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Characteristics of Top-Gate Type Ambipolar Organic Field-Effect Transistors Using Polyfluorene Derivatives

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1. Introduction

Organic semiconductors have attracted considerable attention due to their simple and low-cost processes and potential electronic and optoelectronic applications. They have potential applications for electronic and optoelectronic devices, especially, fabricated by solution processing for large-area and flexible devices. High performance of organic field-effect transistors (OFETs) fabricated using highly crystalline organic materials have been realized, however, solution process has still attention in simple fabrication process for large area.

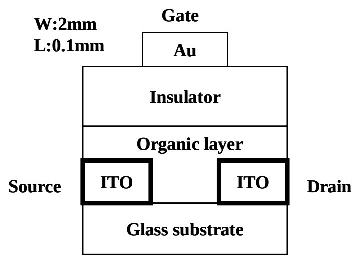
Fluorene-type polymer has emerged as an important class of conducting polymers due to their efficient emission and high stabilities. Fluorene-type polymer also has the potential to be in full color emission via energy transfer to longer wavelength emitters in blends with other fluorescent and phosphorescent dyes.

In this study, we studied the characteristics of top-gate type OFETs using polyfluorene derivatives. We also discussed ambipolar characteristics of OFETs and the application of light emitting field effect transistors by varying the gate voltage.

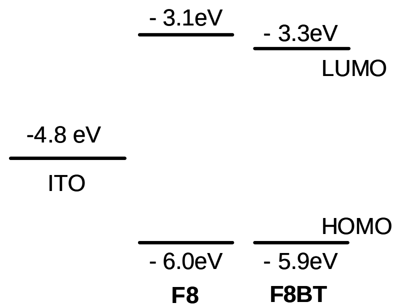
2. Experimental

Top-gate structure was employed for OFETs based on polyfluorene derivatives. Figure 1 shows the device structure and energy diagram of materials used in this study. The substrate was degreased with solvents and cleaned in a UV ozone chamber. Semiconducting layer was formed by spin coating method onto patterned ITO electrodes, which serve as source and drain electrodes, and baked. The channel length and width were 0.1 mm and 2 mm, respectively. Then, poly(methyl methacrylate) (PMMA) was used as gate insulators. PMMA solution was spun onto a patterned ITO-coated glass substrate and baked above 150 ^{o}C in ambient atmosphere. The typical thickness of the gate insulator was appeoximately 400-600 nm. The gate electrode of Au with a 30 nm thickness was vacuum evaporated at a background pressure of about 10^{-4} Pa onto the polymer gate insulating layer which was formed on the polyfluorene semiconducting layer. The deposition rate and the thickness of the deposited electrode were monitored using a quartz crystal oscillator.

The measurements of electrical characteristics of OFETs were carried out at room temperature in a vacuum chamber at a background pressure of about 10^{-4} Pa. For the measurement of electroluminescence (EL) spectra, the devices were covered with a glass plate and encapsulated by epoxy resin in an argon gas atmosphere to prevent oxidation of the cathode and the organic layer.



(a)



(b)

Fig. 1. (a) Device structure and (b) energy diagram of materials used in this study.

3. Results and discussion

Poly(9,9-dioctylfluorene) (F8), which contains only fluorene backbone, exhibits a blue emission and various morphological behaviors. Polyfluorene based block copolymer, poly[(9,9-dioctylfluorenyl-2,7-diyl)-co-(1,4-benzo-{2,1',3} -thiadiazole)] (F8BT) with an electron-withdrawing group was used as an electron transport material. The value of work function of ITO electrode exists in the approximately middle between HOMO and LUMO levels of F8 and F8BT as shown in Fig 1. Therefore, for top-gate type OFETs with F8 and F8BT as active layers, both holes and electrons from ITO drain/source electrodes into the highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) levels of F8 and F8BT can be expected to be injected by applying voltage.

For OFETs, it is well known that charge carriers run a few nm around insulator / semiconductor interface. The OH groups at the interface between polymer gate insulator and organic active layer interferes n-type carrier transport. PMMA, which do not contain electron trapping groups such as OH groups, was used as a gate insulator.

Figure 2 shows the output characteristics of top-gate type OFETs with F8. The F8 layer was processed by spin coating method from xylene solution. From the measurements of drain - source current characteristics shown in Fig. 2(a), the saturation characteristics were typical for p-type OFET working in the accumulation mode. The hole mobility and the threshold voltage of the top-gate type F8 device were estimated as $\mu = 7.2 \times 10^{-4}$ cm^2/Vs and V_{th} = -24 V at the drain-source voltage V_{DS} = -100 V, respectively.

