Effect of the LiF anode interfacial layer on polymer light emitting diodes

Sunyoung Sohn, Daewoo Lee, Keunhee Park, and Donggeun Jung[1]
Department of Physics, Institute of Basic Science, and Brain Korea 21 Physics Research Division, Sungkyunkwan University, Suwon 440-746, South Korea
H. M. Kim, U. Manna, and J. Yi
School of Information and Communication Engineering, Sungkyunkwan University, Suwon 440-746, South Korea

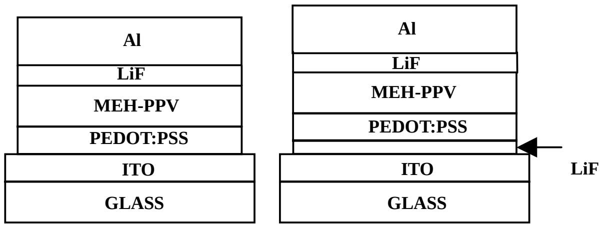
Abstract
Electrical and optical characteristics of MEH-PPV-based PLEDs with the LiF anode interfacial layer were investigated. The maximum luminance efficiency of the device with a LiF anode interfacial layer of 1-nm-thick was 3.0 lm/W, which is higher than 1.97 lm/W of the device without a LiF layer. By inserting LiF, excess injected holes from ITO anode can be blocked and hence the recombination ratio of electrons and holes can be increased in the emitting layer to improve device efficiency.

1. Introduction
After the report of efficient organic light emitting diodes (OLEDs) based on tris-(8-hydroxyquinoline) aluminum (Alq_3) in 1987 [1], R. H. Friend *et al.* used the semiconducting electroluminescent polymers for the fabrication of the polymer light emitting diodes (PLEDs) using the poly(*p*-phenylenevinylene) (PPV) as the π-conjugation polymer [2]. Many efforts has been devoted to the study of the PLEDs in display application due to the advantages such as simple fabrication methods, high luminous efficiency at low voltage, cost effect, and flexible mechanical property [3,4]. One of the most important issues for PLEDs is an improvement of the devices efficiency. The unbalance between the holes and the electrons injected from the anode and the cathode, respectively, is one of the important causes of the low luminance efficiencies of the PLEDs [5,6]. Since holes are usually too many for electrons, it is needed either to increase electron injection or to decrease hole injection without increasing turn-on voltages significantly. In order to increase the electron injection, typical cathode in PLEDs consist of a low work function metals such as Ca (2.9 eV), Mg (3.8 eV), and Li (3.7 eV) [7]. Some group reported that poly(phenyl quinoxaline) increased electron injection [8]. In recent years, the insertion of thin insulating layers, such as Si_3N_4 [9], SiO_2 [10], between the organic layer and ITO in OLEDs can improve the brightness and electroluminescence efficiency of OLEDs, which was suggested due to the band bending and tunneling effect [11]. Moreover, the use of an ionic insulating lithium fluoride (LiF) between ITO and hole transport layer (HTL) in phenyl-substituted poly(*p*-phenylene-vinylene) (Ph-PPV) based PLEDs resulted in a shift of the operating voltage to a lower value [12].

In this work, we report that, in the fabrication of MEH-PPV based PLEDs, insertion of a LiF interfacial layer between the anode electrodes and the organic layers can improve performance of PLEDs significantly.

2. Experiment
The ITO-coated glass with a sheet resistance of 20 Ω/□ was used for the anode of PLEDs. For the preparation of PLEDs, the ITO glass was cleaned sequentially in ultra sonic bath of trichloroethylene, acetone, and methanol, respectively. Finally, the ITO glass was sonicated in deionization water and then blown dry with N_2 gas. The LiF layer as the anode interfacial layer was deposited to the thickness of 0-2 nm by thermal evaporation. Poly(styrenesulfonate) (PSS)-doped poly(3,4-ethylene dioxythiophene) (PEDOT) was used as the hole transport layer (HTL). The emitting material layer (EML) was spin-coated with a 0.6 wt% poly (2-methoxy-5-(2'-ethylhexyloxy)-1,4-phenylene-vinylene) (MEH-PPV) solution in chlorobenzene. The device structures of PLEDs without and with anode interfacial layer were shown in figure 1(a) and 1(b), respectively. The 40-nm-thick PEDOT:PSS layer and the 100-nm-thick MEH-PPV layer were prepared sequentially by spin coating on the substrate. The cathode with 1-nm-thick LiF and 150-nm-thick Al was deposited by thermal evaporation. Thickness of LiF as the cathode interfacial layer was fixed at 1nm, which was optimized to increased electron injection in our experiment.

