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음전극 변화에 따른 유기 발광 소자의 효율 향상

Efficiency Improvement of OLEDs with a Variation of Cathodes

김상걸*, 정동회*, 정택균**, 이호식***, 장경욱****, 최명규****, 홍진웅*, 이준웅*****, 김태완***
(S. K. Kim*, D H. Chung*, T. G. Chung**, H. S. Lee***, K. U. Jang****, M. G. Choi****, J. U. Lee*****, T. W. Kim***)

Abstract

We have investigated the effects of cathode in organic light-emitting diodes of ITO/TPD/Alq_3/Cathodes (Al, LiF/Al, Ca/Al, and LiAl) by measuring current-voltage-luminance characteristics. The device with cathodes other than Al cathode shows the efficiency by an oder of one compared with Al cathode only. This improvement is due to a reduction of barrier height in cathode side.

Key Words: OLEDs, luminous efficiency, external quantum efficiency

1. Introduction

Organic light-emitting doides(OLEDs) based on organic thin layers are similar to conventional simiconductor-based light-emitting diodes, and today they are considered to be one of the possible flat-panel displays of the next generation[1]. They are attractive because of low-operating voltage, low power consumption, easy fabrication, low-cost, and capability of multicolor emission by the selection of emissive materials [2-4]. Light emission in OLEDs is the consequence of the recombination of holes and electrons injected from the electrodes to the organic emissive layer. Such carrier recombination generates excited molecules or excitons, which eventually emit light or become thermally deactivated. Thus, the device efficiency is highly dependent on the amount of carrier recombination in the emissive materials[5].

Cathodes play an essential role in OLEDs, influencing strongly the current-voltage characteristics[6-9]. Using low work function metals or alloys[9], the onset voltage of light emission is lowered. In addition to a reduction of operation voltage, the emission power efficiency (lm/W) is also improved. Futhermore, an adoption of low work function cathode is effective in raising the current efficiency, which is defined as luminance per ampere(cd/A), of the LEDs having an aluminum-hydroxyquinoline(Alq) layer[10]. This effect is related to the distribution of the electron-hole recombination zone, which is strongly dependent on the electron injection characteristics of the cathodes[10].

Among the cathodes so far reported, double-layer cathode consisting of a very thin LiF layer and Al layer are very attractive, because they are prepared using chemically stable starting materials and the operational voltage of the LEDs can be drastically lowered[8,10,11]. Matsumura and Jinde[10] have attributed the lowering of the operational voltages to the low work function of

* Dept. of Electrical Eng., Kwangwoon Univ.
** Vistorm Co.
*** Dept. of Physics, Hongik Univ.
**** Kyungwon College.
***** KIEEME

the cathode, wihch is probably caused by the formaton of the topmost layer consisting of a mixture of Li and Al. On the other hand, Hung et al.[45] explained that LiF forms an insulating layer and assists the tunneling of electrons from the Al electrode into the Alq layer.

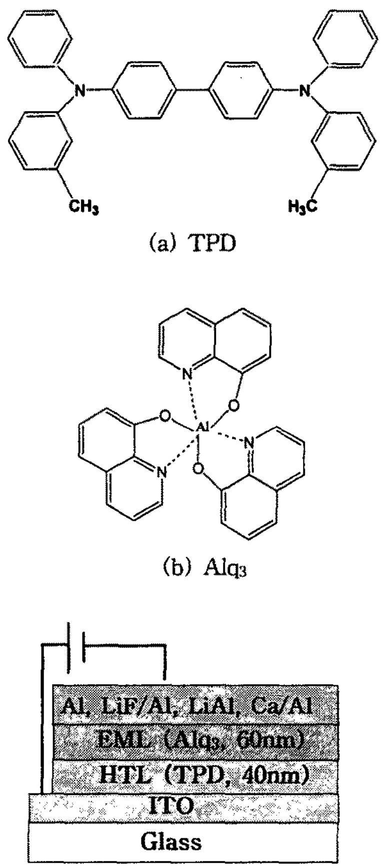
In this paper, we have studied the effects of cathode in OLEDs based on Alq_3 thin films by investigating current-voltage characteristics, luminance-voltage characteristics and luminous efficiency.

