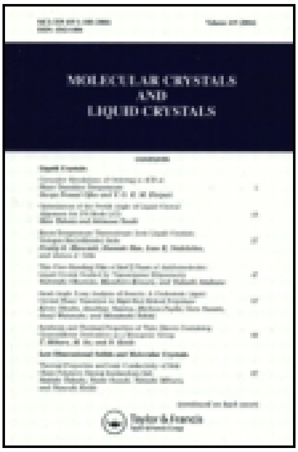

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

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Version of record first published: 12 Sep 2012.

Mol. Cryst. Liq. Cryst., Vol. 566: pp. 87–93, 2012

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2012.701833

Characteristics of Vertical Type Organic Light Emitting Transistor Using IF-dione-F as an Active Layer and DMDCNQI as a n Type Buffer Layer

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High on-off ratio, low turn-on voltage and fast response time are most critical issues in the research and development of organic transistor. In the present work, we have fabricated vertical type organic transistor using 2,8-difluoro-indeno[1,2-b]fluorine-6,12-dione (IF-dione-F) as an organic active semiconductor and DMDCNQI as a n type buffer material. IF-dione-F shows n-type semiconductor property and relatively high electron mobility. The organic light emitting transistor (OLET) configuration is ITO (drain)/PEDOT:PSS/MEH-PPV/IF-dione-F/Metal (gate)/IF-dione-F/DMDCNQI/Metal (source). The characteristics of OLET were investigated from the measurements of current-radiance voltage characteristics, electron mobility and external quantum efficiency

Keywords Vertical type organic light emitting transistor; IF-dione-F; On-off ratio; DMDCNQI; Charge transfer material; External quantum efficiency

Introduction

Organic field effect transistor (OFET) having advantages such as simple fabrication process, large area coverage, structural flexibility and low cost have been much attention because of the feasibility of application in flexible display, information tag, smart card and e-paper etc [1]. The performance of OFET has greatly improved in the last decade. However, the conventional OFET has some disadvantages such as low speed, low power and relatively high operation voltage [2–6]. On the other hand, vertical type static induction transistor is a promising device to obtain high speed and high power operation owing to the very short distance between source and drain electrodes [7,8]. Also, the vertical type OFET has high current density and good structure suitability in organic electroluminescence device of multilayered configuration. Recently, the charge injection process through metal/organic interface has been widely studied by a variety of methods. Especially, contact resistance and electrical properties of the conventional lateral type OFET were improved by using various metals and charge transfer materials [9].

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In this study, we have fabricated vertical type organic light emitting transistor (OLET) consisting of ITO (drain)/PEDOT:PSS/MEH-PPV/2,8-difluoro-indeno[1,2-b]fluorine-6,12-dione (IF-dione-F)/Metal (gate)/2,8-difluoro-indeno[1,2-b]fluorine-6,12-dione (IF-dione-F)/dimethyldicyanoquinonediimine (DMDCNQI)/Metal (source). We have used 2,8-difluoro-indeno[1,2-b]fluorine-6,12-dione (IF-dione-F) as a n-type semiconductor active material. Here, the number of fluorine group in IF-dione-F backbone shows high electron affinity and good durability. Also, dimethyldicyanoquinonediimine (DMDCNQI) was used to improve the contact resistance and electron transport ability as an organic n-type charge transfer buffer layer between cathode electrode and organic active layer.

Furthermore, it has been reported that the improvements of contact resistance and electrical properties using various metals and DMDCNQI as active layer for the conventional lateral type OFET. The field effect mobility of DMDCNQI was 0.011 cm^2/V s at lateral type OFETs using Au metal electrode [10]. Finally, we have investigated the physical effects of IF-dione-F as n-type active layer and DMDCNQI as n-type buffer layer on the performance of organic light emitting transistor.

Experimental Details

Reagents and Materials

Poly(3,4-ethylenedioxy thiophene)-poly(styrenesulfonic acid) (PEDOT-PSS) was purchased from Bayer Co., Ltd. Poly(2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene) (MEH-PPV) was purchased from Aldrich Co., Ltd. Dimethyldicyanoquinonediimine (DMDCNQI) was purchased from Fluka Co., Ltd. Other chemicals were used as a reagent grade. Synthesis of 2,8-difluoro-indeno[1,2-b]fluorine-6,12-dione (IF-dione-F) as a n-type material was carried out by previous reported method [11].

