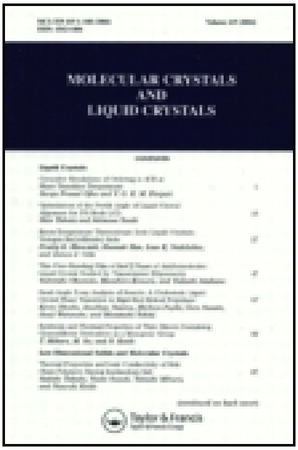

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Effects of Bphen Layer as Hole Blocking Material on the Performance of Vertical Type Light Emitting Transistor Using C_{60} and MEH-PPV

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Vertical type organic light emitting transistors (OLETs) using C_{60} as a n-type active material and MEH-PPV as an emitting polymer were fabricated. C_{60} shows n-type semiconductor property and relatively high electron mobility. Furthermore, MEH-PPV has high quantum efficiency for light emitting diode. We have investigated structural effects of C_{60} and Bphen blocking layer on the performance of light emitting diode consisting of ITO/PEDOT-PSS (50 nm)/MEH-PPV (80 nm)/Bphen (3 nm)/C_{60} (30 nm)/Al (100 nm). Vertical type OLET has layered structure of metal(source)/C_{60}/metal(gate)/C_{60}/Bphen/MEH-PPV/PEDOT-PSS/ITO glass. The thickness of source and gate electrode was 100 nm and 10 nm, respectively. Source and gate electrodes were deposited with several kinds of materials. The characteristics of the fabricated OLETs were studied from the measurements of current-voltage and on-off ratio.

Keywords: Bphen blocking layer; C_{60}; MEH-PPV; vertical type organic light emitting transistor

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INTRODUCTION

Organic field effect transistors (OFETs) are promising for the active devices because of structural flexibility, low cost, simple process and large area photoelectric devices [1–3]. Recently, OFETs based on small organic molecules or conjugated conducting polymers have been widely studied. However, the conventional field effect transistors using organic materials have low-speed, low-power and high-resistivity owing to their long channel length between drain and source electrodes [4]. On the other hand, vertical type static induction transistor (SIT) is a promising device to obtain high speed and high power operation compared to the conventional field effect transistor because of short channel length [5,6]. Also, vertical type transistors have some advantages such as low temperature processing, large area coverage and similar configuration for the conventional organic light emitting diode. Accordingly, the vertical type SIT is suitable for novel organic light emitting transistor.

In the present work, we have fabricated vertical type light-emitting transistor using C_{60} as n-type semiconductor active material as well as electron transport material and MEH-PPV as an emitting polymer. The effect of high electron mobility of C_{60} on the performance of light-emitting diode was investigated. C_{60} has been used in organic solar cells because photoinduced charge transfer between C_{60} and conducting polymer leads to photovoltaic effect [7,8]. It has been found that the C_{60} can be used as a weak electron acceptor dopant in conducting polymers, and the enhancement of photoconductivity was observed in C_{60}/conducting polymer system [9]. However, photoinduced charge transfer between C_{60} and conducting polymer induces the electroluminescence quenching in C_{60}/conducting polymer system, which leads to weak electroluminescence in organic light emitting diode containing C_{60} [10]. In order to overcome the electroluminescence quenching in C_{60}/poymer system, 4,7-diphenyl-1,10-phenanthroline (Bphen) was used as a blocking layer in the OLET. The OLET was composed of metal(source)/C_{60}/metal(gate)/C_{60}/Bphen/MEH-PPV/PEDOT-PSS/ITO. Source and gate electrodes were deposited with several kinds of metals. The characteristics of the fabricated OLETs were investigated using source meter and radiance photodiode.

Experimental

The organic light emitting diodes (OLED) configuration used in the present study was Al/C_{60}/Bphen/MEH-PPV/PEDOT-PSS/ITO. All layers were fabricated on patterned ITO ($\leq 15\,\Omega$/sq sheet resistance)