2. Experimentals

We have fabricated the OLEDs with a use of N,N'-diphenyl-N,N'-bis(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine (TPD) as a hole-transport and 8-hydroxyquinoline aluminum (Alq_3) as an electron transport and emissive material. The ITO glass, having a sheet resistance of 15Ω/□ and 170nm thick, was received from Samsung Corning Co. A 5mm wide ITO strip line was formed by selective etching in solution made with hydrochloric acid (HCl) and nitric acid(HNO_3) with a volume ratio of 3:1 for 10~20 minutes at room temperature. And then the patterned ITO glass was cleaned by sonicating it in chloroform for 20 minutes at 50℃. And then the ITO glass was heated for 1 hour at 80℃ in solution made with second distilled deionized water, ammonia water and hydrogen peroxide with a volume ratio of 5:1:1. We sonicated the substrate again in chloroform solution for 20 minutes at 50℃ and in deionized water for 20 minutes at 50℃. After sonication, the substrate was dried with N_2 gas stream and stored it under vaccum. Fig. 1 shows molecular structures of TPD, Alq_3 and device structure. The organic materials were successively evaporated under 10^{-6} torr with a ratio of about 0.5~1Å/s.

The film thickness of TPD and Alq_3 was made to be 40nm and 60nm, respectively. And cathodes (Al(150nm), LiF(0.5nm)/Al(150nm), LiAl(150nm), Ca(50nm)/Al(150nm)) were deposited at 1.0×10^{-5} Torr. Light-emitting area was defined by using a shadow mask to be 0.3×0.5 cm^2.

Current-voltage characteristics and luminance-voltage characteristics of OLEDs were measured using Keithley 236 SMU source-measure unit, 617 electrometer and Si-photodiode. Luminance-voltage characteristics and luminous efficiency were also measured at the same time when the current-voltage characteristics were measured. Luminous efficiency was calculated based on the luminance, EL spectra and current densities.



(a) TPD

(b) Alq_3

(c) device structures

Fig. 1. Molecular structure of (a) TPD, (b) Alq_3 and (c) device structures.

3. Results and Discussion

Fig. 2 shows the UV/visible absorption spectrum of Alq_3 and electroluminescent (EL) spectrum in ITO/TPD/Alq_3/Al device. The λ_{peak} in UV/visible absorption spectrum is 359nm, and that of EL spectrum is 507nm. It shows green light emission.

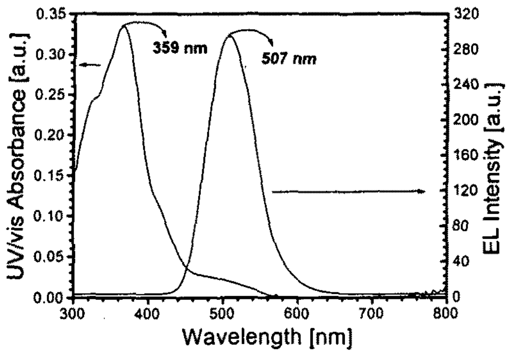


Fig. 2. UV/visible absorption of Alq_3 and electro-luminescent spectrum of ITO/TPD/Alq_3/Al device.

Fig. 3(a) shows typical nonlinear current-voltage characteristics of ITO/TPD/Alq_3/Cathode devices with several different cathodes such as Al, LiF/Al, LiAl, Ca/Al, respectively. Fig. 3(b) is a corresponding luminance of device depending on the applied voltage. All devices show green light emission with a peak at 507nm, characteristic of Alq_3. For Al cathode, as the voltage increases above 5V, the current density and luminance start to increase rapidly and there occurs a light emission. But for other cathodes other than Al, they show similar behavior of I-V and L-V characteristics. The operating voltage is near 3V, which is reduced to that of Al device.

This is due to a reduction of barrier height between Alq_3/cathode with a use of low value of work function. Thus the charge injection is easier.

Table 1 shows a work function of metal cathode and barrier height between Alq_3/cathode.