Device Fabrication

The configuration of OLET is ITO (drain)/PEDOT:PSS (100 nm)/MEH-PPV (40 nm)/IF-dione-F (100 nm)/metal (gate)/IF-dione-F (100 nm)/DMDCNQI (10 nm)/metal (source). The all layers were fabricated on patterned ITO ($\leq$15 $\Omega/\square$ sheet resistance) glass substrate using spin-coater (MIDAS SPIN-1200D) and vacuum evaporator (ULVAC VTR-300M/1ERH evaporator, Japan) under 10^{-6} Torr. Before the deposition of each layers, the patterned ITO substrate was immersed into the ultrasonic bath of deionized water, acetone and 2-propanol for 60 min, respectively. Then, the cleaned ITO glass substrated was rinsed in deionized water and blown by N_2 gas. PEDOT-PSS layer was spin-coated onto the ITO glass and dried at 70°C for 60 min under a vacuum oven. MEH-PPV layer was spin-coated from THF solution on PEDOT:PSS thin film. The THF solution of MEH-PPV was used after filtering with a 0.2 μm pore size PTFE membrane syringe filter. IF-dione-F layer was deposited onto the MEH-PPV layer. A grid type metal gate was deposited on the top of deposited IF-dione-F layer. And then, IF-dione-F layer was deposited onto the gate layer. Finally, metal source electrode was deposited onto the IF-dione-F layer. The prepared device was annealed at 150°C for 10 min in a vacuum oven. The chemical structure of IF-dione-F, the configuration of vertical type organic field effect transistor (OFET) and organic light emitting transistor (OLET) were shown in Fig. 1.

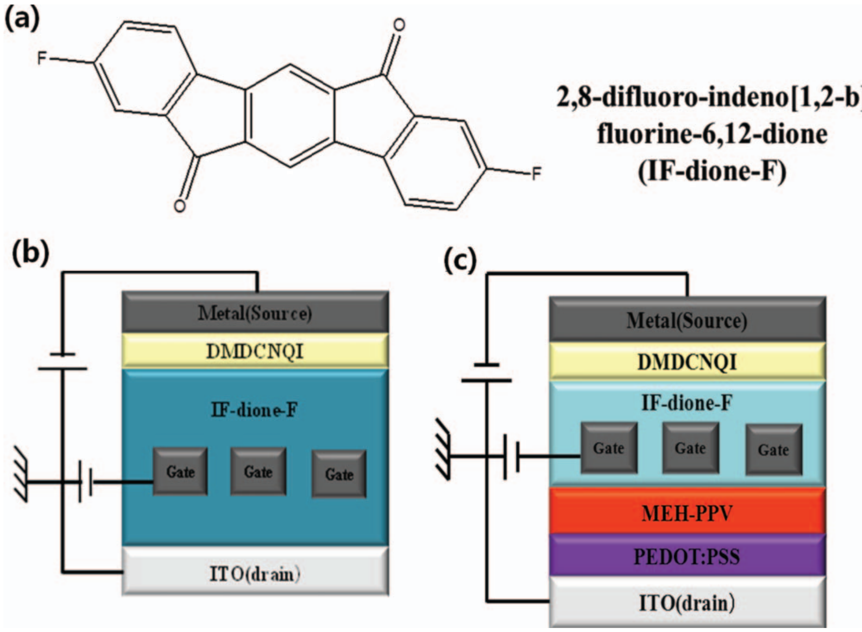

Figure 1. Chemical structure of (a) MonoF-IF-dione, configuration of (b) organic field effect transistor (OFET) and (c) organic light emitting transistor (OLET).

Measurements of Device Characteristics

Current-voltage characteristics were measured using source meters (KEITHLEY-2400, 237). The radiance measurements were carried out using a Newport 1830-C photodiode. All the measurements were performed under N_2 atmosphere and dark room at room temperature.

Results and Discussion

We have fabricated vertical type organic field effect transistor (OFET) using two kinds of source and gate metals such as Al and LiAl. Table 1 showed on-off ratios of the prepared vertical type organic transistors using various source and gate metals. The prepared organic transistor using LiAl as a source electrode exhibited high drain-source current compared to the case of Al source electrode having high work function. It is mainly due to the improvement of electron injection from the source electrode to active layer because of the

Table 1. I-V characteristics of vertical type OFET using IF-dione-F active layer at a constant V_{DS} (3 V)

Electrode material (source-gate)	On current (mA)	Off current (mA)	On-off ratio
Al-Al	1.35406	6.5×10^{-3}	2.0×10^{2}
LiAl-LiAl	2.78944	1.0×10^{-3}	2.6×10^{3}