glass substrate using vacuum evaporation technique (ULVAC VTR-300 M/1ERH evaporator) under 10^{-6} Torr. Before the deposition of each layers, the patterned ITO substrate was immersed into ultrasonic bath of deionized water, acetone and methanol for 60 min, respectively. Then, cleaned ITO glass substrate was dried under nitrogen stream. Poly(3,4-ethylenedioxy thiophene)-poly(styrenesulfonic acid) (PEDOT-
PSS) was purchased from Bayer Co. Ltd. Poly(2-methoxy-5-(2′-ethylhexyloxy)-1,4-phenylene vinylene) (MEH-PPV), fullerene (C_{60}) and Bphen were purchased from Aldrich Co. Ltd. PEDOT-PSS and MEH-PPV were sequential spin-coated onto the ITO. And then, Bphen, C_{60} and Al source electrode were deposited onto the MEH-PPV, subsequently. The organic light emitting transistor (OLET) was fabricated to similar structure with the OLED. And also, all layers were formed onto ITO glass by the same method of the OLED. The Al gate electrode of grid type was deposited on the top of deposited layer of first C_{60} by shadow evaporation technique. The grid type Al gate electrode should be buried in C_{60} active layer. The source electrodes were used several kinds of metals such as Al, LiAl and Mg. The depositions were used vacuum evaporation technique (ULVAC VTR-300 M/1ERH evaporator) under 10^{-6} Torr. Current-voltage characteristics were measured using source meters (KEITHLEY-2400, 237). The radiance measurements were performed using the Newport 1830-C photodiode. All the measurements were carried out under N_2 atmosphere at room temperature.

Results and Discussion

Most organic light emitting devices consist of several organic layers between two electrodes, in which the layers are formed by spin-coating or thermal evaporation under high vacuum. We have fabricated light emitting diodes using MEH-PPV as a light emitting polymer, C_{60} as an electron transport material and Bphen as a hole blocking material. I-V-L curves of the devices fabricated with and without Bphen layer are shown in Figure 1. In the absence of Bphen layer, low radiance performance was obtained due to the charge transfer between C_{60} and MEH-PPV polymer induces the electroluminescence quenching. In the case of C_{60}, it can absorb six electrons per molecule and it can play a role in electron trapping center at polymer/C_{60} system [11]. On the other hand, the device introduced Bphen layer as a blocking material between C_{60} and MEH-PPV showed high radiance characteristic compared to the case without Bphen layer, which is mainly due to the deactivation of the electroluminescence quenching because of the

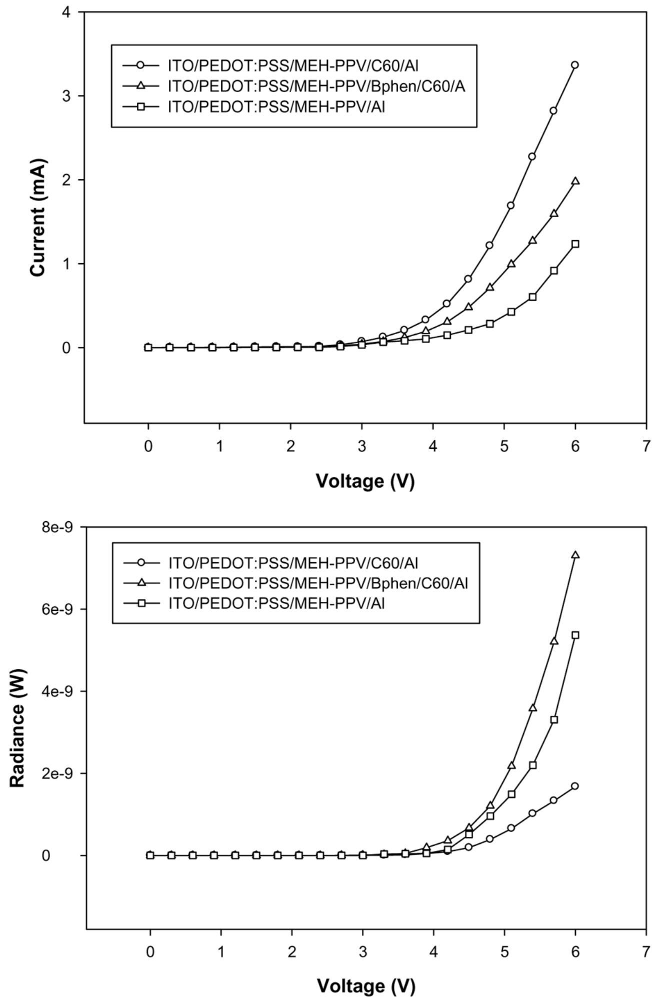

FIGURE 1 I-V characteristics of organic light emitting diodes.

blocking effect of Bphen interlayer. Especially, the devices using C_{60} showed low turn on voltage of 3 V owing to the improvement of electron transport. Thus, it can be founded that the Bphen layer may be effective in the fabrication of organic light emitting transistor(OLET) consisting of Al/C_{60}/Al gate/C_{60}/MEH-PPV/PEDOT-PSS/ITO.

Figure 2 showed the I-V and L-V curves of the OLET using C_{60} as a n-type semiconductor active layer, MEH-PPV as a light emitting material and Bphen as a blocking interlayer. The on-off ratio was about 80.

