Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp916-917

Improved Light-Emitting Properties of Bilayer Polymer Light-Emitting Transistors with Phosphorescent Dye Doped in Fluorene-Type Polymers

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Abstract

In order to improve the emission characteristics of organic light-emitting transistors, the fabrication and properties of bilayer polymer light-emitting transistors with phosphorescent dye doped in fluorene-type polymers are investigated. Devices with phosphorescent dye doped layer exhibit the ambipolar and light-emitting properties. Both fluorescence and phosphorescence emissions can be achieved for bilayer devices.

1. Introduction

Organic light-emitting transistors (OLETs) have attracted considerable attention because they have potential for new optoelectronic applications. OLETs are relatively new devices that combine the light emission from an organic light-emitting diode with the switching properties of a field-effect transistor in a single device architecture. Therefore, optoelectronic devices can be fabricated by simple and low-cost processes by using OLETs.

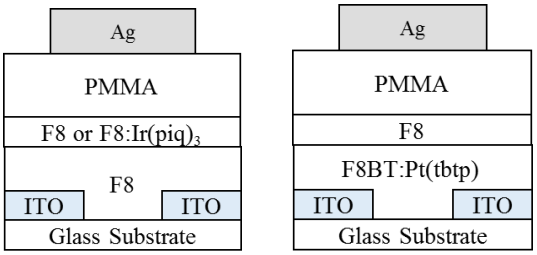
Liquid-crystalline semiconducting polymers were self-organized due to both the reorientation of molecules and the growth of size of crystalline regions during thermal annealing process. Fluorene-type polymers have emerged as an important class of conducting polymers owing to their efficient emission, relatively high mobility, and high stability. Fluorene-type polymers also have the potential for full-color emission via energy transfer to longer wavelength emitters in blends with other fluorescent and phosphorescent dyes. Employing phosphorescent materials yields high efficiencies because breaking the spin conservation rule allows both singlet and triplet excitons to contribute to emission. A specific class of organic light-emitting diodes (OLEDs) has achieved high luminescence efficiency using the phosphorescent emission from a triplet state of Ir and Pt complexes. Top-gate-type single-layer devices based on fluorene-type polymers exhibit the ambipolar and light-emitting properties. [1-3]

In this paper, we investigated the fabrication and properties of bilayer polymer light-emitting transistors with phosphorescent dye doped in fluorene-type polymers.

2. Experimental Procedure

A top-gate bilayer structure was employed for the OLETs based on crystalized fluorene-type polymer films, as shown in Fig. 1. Indium tin oxide (ITO) was used for source/drain electrodes. ITO electrodes were patterned by photolithography on a substrate. The channel length and width were 0.1 and 2 mm, respectively. We fabricated OLETs using various phosphorescent dyes, tris(1-phenylisoquinoline)iridium(III) ($Ir(piq)_3$) and Pt-tetraphenyltetrabenzoporphyrin (Pt(tpbp)) as red and near-infrared emitters, as shown in Fig.1. Poly(9,9-dioctyl fluorene) (F8), $Ir(piq)_3$ doped in F8 and Pt(tpbp) doped in poly(9,9-dioctylfluorene-co-benzothiadiazole) (F8BT) were used as the active layers. The doping concentration of $Ir(piq)_3$ was fixed at 15 wt% relative to the host of F8. Poly(methyl methacrylate)(PMMA) was used as a gate insulator. PMMA solution was spun onto the semiconducting layer and baked at 150 ^{o}C. The typical thickness of the gate insulator was 550 nm. 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.

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). The electroluminescent (EL) spectra were measured using a photonic multichannel spectral analyzer (Hamamatsu Photonics PMA-11).



(a) devices A and B (b) device C

Fig.1 Device structures.

3. Results and Discussion

For the top-gate type structure, the transistor channel can be assumed to be near the surface of the film, because it forms within a few nanometers of the semiconductor/ insulator interface. For the F8:$Ir(piq)_3$ layer, energy transfer from the F8 to $Ir(piq)_3$ occurred. 40 nm-thick lower layer and 10nm-thick upper layer were fabricated by spin-coating and contact printing methods, respectively. Figure 2 shows output characteristics of device A with $Ir(piq)_3$ doped in F8 as an upper layer and device B with F8 as an upper layer.

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 devices A and B.

Transfer and corresponding EL output characteristics of devices A and B for a drain voltage of 100 V are shown in Fig. 3. The electron mobility and threshold voltage of the device A were estimated to be approximately $\mu = 1.5 \times 10^{-3}$ cm^2/Vs and $V_{th} = 54$ V, respectively, at the drain voltage of 100 V. For device B, $\mu = 1.2 \times 10^{-3}$ cm^2/Vs and $V_{th} = 52$ V. On the other hand, for p-channel operation of device A, the effective hole mobility and threshold voltage were estimated to be $\mu = 4.5 \times 10^{-4}$ cm^2/Vs and $V_{th} = -26$ V, respectively, at the drain voltage of -100 V. For device B, $\mu = 4.4 \times 10^{-4}$ cm^2/Vs and $V_{th} = -27$ V. The mobility and threshold voltage of device A are almost the same as those of device B although for device A, the upper layer consists of red emissive $Ir(piq)_3$ doped in F8. This result suggests that for device A, $Ir(piq)_3$ do not necessarily act as a trap site for carriers.

