

Polymer light-emitting diodes operating in ultraviolet region containing carrier-transporting materials in active layers

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Abstract

We fabricated polymer light-emitting diodes (PLEDs) operating in the ultraviolet (UV) region by a wet-process. The samples consisted of simple bilayer structures. In particular, the electron- and hole-transporting materials were doped in the active layers to improve the carrier injection into the active layer. We observed a peaking wavelength of 389 nm was observed in the electroluminescence (EL) spectrum. In addition, the maximum external quantum efficiency was 1.8%.

1. Introduction

Polymer light-emitting diodes (PLEDs) have been investigated for the applications to flat panel displays and novel illumination sources, because the solution process of PLEDs leads to low-cost production [1]. Studies on PLEDs operation in the ultraviolet (UV) regime have also been reported [2, 3]. In this study, we fabricated PLEDs operating in the UV regime by a wet-process. They consist of simple bilayer structures. In particular, the electron- and hole-transporting materials were co-doped in the active layer to improve the carrier injection.

2. Experimental

Sample fabrication

The UV emissive material is poly[(9,9-dihexylfluorene-2,7-diyl)-co-(1,4-dimethylbenzene-2,5-diyl)] (PF-DMB). We confirmed that PF-DMB reveals a peaking-wavelength of 389 nm in a photoluminescence (PL) spectrum. Poly(N-vinylcarbazole) (PVK) was used as a hole-transporting material, and 3-(Biphenyl-4-yl)-5-(4-tert-butylphenyl)-4-phenyl-4H-1,2,4-triazole (TAZ) was used as an electron-transporting material. As a hole-injection layer, a poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS) layer was fabricated by spin-coating on cleaned indium-tin-oxide (ITO)-coated glass substrates. We also fabricated an active layer that consists of PF-DMB by spin-coating using chloroform as a solvent in which PVK and TAZ were doped. Finally, an aluminum (Al) layer was vacuum deposited as a cathode metal. The device structure was ITO/PEDOT:PSS/PF-DMB:PVK:TAZ/Al.

Experimental setup

Electroluminescence (EL) spectra, current-voltage characteristics, and external quantum efficiencies (η_{ext}) were automatically measured by a system that combined an integrat-

ing sphere, a parameter analyzer (4155C, Agilent Technologies), and a CCD spectrophotometer (PMA-12, Hamamatsu). The film thickness was measured by a step profiler (XP-1, Techscience). All measurements were performed at room temperature and in atmosphere.

3. Results and discussion

We evaluated four kinds of samples. Sample A consists of the undoped active layer, sample B-1 consists of the PVK-doped active layer, sample B-2 consists of the TAZ-doped active layer, and sample C consists of a PVK- and TAZ-doped active layer. Since the active layer was about 60 nm thick, and the PEDOT:PSS layer was about 40 nm thick, the combined thicknesses of the organic bilayers of the four samples was 100 nm.

Sample A

Figure 1 shows the EL spectrum of sample A. An emission peaking-wavelength is clearly observed at 389 nm, demonstrating the successful fabrication of a PLED operating in the UV regime using PF-DMB. However, the EL emission stabilized when a large voltage was applied because PF-DMB is a large bandgap material. Thus, large applied voltage and large current injection are necessary for stable UV emission from sample A.

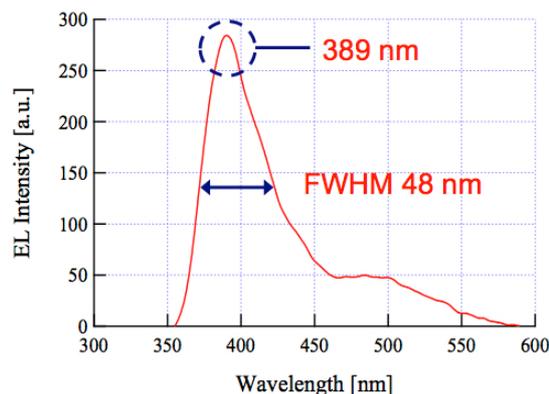


Fig. 1 EL spectrum of sample A: Applied voltage is 18 V, and injected current is about 20 mA.

Sample B-1

To improve the current injection into the active layer, the PVK is doped as a hole-transporting material. By changing its doping density, we found that the EL intensity became maximum when the doping ratio of PF-DMB:PVK was 10:4

(Fig. 2). The emission stabilized when the applied voltage was 13 V and the current injection was 20 mA. Thus, the operation voltage of sample B-1 is lower than that of sample A due to the improved hole-injection by PVK-doping. In addition, the maximum η_{ext} of sample B-1 was 0.0032%.