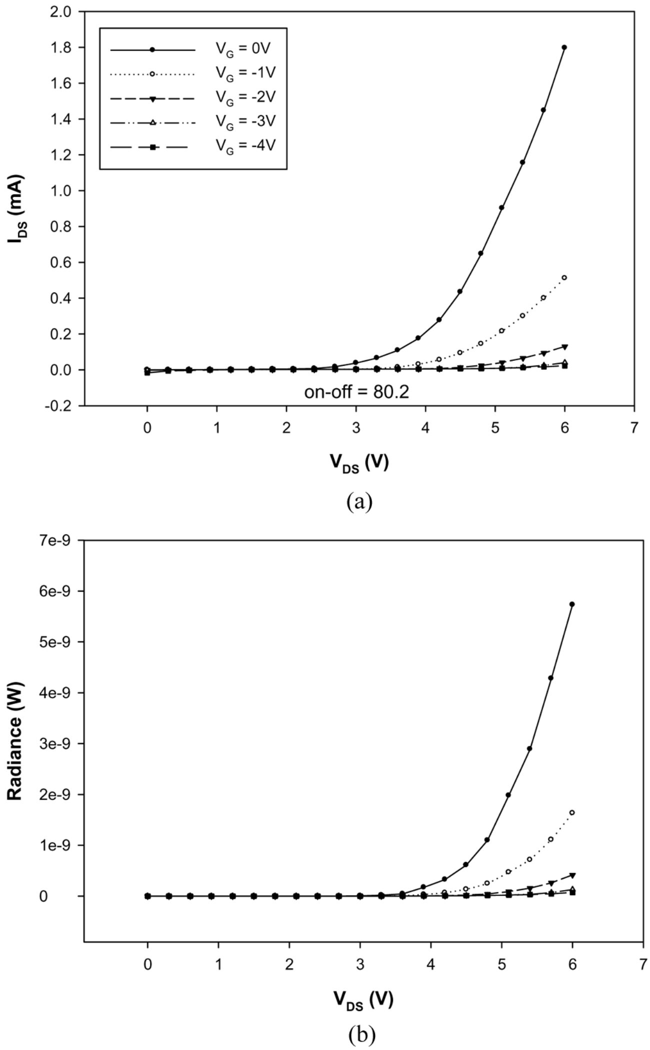

FIGURE 2 I-V-L characteristics of OLET consisting of Al/C_{60}/gate/C_{60}/Bphen/MEH-PPV/PEDOT-PSS/ITO. (a) I-V curve and (b) L-V curve.

Drain-source current at a constant drain-source voltage decreased with increasing a gate voltage. The electron carriers injected from the source electrode flow between source and drain electrodes through potential barrier near the gate electrode. The gate electrode blocks the carrier flow from the source to drain electrodes through the formation of double Schottky barriers [12,13]. The potential barrier is increased

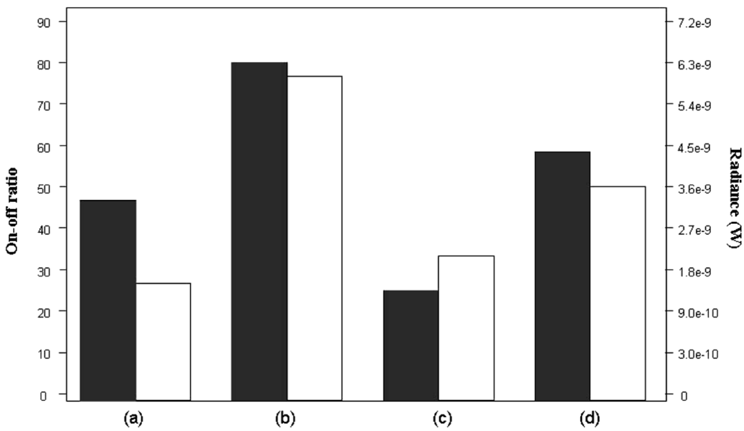

FIGURE 3 On-off ratios (the shadowed column) and radiances (the blank column) of devices under various active layers. (a) Al/C_{60}/gate/C_{60}/MEH-PPV/PEDOT-PSS/ITO, (b) Al/C_{60}/gate/C_{60}/Bphen/MEH-PPV/PEDOT-PSS/ITO, (c) Al/F_{16}CuPc/gate/F_{16}CuPc/MEH-PPV/PEDOT-PSS/ITO, and (d) Al/C_{60}/gate/F_{16}CuPc/MEH-PPV/PEDOT-PSS/ITO.