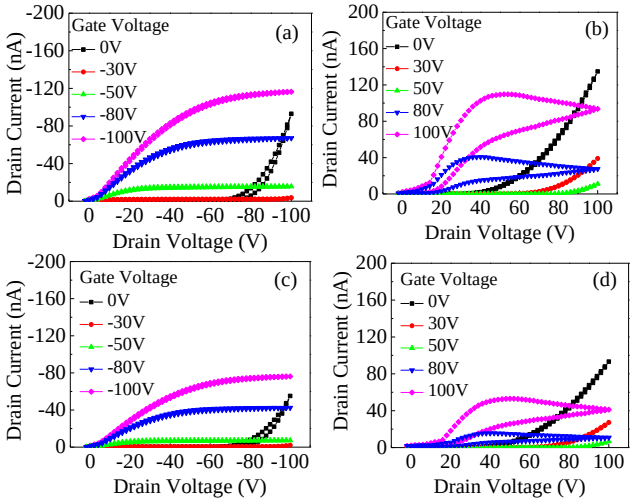


Fig. 2 Output characteristics of (a, b) device A and (c, d) device B for different gate voltages in the hole and electron enhancement modes, respectively.

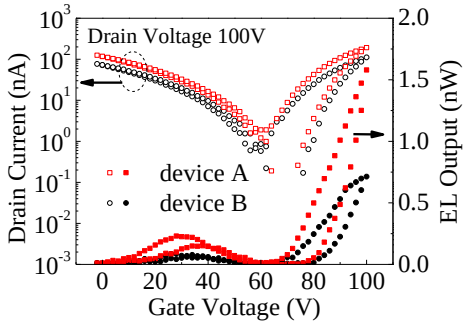


Fig. 3 Transfer characteristics and corresponding EL output of devices A and B for a drain voltage of 100 V.

A peak of EL intensity was observed when hole current dominated at gate voltages between 0 and 60 V. The EL intensity was at a minimum when the drain current reached a minimum. On the other hand, EL intensity increased with gate voltage when electron current dominated above approximately 60 V. The EL output of device A is bigger than that of device B as shown in Fig. 3. The device A exhibited the highest EQE of 0.6% compared to device B. This is because device A clearly shows both blue and red emissions from F8 and $Ir(piq)_3$ as shown in Fig. 4.

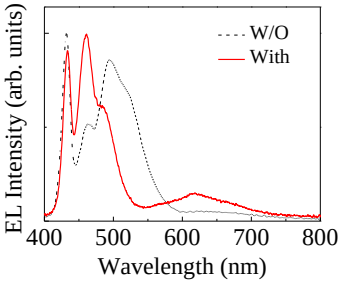


Fig. 4 EL spectra of devices A and B.

For device C, F8 can be expected to act as an electron blocking layer because the lowest unoccupied molecular orbital (LUMO) level of F8BT is lower than that of F8. Carriers can be expected to transport at the bilayer interface between F8BT and F8. Both yellow-green fluorescence and near-infrared phosphorescent emissions from F8BT and Pt(tpbp) can be achieved for device C as shown in Fig. 5. The emission intensity of the Pt(tpbp) peak relative to of the F8BT peak increased with doping ratio of Pt(tpbp).

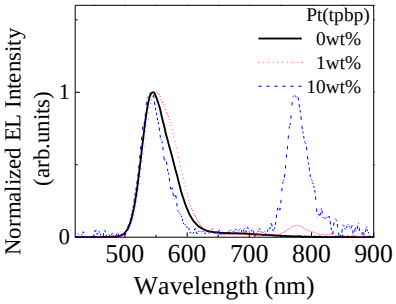


Fig.5 EL spectra of device C with various Pt(tpbp) doping ratios.

4. Conclusions

The device A with $Ir(piq)_3$ exhibited the highest EQE of 0.6% compared to device B without $Ir(piq)_3$. Our results illustrate that OLETs with ambipolar carrier transport and both fluorescence and phosphorescent emissions can be achieved.

Acknowledgements

Part of this work was supported by Grant-in-Aid for Scientific Research, from the Ministry of Education, Culture, Sports, Science and Technology, Japan. This research was also partially supported financially by a grant for a Grant in Aid of Special Coordination Funds for Promoting Science and Technology. The authors thank Sumitomo Chemical Co., Ltd for providing F8BT.

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