length because current carriers flow across the multilayered organic films as shown in Figure 1.

We have investigated the effects of carrier mobility of n-type organic semiconductor materials, thickness control of organic multilayers and structure of gate electrode on I–V and on–off ratio characteristics. In addition, the device performance of organic light emitting transistor using the n-type SIT and p-type light emitting polymer was described.

EXPERIMENTAL

F16CuPc (Aldrich, USA), NTCDA (Aldrich, USA) and PTCDI C-8 were used as n-type semiconductor materials. PTCDI C-8 was synthesized according to the other publication reported previously [12]. Light emitting polymer, poly-3-hexylthiophene (P3HT) and PEDOT-PSS (poly(3,4-ethylenedioxy thiophene)/poly(styrenesulfonic acid)) as an hole injection material were purchased from Aldrich and Bayer Co. Ltd., respectively. Chloroform was distilled from first grade solvent purchased on the market. ITO (Indium-tin-oxide) coated glass substrate (Samsung Corning, Korea) with sheet resistance less than 20 Ω was cleaned ultrasonically with a series of organic solvents.

Vertical type organic transistor configuration was shown in Figure 1. All layers were fabricated on ITO glass substrate using vacuum evaporation technique (ULVAC VPC-200F evaporator) at approximately 10^{-6} Torr. During the evaporation, the substrate temperature was maintained at room temperature. Firstly, n-type organic semiconductor material was deposited onto the cleaned ITO glass substrate. The evaporation rate was maintained at below 1 Å/sec. The thickness of organic semiconductor layer was approximately 500 Å, 1000 Å, and 1500 Å, respectively. Secondly, Al gate electrodes were fabricated with patterned masks of 100 μm line, 300 μm line, 500 μm

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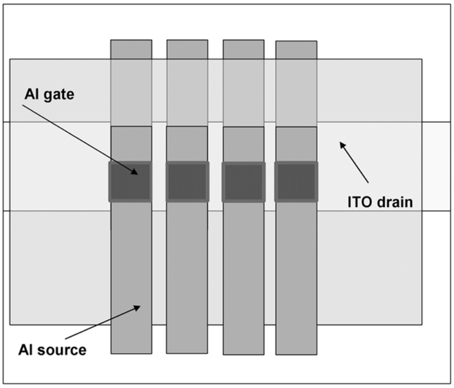

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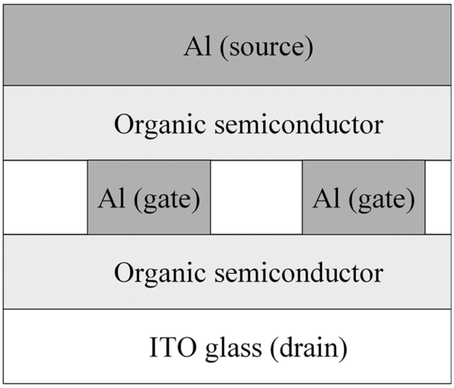

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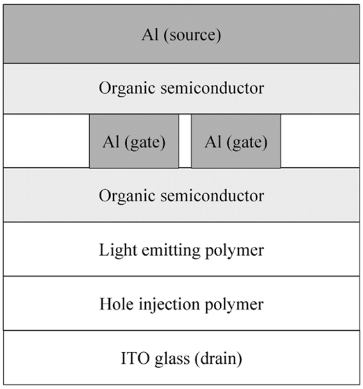

(c)

FIGURE 1 Schematic illustrations of vertical type organic transistor: (a) The front side of device, (b) The lateral face of device, and (c) Light emitting transistor.