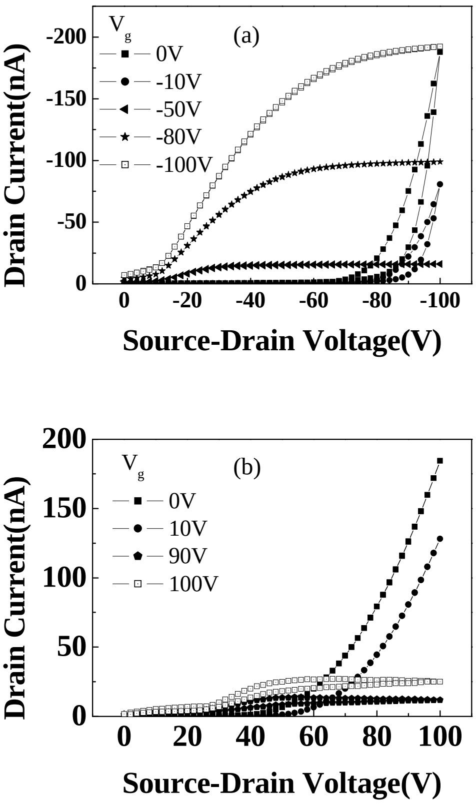


Fig. 2. Output characteristics of a top-gate type OFET with F8 in (a) p-type operation and n-type operation.

Output characteristics of the device operated in n-type mode are shown in Fig. 2(b). The leakage drain-source current increased superlinearly with drain-source voltage at lower gate voltages. Application of positive gate voltage suppressed this component and the typical saturation characteristics of n-type OFET were observed above the gate voltage of 80V. Hysteresis was observed due to the charge trapping. For F8 device, the threshold voltage in p-type operation is lower than that in n-type operation because the hole injection barrier is lower than the electron injection barrier as shown in Fig. 1(b). For n-type operation, the effective electron mobility and threshold voltage were estimated as $\mu = 1.2 \times 10^{-3}$ cm^2/Vs and V_{th} = 60.8 V at a drain voltage V_{DS} = 100 V, respectively. That is, ambipolar characteristics were obtained from the top-gate type F8 device with ITO drain/source electrodes.

For both p-type and n-type modes, the drain-source current superlinearly increased at lower drain-source voltages. The injection barriers of both holes and electrons from ITO drain/source electrodes into the HOMO and LUMO levels are relatively high and those values are more than 1 eV. These superlinear currents result from the relatively large contact resistance for both hole and electron injection.

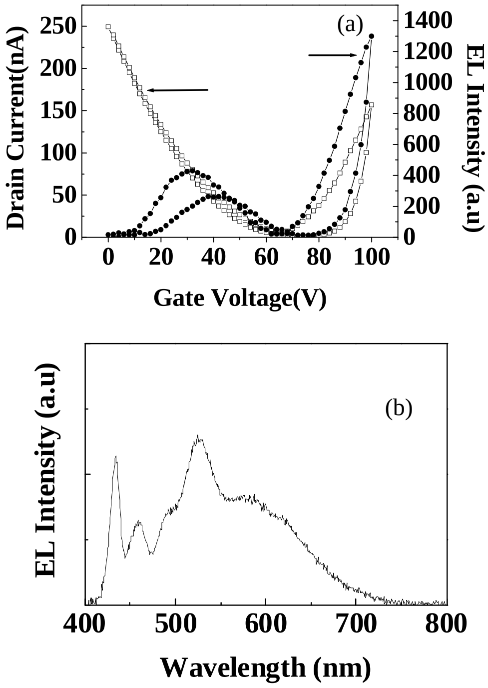


Fig. 3. (a) Transfer characteristic of F8 device and (b) EL spectrum of a F8:F8BTdevice.

For this ambipolar OFET with F8, a blue light emission was observed by varying the gate voltage as shown in Fig. 3. A peak of EL intensity was observed when hole current dominated at the gate voltage between 0 and 60 V. On the other hand, EL intensity increased with gate voltage when electron current dominated above approximately 60 V.

The dye doping method is practically important because it is easy to improve performance such as color tunability. OFETs with F8BT and 5 vol% F8BT doped in F8 as active layers also had ambipolar characteristics. For a F8:F8BT device, the white emission with CIE coordinate of (0.34, 0.40) was obtained owing to the blue and yellow-green emission from F8 and F8BT as shown in Fig.1(b). That is, top gate-type fluorene OFETs with ITO drain/source electrodes can be applied to the light-emitting transistors.

Acknowledgements

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