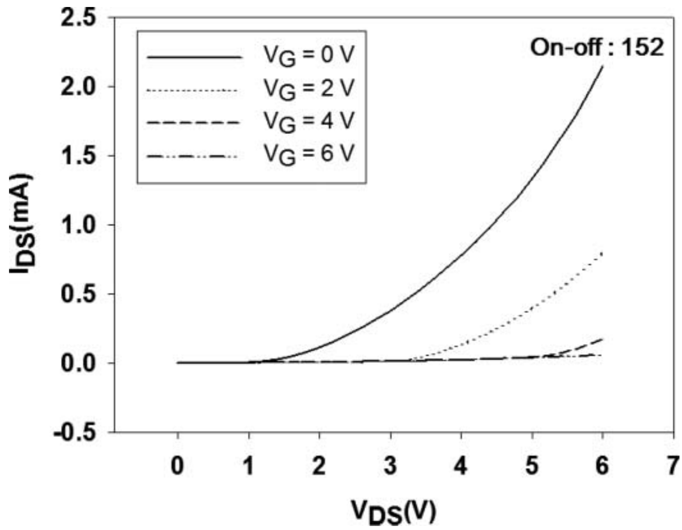

Figure 2. Current-voltage characteristics of organic light emitting transistor consisting of ITO (drain)/PEDOT:PSS/MEH-PPV/IF-dione-F (100 nm)/LiAl (gate)/IF-dione-F (100 nm)/LiAl (source) under various gate voltages (V_G).

low work function. Especially, the device using LiAl gate electrode shows high on-off ratio, which is caused to the effective carrier blocking owing to the formation of high Schottky barrier.

Current-voltage characteristics of vertical type organic light emitting transistor (OLET) consisting of ITO (drain)/PEDOT:PSS/MEH-PPV/IF-dione-F/LiAl (gate)/IF-dione-F/LiAl (source) was shown in Fig. 2.

The electron carriers injected from source electrode flow between IF-dione-F active layers through potential barrier near Al gate electrode. The gate electrode blocks the electron carrier migration from the first IF-dione-F layer to second IF-dione-F layer due to the formation of double Schottky barriers. Thus, the drain-source current (I_{DS}) is controlled by relatively small gate voltage of 6V.

Figure 3 showed the radiance characteristics of the OLET under various gate voltages. The radiance at a constant drain-source voltage (V_{DS}) was decreased with increasing gate voltage (V_G), which is caused to the depletion mode of the prepared vertical type organic transistor using a n type IF-dione-F active layer. Finally, it can be mentioned that the light emitting characteristic can be controlled by a small gate voltage.

We have also investigated the physical effects of DMDCNQI charge transfer material on the performance of the OLET. Figure 4 showed the I-V characteristics of OLET consisting of ITO (drain)/PEDOT:PSS/MEH-PPV/IF-dione-F (100 nm)/LiAl (gate)/IF-dione-F (100 nm)/DMDCNQI (10 nm)/LiAl (source) under various gate voltages.

Drain-source current (I_{DS}) of the device using a DMDCNQI buffer layer of 10 nm was increased compared to the case of without DMDCNQI layer, which imply that the DMDCNQI charge transfer complex reduce contact resistance between IF-dione-F active layer and LiAl electrode. Mori et al. reported that DMDCNQI layer shows low contact resistance between organic active layer and Cu electrode owing to the formation of highly conducting metal complex in n-channel lateral type organic field effect transistor [12–14].

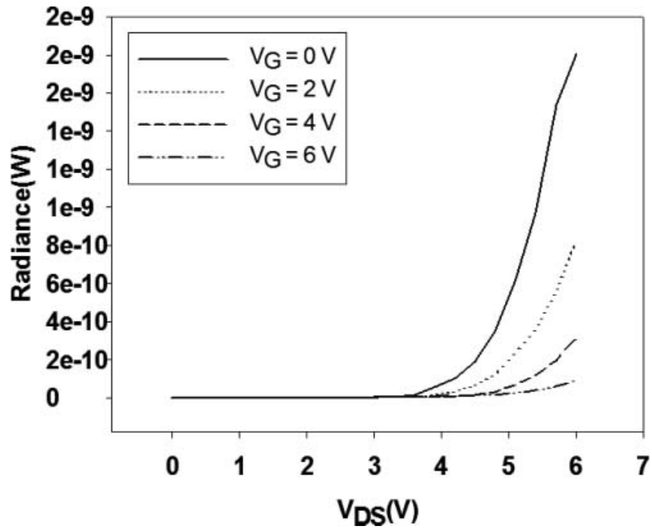

Figure 3. Radiance characteristics of organic light emitting transistor consisting of ITO (drain)/PEDOT:PSS/MEH-PPV/IF-dione-F (100 nm)/LiAl (gate)/IF-dione-F (100 nm)/LiAl (source) under various gate voltages (V_G).

