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Influence of Source/Drain Electrodes on the Properties of Top-gate-type Polymer Light-emitting Transistors

Ikuya Ikezoe, Yusuke Kusumoto, Hirotake Kajii, and Yutaka Ohmori

Graduate School of Engineering, Osaka University
2-1 Yamada-oka, Suita, Osaka 565-0871, Japan
Phone: +81-6-6879-4213 E-mail: ohmori@oled.eei.eng.osaka-u.ac.jp

1. Introduction

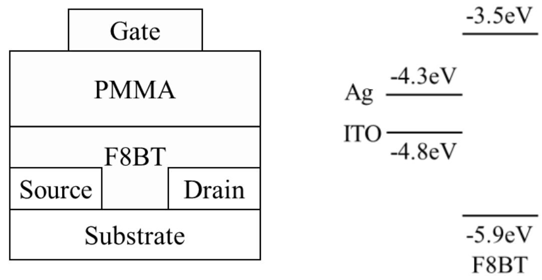
Organic field-effect transistors (OFETs) with various device structures have been reported to show ambipolar characteristics and light emission. In particular, ambipolar materials are useful for fabricating OFETs, because they can be used either as a p-channel or a n-channel by changing the polarity of the gate voltage and be expected to emit light. Top-gate-type OFETs with fluorene-type polymer exhibited ambipolar and light-emitting characteristics. [1]

It is important to research the influence of source/drain electrodes on the properties of organic light-emitting transistors (OLETs). Indium tin oxide (ITO) is suitable for the electrode of light-emitting devices due to its optical transparency. Besides, the work function of ITO is relatively low. Ag electrodes which can be fabricated by Ag nano-ink are also suitable for OLETs to realize all-solution processed devices. In this study, we investigated the differences of electrical and optical characteristics between top-gate-type polymer LETs with ITO and with Ag as source/drain electrodes.

2. Experimental Procedure

ITO or Ag was used for source/drain electrodes. ITO electrodes were patterned by photolithography on a substrate. On the other hand, Ag electrodes were vacuum-deposited at a background pressure of about 10^{-4} Pa onto a substrate. The channel length and width were 0.1 and 2 mm, respectively. Polyfluorene based block copolymer, poly[(9,9-dioctylfluorene)-co-(benzothiadiazole)] (F8BT) was used as a semiconducting layer. F8BT solution was spun onto the substrate and baked at 200 ^{o}C in a dry nitrogen glove box and poly(methyl methacrylate)(PMMA) was used as a gate insulator. It is well-known in OLETs that charge carriers run a few nanometers around the insulator/semiconductor interface. The OH groups at the interface between the polymer gate insulator and the organic active layer interfere with n-type carrier transport. PMMA does not contain electron-trapping groups, such as OH. PMMA solution was spun onto the semiconducting layer and baked at 150 ^{o}C. The typical thickness of the semiconducting layer and the gate insulator were 60 nm and 550 nm, respectively. A gate electrode of Ag with a 50 nm thickness was vacuum-deposited onto the polymer gate insulating layer which was formed on the semiconducting layer at a background pressure of about 10^{-4} Pa. The deposition rate and the thickness of the deposited electrode were monitored using a quartz crystal oscillator. Figure 1 shows the device structure and schematic energy level diagram of a F8BT film.

All measurements of characteristics of the OLETs were carried out in a vacuum chamber at a background pressure of about 10^{-4} Pa. The current-voltage characteristics were obtained using 2400 and 6517A source meters (Keithley). The electroluminescence (EL) output was measured using photodiode (Hamamatsu Photonics).



(a) (b)

Fig. 1 (a) Device structure and (b) energy diagram

3. Results and Discussion

The value of work function of ITO is located approximately in the middle between the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) levels of F8BT, as shown in Fig. 1(b). Although the work function of Ag is lower than that of ITO, both holes and electrons can be expected to be injected from source/drain electrodes into the HOMO and the LUMO levels of F8BT by applying a voltage.

Figure 2 shows output characteristics of OLETs with ITO and with Ag as source/drain electrodes. For both OLETs, the saturation characteristics were typical for both p-channel and n-channel OLETs working in the accumulation mode. That is, ambipolar characteristic were obtained from both OLETs with ITO and Ag as source/drain electrodes.

Transfer and corresponding EL output characteristics of OLETs with ITO and with Ag are shown in Fig. 3 (a) and (b), respectively. The electron mobility and threshold voltage of the OLET with ITO were estimated to be approximately μ = 8.2 x 10^{-4} cm^2/Vs and V_{th} = 25 V, respectively, at the drain voltage of 100 V. For OLET with Ag, μ = 8.8 x 10^{-4} cm^2/Vs and V_{th} = 34 V. On the other hand, for p-channel operation of OLET with ITO, the effective hole mobility and threshold voltage were estimated to be μ = 6.3 x 10^{-4} cm^2/Vs and V_{th} = -9.4 V, respectively, at the drain voltage of -100 V. For OLET with Ag, μ = 5.8 x 10^{-4}

cm^2/Vs and V_{th} = -6.4 V. The mobility and threshold voltage of OLET with Ag are almost the same as those with ITO although the work function of Ag is lower than that of ITO. For both OLETs, two peaks in EL output were observed when either hole or electron currents dominate, but the applied gate voltages were different. The voltages were about 25 and 85V for OLET with ITO and about 40 and 70V for OLET with Ag.