Table 1. Work funtion of metal cathode and barrier height between Alq_3 and cathode

Cathode	Al	LiF/Al	LiAl	Ca/Al
Work function [eV]	4.3	3.1	3.0	2.9
Barrier height (Alq_3/cathode)	1.2	0	-0.1	-0.2

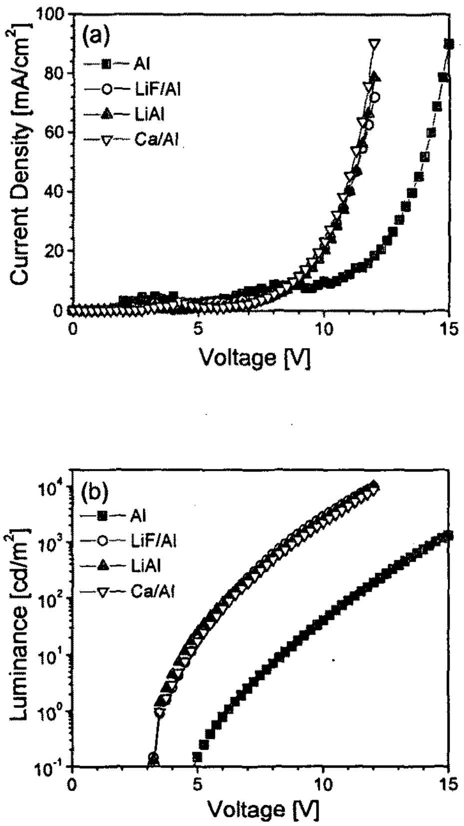


Fig. 3. (a) Current density and (b) luminance-voltage characteristics with a variation of cathode in ITO/TPD/Alq_3/Cathode devices.

To see how the electrical current affects on the luminance, the luminous efficiency, and the external quantum efficiency of device was calculated using the current-voltage and the luminance-voltage characteristics. The external quantum efficiency relates the number of emitted photons out of device to the number of injected carrier. The number of injected carrier is calculated from the current density and the number of photon is obtained from the luminance and electroluminescent spectrum of device.

Fig. 4(a) shows the luminous efficiency as a function of applied voltage. For Al cathode, the maximum luminous efficiency is 0.1[lm/W]. However, the devices with low work function cathode shows the maximum luminous efficiency of 1.7[lm/W] for LiF/Al, 1.5[lm/W] for LiAl, and 1.3[lm/W] for Ca/Al, respectively. There is an improvement of efficiency by an oder of one. In the device with Al cathode, the luminous efficiency increases gradually and reaches a maximum near 14V. However, when the low work function cathodes are used, the luminous efficiency increases rapidly near 4V and 5V. And it decreases again a little bit about 8V.

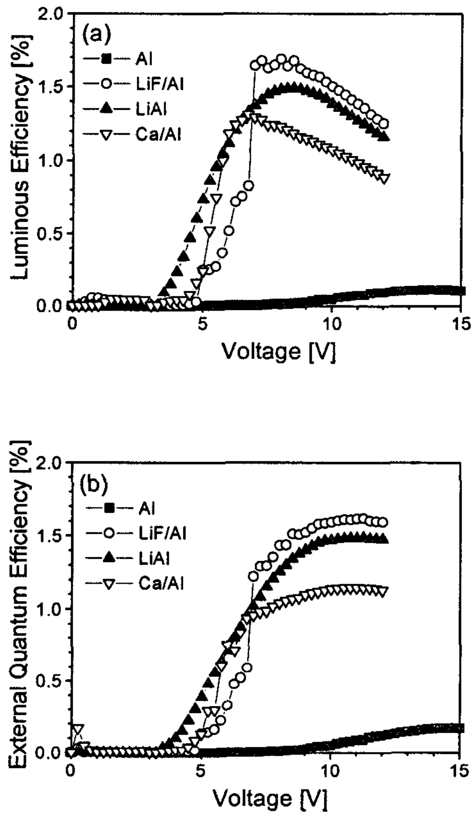


Fig. 4 (a) Luminous efficiency and (b) external quantum efficiency-voltage characteristics with a variation of cathode in ITO/TPD/Alq_3/Cathode devices.

Fig. 4(b) shows the external quantum efficiency as a function of applied voltage. For Al cathode, the maximum external quantum efficiency is 0.16[%]. However, the devices with low work function cathode shows the maximum luminous efficiency of 1.6[%] for LiF/Al, 1.5[%] for LiAl, and 1.15[%] for Ca/Al, respectively. There is an improvement of efficiency by a factor of ten.

From these results, we can expect the improvement of efficiency by controlling the barrier height in cathode side.

4. Conclusions

We have fabricated the efficient OLEDs using the cathode with the low work function in a device structure of ITO/TPD/Alq_3/Cathode. By using the cathode with the low work function, the luminous efficiency and the external quantum efficiency of device has improved by on oder of one. This improvement is due to a reduction of energy barrier-height in cathode side.

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