1 Corresponding author e-mail address : djung@skku.ac.kr



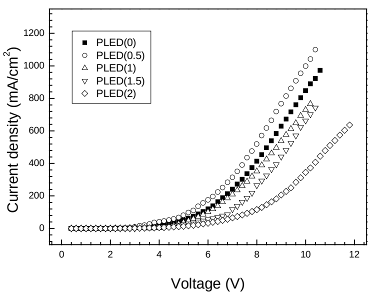
(a) (b)

Figure 1. The device structures of PLEDs without (a) and with (b) LiF interfacial layer.

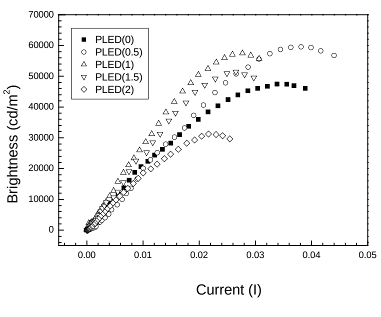
For electrical measurements, a Keithley 2400 electrometer was used as a voltage source and current measurement equipment. The capacitance-voltage (C-V) measurement was done by using LF 4192A Impedance analyzer. The brightness characteristics of PLEDs were investigated by measuring the photocurrent induced by the light emission from the PLEDs using a Keithley 485 picoammeter.

3. Results

Figures 2(a) and 2(b) show the current density versus voltage (J-V) and brightness versus current (B-I) characteristics for devices with different thicknesses of LiF.



(a)



(b)

Figure 2. Current density versus voltage (J-V) (a) and brightness versus current (B-I) (b) characteristics of PLEDs as a function of the LiF thickness.

PLEDs whose LiF thickness were 0, 0.5, 1, 1.5, and 2 nm were referred to as PLED(0), PLED(0.5), PLED(1), PLED(1.5), and PLED(2), respectively. The increased injection of holes at PLED(0.5) resulted in the decreased turn-on voltage compared to those of the PLED(0). Such enhancements were suggested by the tunneling effect and energy level alignment at interface due to the insertion of a thin insulating layer. When thickness of interfacial layers was over 1 nm, the turn-on voltage of devices was increased due to the excess of possible tunneling barrier. The PLED(0.5) and PLED(1) showed better performance than PLED(0), especially in B-I characteristics in high current range.

Figure 3 shows the capacitance versus voltage (C-V) characteristics of the PLEDs measured at high frequency (1,000 kHz) for various thicknesses of the LiF anode interfacial layers.

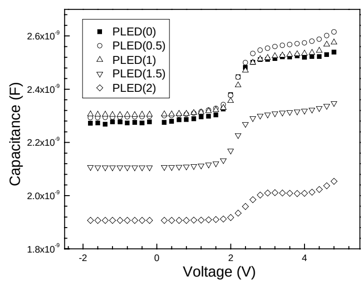
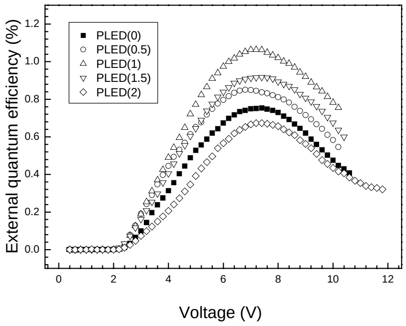


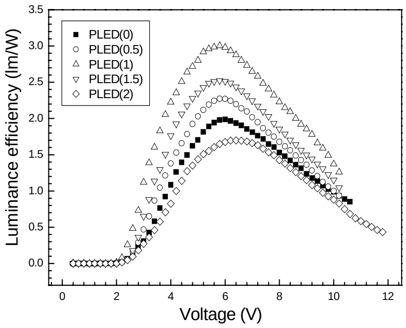
Figure 3. Capacitance versus voltage (C-V) characteristics of PLEDs as a function of the LiF thickness.