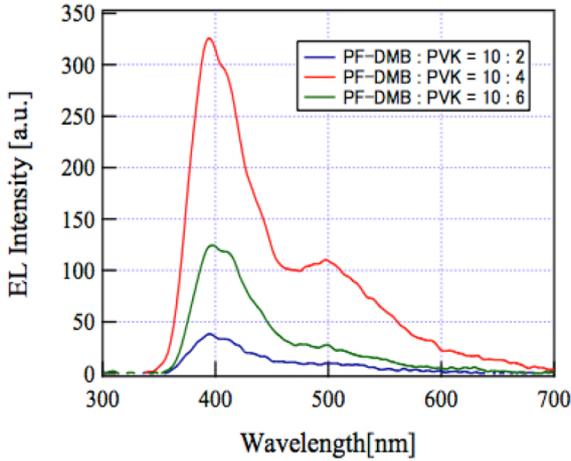


Fig. 2 EL spectra of sample B-1 when doping ratios of PF-DMB:PVK are 10:2, 10:4, and 10:6.

Sample B-2

To improve the electron injection into the active layer, we doped TAZ as an electron-transporting material and changed its doping density. However, we only observed EL emissions when the doping ratio of PF-DMB:TAZ was 10:4 (Fig. 3). In addition, since the EL emission was very weak, η_{ext} could not be evaluated. Moreover, the current injection did not improve because it became 20 mA when the applied voltage was 17 V.

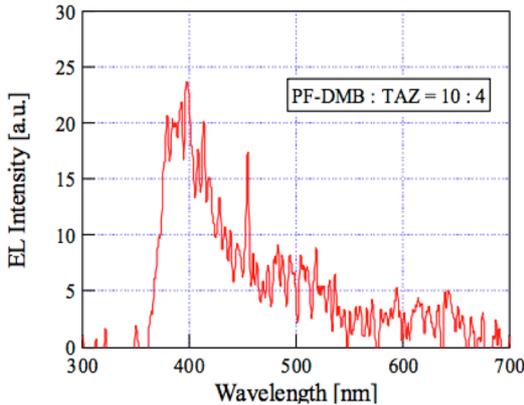


Fig. 3 EL spectrum of sample B-2 when PF-DMB:TAZ is 10:4.

These results show that the doping of the hole-transporting material is more effective for PF-DMB, indicating that it is probably an electron-transporting material.

Even though sample B-1's operation voltage was lower than sample A, sample B-1's EL intensity almost equaled that of sample A. This is because hole-injection into the active layer of sample B-1 is much larger than the electron-injection. This suggests that the optimal balance of both electron- and

hole-injections, which is necessary, can be controlled by the densities of the electron- and hole-transporting materials in the active layer.

Sample C

We next evaluated the co-doping effect in sample C. PVK and TAZ were co-doped in the PF-DMB active layer. The ratio of PF-DMB:PVK was fixed as 10:4, and then the doping density of TAZ was changed. Fig. 3 shows the EL spectra of sample C. Clearly the EL intensity drastically increased when the ration of PF-DMB:PVK:TAZ was 10:4:4, resulting in a maximum η_{ext} observed as 1.8%. Moreover, the EL emission stabilized at a lower applied voltage than sample B-1.

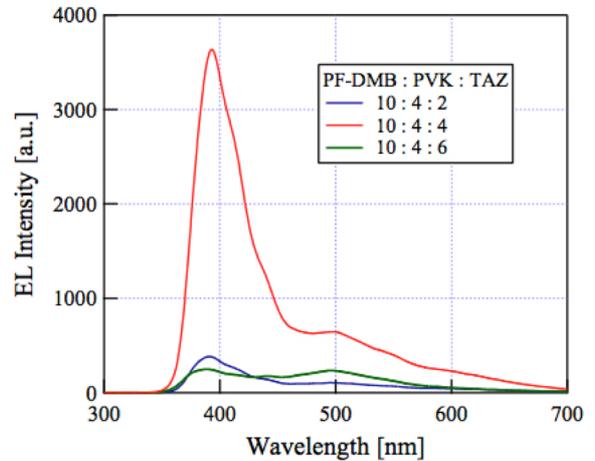


Fig. 4 EL spectra of sample C when the applied voltage is 12 V.

3. Conclusions

PLEDs operating in the UV regime were fabricated by a wet-process, consisting of simple bilayer structures. We evaluated the co-doping effect to improve the balance of the electron- and hole-injections into the active layer. We observed maximum η_{ext} as 1.8% by optimizing their doping densities.

Acknowledgements

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References

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