with the increase of gate voltage. Thus, I_{DS} could be controlled by the negative gate voltage. In addition, no luminescence was observed at a gate of 4 V, which is low value due to the blocking effect of Bphen layer in the MEH-PPV/C_{60} system. Figure 3 showed the on-off ratios and radiance characteristics of devices using various n-type semiconductor materials. The device using C_{60} a n-type semiconductor active layer without Bphen layer exhibited relatively high current, but the radiance of device was low because of the electroluminescence quenching between MEH-PPV polymer and C_{60} layers. The device using Bphen layer as a blocking material showed high on-off ratio and radiance. It can be explained that Bphen and C_{60} materials can play a role in the blocking of electroluminescence quenching and electron transport, respectively in the interface of polymer and C_{60}. By the way, the device using F_{16}CuPc as a n-type material showed the low radiance compared to the device using Bphen and C_{60} materials, which is caused to the decrease in electron transport ability of F_{16}CuPc. The electron mobility of C_{60} and F_{16}CuPc was 0.08 cm^2/Vs and 0.02 cm^2/Vs, respectively [14,15]. Figure 4 showed the characteristics of vertical type light emitting transistors using Al, LiAl and Mg as source and gate electrodes. Low work-function of source electrode is easy to inject electron carriers from cathode electrode. In the case of low work-function of gate electrode, the electron blocking between cathode and gate electrodes is more effective compared to the case of Al gate electrode. As shown

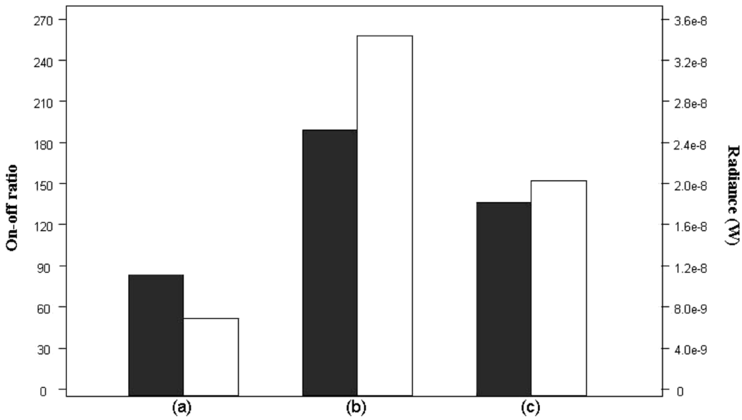

FIGURE 4 On-off ratios (shadowed column) and radiances (blank column) of vertical type transistors consisting of metals(source)/C_{60}/metals(gate)/C_{60}/Bphen/MEH-PPV/PEDOT-PSS/ITO. (a) Al as source and gate electrodes, (b) LiAl as source and gate electrodes, and (c) Mg as source and gate electrodes.

in Figure 4, vertical type devices using low work-function metals showed high on-off ratio, which is attributed to the effective control of excessive electron carrier. Especially, high radiance was obtained in the device using low work-function metal. Table 1 showed characteristics of OLET under various electrodes and active materials using in this study.

TABLE 1 The Characteristics of Vertical Type Organic Light Emitting Transistors Using Various Active Materials and Electrodes

Devices	Current	Radiance	On-off ratio	Turn-on voltage
Al/C_{60}/gate/C_{60}/MEH-PPV/PEDOT-PSS/ITO	3.2 mA	1.5×10^{-9}	45.5	2.6 V
Al/C_{60}/gate/C_{60}/Bphen/MEH-PPV/PEDOT-PSS/ITO	1.9 mA	6.0×10^{-9}	80.2	2.65 V
Al/F_{16}CuPc/gate/F_{16}CuPc/MEH-PPV/PEDOT-PSS/ITO	1.2 mA	2.1×10^{-9}	24	3.1 V
Al/C_{60}/gate/F_{16}CuPc/MEH-PPV/PEDOT-PSS/ITO	1.5 mA	3.4×10^{-9}	60	3.1 V
LiAl/C_{60}/LiAl gate/C_{60}/Bphen/MEH-PPV/PEDOT-PSS/ITO	8.1 mA	2.7×10^{-8}	192.1	1.8 V
Mg/C_{60}/Mg gate/C_{60}/Bphen/MEH-PPV/PEDOT-PSS/ITO	6.2 mA	1.9×10^{-8}	136.4	2.2 V

CONCLUSION

Novel organic light emitting transistor consiting of Al/C_{60}/Al gate/C_{60}/MEH-PPV/PEDOT-PSS/ITO was successfully fabricated. Especially, the device using Bphen as a blocking material showed relatively low turn on voltage and high on-off ratio. The prepared vertical type light emitting transistor showed the depletion mode as a like a conventional OTFT. It should be noted that the switching characteristic of light emitting transistor was observed at a gate of 4 V. Also, high on-off ratio of 192 was obtained in the device using LiAl source and gate electrods.

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