By sweeping the bias from reverse to forward direction, the capacitance value of the device was increased in turn-on voltage range, and then was saturated. The capacitance of PLED(0) varies from 2.2×10^{-9} F to 2.5×10^{-9} F as the voltage increases from -2V to 5V. By comparing *C-V* curves to *J-V* curves, it is observed that the PLED with a higher *J* value at a given voltage shows a higher *C* value at that voltage [13].

Figure 4(a) and 4(b) show the external quantum efficiency and luminance efficiency of PLEDs. PLED(0), PLED(0.5), PLED(1), PLED(1.5), and PLED(2) show the maximum external quantum efficiencies of the 0.75%, 0.84%, 1.06%, 0.91%, 0.67%, respectively, at about 7.2 V. Also, the maximum luminance efficiency of PLED(0), PLED(0.5), PLED(1), PLED(1.5), and PLED(2) showed the 1.97 lm/W, 2.27 lm/W, 3 lm/W, 2.5 lm/W, and 1.7 lm/W at 5.8 V, 5.8 V, 5.8 V, 5.8 V, and 6.4 V, respectively.



(a)



(b)

Figure 4. External quantum efficiency (a) and luminance efficiency (b) of PLEDs as a function of LiF deposition thickness.

Especially, PLED(1) showed a higher external quantum efficiency and luminance efficiency than the other PLEDs. We thick that, by inserting LiF as the interfacial layer, excess injected holes from ITO anode can be blocked, and the unbalance between holes and electrons in the emitting layer is reduced, and hence the recombination ratio of electrons and holes can be increased in the emitting layer to improve device efficiency.

4. Conclusions

In conclusion, we have studied effects of the LiF anode interfacial layer on the characteristics of PLEDs as a function of the LiF thickness. The characteristics of the PLEDs were affected significantly by existence of the LiF anode interfacial layer. J-V and B-I characteristics of PLED(0.5) showed better performance than the other devices. However, PLED(1) with an optimized thickness showed the highest external quantum efficiency and luminance efficiency. It is suggested that the insertion of a LiF anode interfacial layer with a proper thickness contributed to the increased performance of PLED by enhancing the balance of holes and electrons.

5. Acknowledgements

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6. References

[1] C. W. Tang and S. A. VanSlyke, *Appl. Phys. Lett.*, **51**, 913 (1987).

[2] J. H. Burroughes, D. D. C. Bradley, A. R. Brown, R. N. Marks, R. H. Friend, P. L. Burns, and A. B. Holmes, *Nature*, **347**, 539 (1990).

[3] J. C. Scott, J. H. Kaufman, P.J. Brock, R. Dipietro, J. Salem, and J. A. Goitia, *J. Appl. Phys.*, **79**, 2745 (1996).

[4] Tae-Woo Lee and O Ok Park, *Advanced Material*, **12**, 801 (2000).

[5] I. H. Campbell, D. L. Smith, C. J. Neef, and J. P. Ferraris, *Appl. Phys. Lett.*, **74**, 2809 (1999).

[6] I. D. Parker, *J. Appl. Phys.*, **75**, 1656 (1994).

[7] D. Braun and A. J. Heeger, *Appl. Phys. Lett.*, **58**, 1982 (1991).

[8] D. O'Brien, M. S. Weaver, D. G. Lidzey, and D. D. C. Bradley, *Appl. Phys. Lett.*, **69**, 881 (1996).

[9] Hongjin Jiang, Yan Zhou, Boon Siew Ooi, Yuwen Chen, Terence Wee, Yee Loy Lam, Jingsong Huang, and Shiyong Liu, *Thin Solid Films*, **363**, 25 (2000).

[10] Z. B. Deng, X. M. Ding, S. T. Lee, and W. A. Gambling, *Appl. Phys. Lett.*, **74**, 2227 (1999).

[11] L. S. Hung, C. W. Tang, and M. G. Mason, *Appl. Phys. Lett.*, **70**, 152 (1997).

[12] Furong Zhu, Beeling Low, Keran Zhang, and Soojin Chua, *Appl. Phys. Lett.*, **79**, 1205 (2001).

[13] V. Shrotriya and Y. Yang, *J. Appl. Phys.*, **97** (2005).