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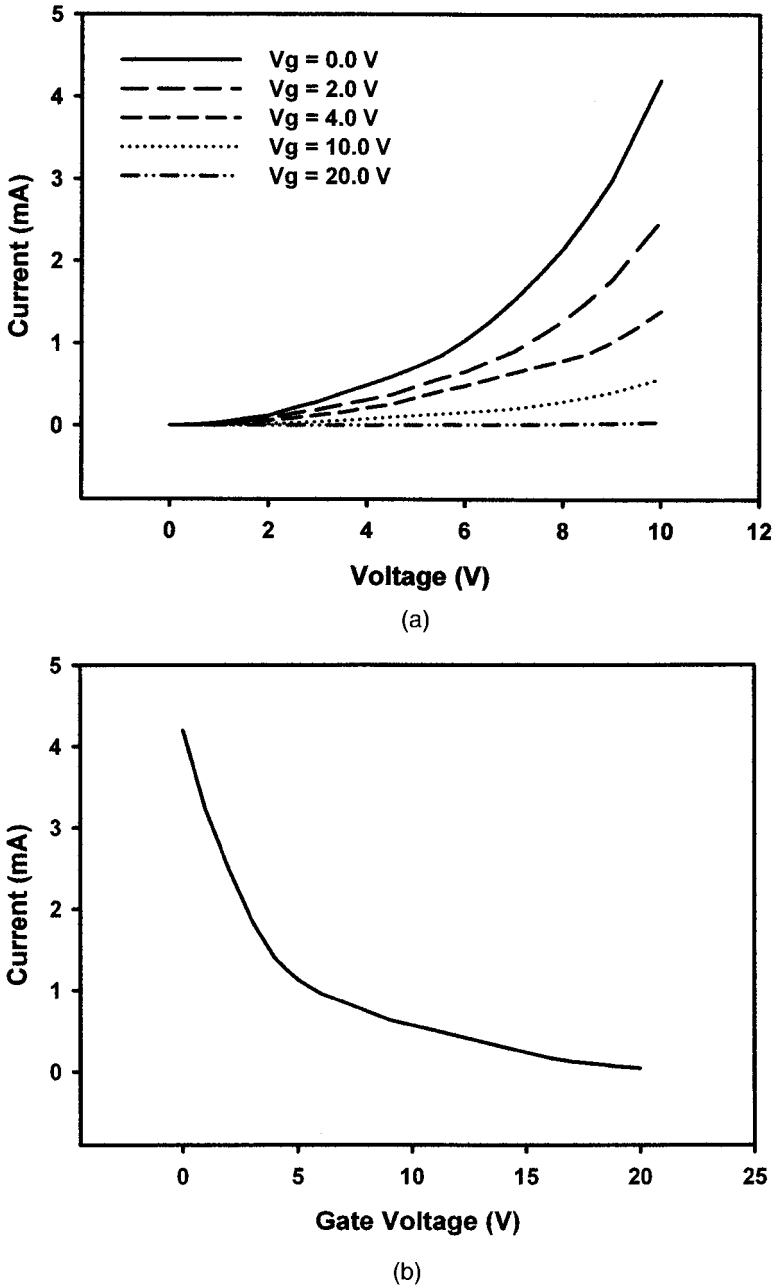

FIGURE 2 I–V characteristics of vertical type organic transistor consisting of Al/F16CuPc/Al gate/F16CuPc/ITO: (a) Current-voltage characteristics, (b) Current-gate voltage characteristics.

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line and 100 μm grid type. The second organic semiconductor layer was deposited according to the same method of first layer. Lastly, Al source electrode was deposited. P3HT and PTCDI C-8 were spin-coated from chloroform solution at a speed of 1000 rpm. The I–V and luminance characteristics were measured by Keithly 237 programmable source meter and Newport 1830-C photodiode. The luminance property of light emitting transistor was obtained by using an Acton 300i spectrofluorometer.

RESULTS AND DISCUSSION

I–V characteristics of vertical type organic transistors were shown in Figure 2. Drain-source current (I_{DS}) at a constant drain-source voltage

TABLE 1 I–V and on–off Characteristics of Vertical Type Organic Transistors under Various Thickness of n-type Layers

	PTCDI C-8		F16CuPc		NTCDA	
	[1]0.6		[1]0.03		[1]3×10^{-3}	
Mobility (cm^2/Vs) Thickness(□)	[2]Current (mA)	[3]on–off ratio	[2]Current (mA)	[3]on–off ratio	[2]Current (mA)	[3]on–off ratio
1000	81.088	3.10	46.350	10.00	1.495	1.04
2000	31.503	89.20	4.831	28.20	0.293	5.25
3000	0.992	5.80	0.752	4.97	0.012	1.60
4000	–	–	0.306	2.56	0.020	1.63

[1] Literature value [3].
[2]Source-drain current at a gate voltage of 0 V and a source-drain voltage of 10 V.
[3]On–off ratio at a source-drain voltage of 10 V and gate voltages of 0 V and 20 V.

TABLE 2 I–V and on–off Characteristics of Vertical Type Organic Transistors under Various Gate Structures

	F16CuPc		NTCDA	
Gate structure	[1]Current (mA)	[2]on–off ratio	[1]Current (mA)	[2]on–off ratio
100 μm grid type	4.830	28.20	0.230	16.60
100 μm line	9.300	22.00	0.257	13.00
300 μm line	9.450	17.80	0.213	9.40
500 μm line	7.080	12.10	0.259	7.45

[1]Source-drain current at a gate voltage of 0 V and a source-drain voltage of 10 V.
[2]On–off ratio at a source-drain voltage of 10 V and gate voltages of 0 V and 20 V.