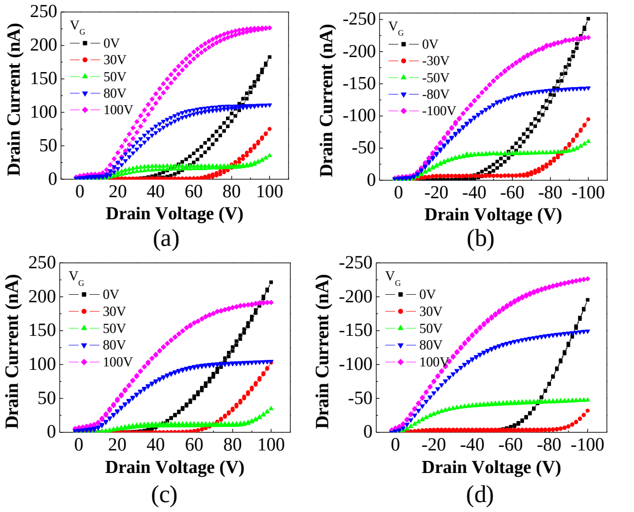


Fig. 2 Output characteristics of OLETs with (a, b) ITO and (c, d) Ag as source/drain electrodes, for different gate voltages in the hole and electron enhancement modes, respectively.

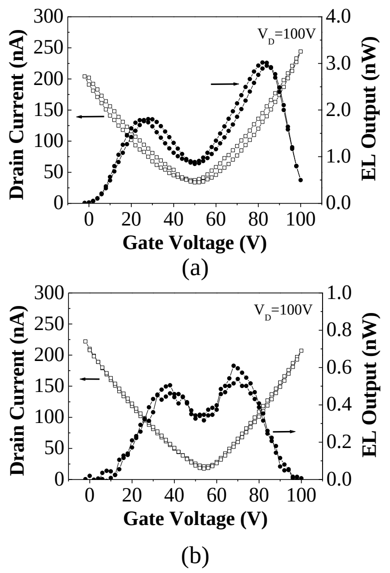


Fig. 3 Transfer characteristics and corresponding EL output of OLETs with (a) ITO and (b) Ag as source/drain electrodes for a drain voltage of 100 V.

For devices, yellow-green emission was observed as shown in Fig. 4. The emission site depended on the applied gate voltage. For the electron enhancement mode, OLETs fabricated in this study emitted light close to the source electrode at the lower gate voltage because holes were injected from the drain electrode and hole current dominated. As the gate voltage was increased, the electron injection was accelerated and then the emission site moved from source to drain side in the channel region. At the higher gate voltage, the channel was dominated by electrons and light is emitted close to the drain electrode. Local maximum value of light emission occurred close to electrodes.

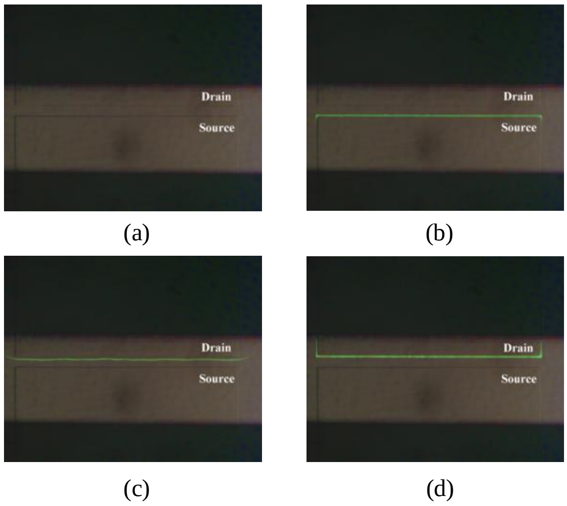


Fig. 4 Optical images of the light emission for different voltage of (a) 0 V, (b) 30 V, (c) 50 V and (d)80 V for OLET with ITO as source/drain electrodes.

External quantum efficiency (EQE) of those OLETs are shown in Fig.5. For OLET with ITO, high EQE was observed from low gate voltage to high gate voltage regardless of the emission site. On the other hand, for OLET with Ag, EQE was low at the voltage at which light emitted close to electrodes and a maximum peak of EQE took place at the voltage at which light emitted almost in the middle of channel. This result suggests that emission close to Ag source/drain electrodes is less efficient due to quenching of excitons by the electrodes. The maximum EQE of both devices were approximately 1 %.

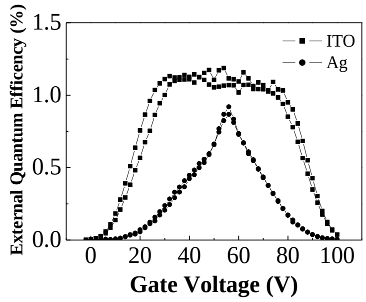


Fig. 5 External quantum efficiency of OLETs with ITO and Ag as source/drain electrodes.

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References

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