We have investigated the external quantum efficiency in the prepared light emitting transistor to explore the electron transport ability of n type DMDCNQI buffer layer.

Figure 5 showed the external quantum efficiency of the vertical type organic light emitting transistor. The external quantum efficiency of device with a DMDCNQI layer was higher than that of device without DMDCNQI layer. It can be concluded that the external

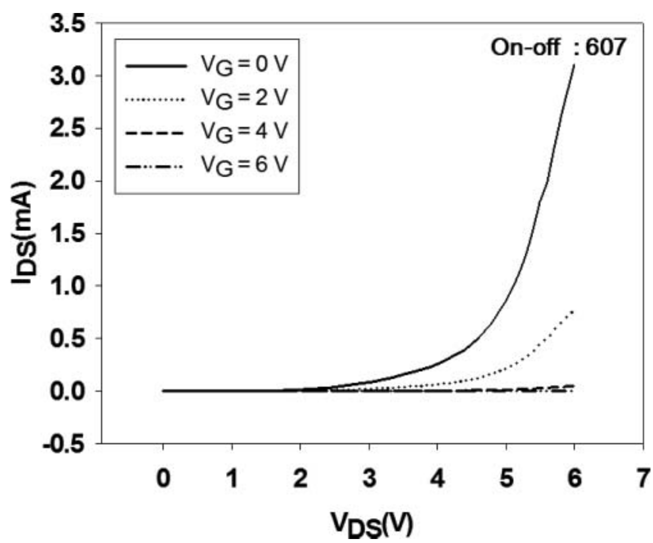

Figure 4. Current-voltage characteristics of organic light emitting transistor consisting of ITO (drain)/PEDOT:PSS/MEH-PPV/IF-dione-F (100 nm)/LiAl (gate)/IF-dione-F (100 nm)/DMDCNQI (10 nm)/LiAl (source) under various gate voltages (V_G).

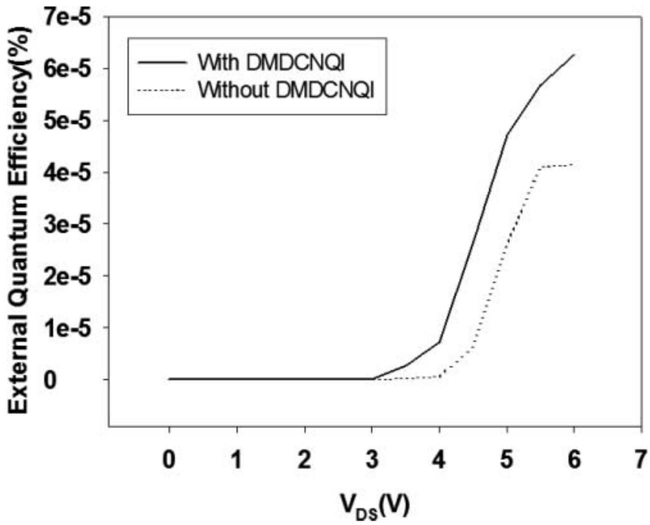

Figure 5. External quantum efficiency of vertical type organic light emitting transistor consisting of ITO/PEDOT:PSS/EH-PPV/IF-dione-F/LiAl (gate)/IF-dione-F/DMDCNQI/LiAl (source).

quantum efficiency of device using a n type DMDCNQI buffer layer was increased due to the improvement of hole and electron carrier balance.

Conclusions

We have successfully fabricated the high performance vertical type light emitting transistor using IF-dione-F active layer and DMDCNQI n type buffer layer. The prepared vertical type light emitting transistor showed the depletion mode as a like conventional OFET. It should be noted that the switching characteristic was observed at a low gate voltage of 6 V, and high on-off ratio of 2.6×10^3 was obtained in the device using LiAl source and gate electrodes of low work function. Especially, we have obtained high radiance characteristic using DMDCNQI as a charge transfer complex material, which is caused to the decrease in contact resistance between organic active layer and cathode electrode.

Acknowledgments

This work was supported by the Human Resource Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea Government Ministry of Knowledge Economy (No.20114010203090), Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No.20100026294) and Sogang University Foundation Research Grants in 2011.

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