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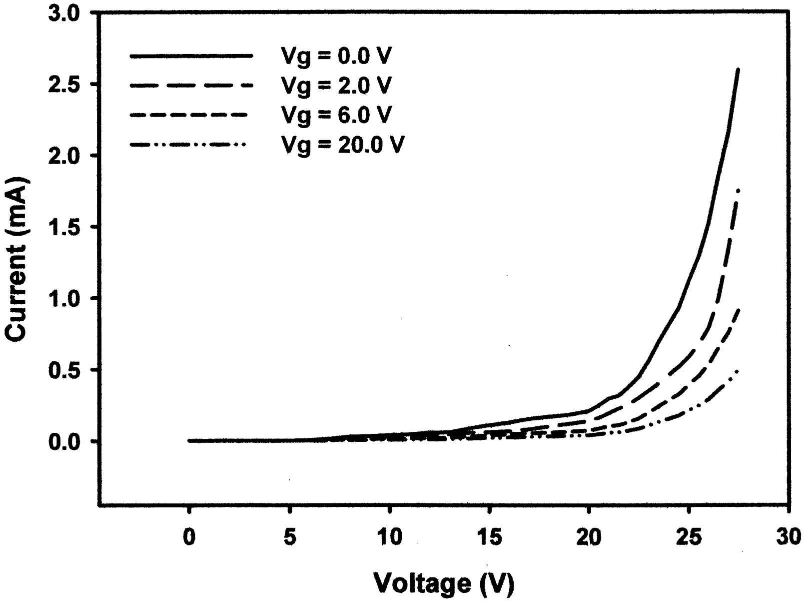
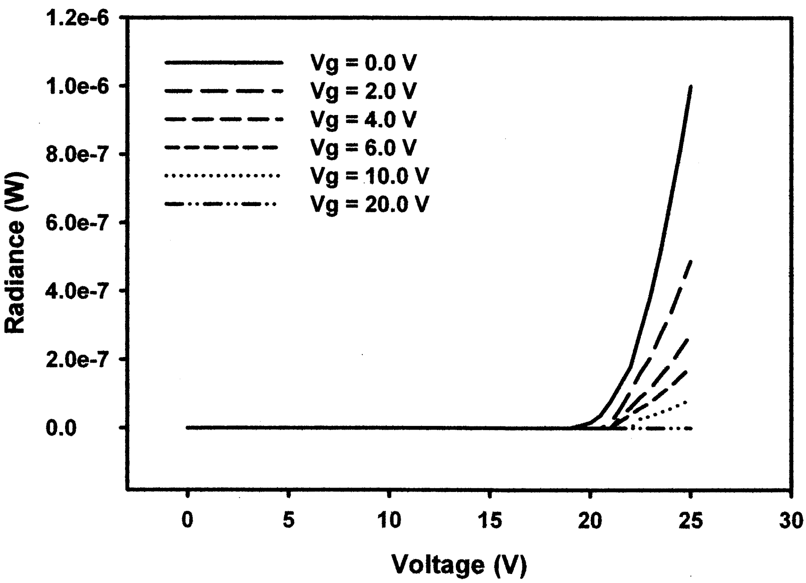


(a)



(b)

FIGURE 3 I–V characteristics (a), and luminance–voltage characteristics (b), of light emitting transistor consisting of Al/F16CuPc/Al gate/F16CuPc/P3HT/PEDOT-PSS/ITO.

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(V_{DS}) decreased with increasing gate voltage (V_G). The electron carriers injected from the source electrode flow between source and drain electrodes through potential barrier near the gate electrode. The potential barrier increased with increasing the gate voltage. Thus, it can be concluded that the I_{DS} was controlled by V_G like a depletion type FET.

In order to improve the performance of vertical type organic transistor, different techniques such as optimizing the thickness of n-type active layers in the heterostructure and varying the fabrication of gate electrode were used. Table 1 showed the I–V and on–off characteristics of vertical type organic transistors under various thickness of n-type active layers. When PTCDI C-8 having high mobility was used as n-type material, the vertical type organic transistor exhibited high on–off ratio compared to the other n-type materials. Especially, all devices exhibited optimized static induction transistor characteristics, when the thickness of n-type active layers was 2000 Å. It can be found that carrier mobility and film thickness were influenced extensively on the characteristics of vertical type organic transistor.

Table 2 showed the I–V and on–off characteristics of vertical type organic transistors with various gate structures. As shown in Table 2, vertical type organic transistor with a grid type gate exhibited high on–off ratio of 28.2. It is mainly due to the difference in effective electric field by the fine structural control of gate electrode.

Figure 3 showed I–V and luminance–voltage (L–V) characteristics of light emitting transistor consisting of Al/F16CuPc/Al gate/F16CuPc/P3HT/PEDOT-PSS/ITO. Drain-source current (I_{DS}) at a constant drain-source voltage (V_{DS}) decreased with increasing a gate voltage (V_G). The I_{DS} was controlled by small V_G, and a typical depletion transistor characteristic was obtained. The luminance also decreased corresponding to I–V characteristics and was not observed at a gate voltage of 20 V.

CONCLUSION

Vertical type organic transistors with n-type organic semiconductor materials were fabricated, and then the static induction transistor characteristics were studied. Relatively high current and on–off ratio (89.2) were observed in the vertical type organic transistor using PTCDI C-8. In addition, light emitting transistor combined with the vertical type organic transistor and P3HT light emitting polymer was fabricated. It should be noted that the switching characteristic of light emitting transistor was observed at a gate voltage of 20 V.

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