

Characteristic Improvements of Organic Light Emitting Diodes By Using Co-Evaporated Cathodes

Y. H. Kwak

Dept. of Electrical and Control Engineering, Hongik Univ., 72-1, Sangsu-dong, Mapo-gu, Seoul, Korea

Y. S. Lee, J. H. Park, and Jong Sun Choi

Dept. of Electrical and Control Engineering, Hongik Univ., 72-1, Sangsu-dong, Mapo-gu, Seoul, Korea

Abstract

In order to improve the power efficiency of multi-layer organic light emitting diodes (OLEDs), electron injection into ETL (electron transport layer) from cathode at the interface between ETL and cathode was enhanced by interposing a proper electron injection layer at the interface. The HTL (hole transport layer) and ETL materials used were N, N'-diphenyl - N, N' - bis(3-methylphenyl)-1, 1'-biphenyl - 4, 4'-diamine (TPD) and tris (8-hydroxyquinoline) aluminum (Alq₃) respectively. Cathodes using co-evaporated Al-CsF, Al-KF, and Al-NaF composites are adopted to enhance the electrical and optical properties of OLEDs. OLEDs with alkaline metal-doped cathode show a luminance of as high as 35,000 cd/m², and external quantum efficiency about 1.35 %. In addition, they show higher power efficiency at all bias conditions and good reproducibility.

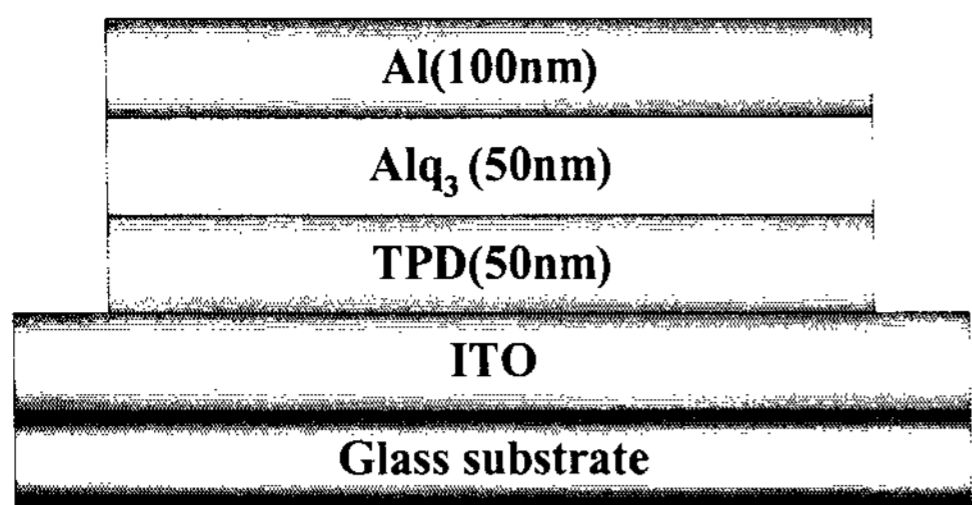
1. Introduction

OLEDs have been paid much attention due to wide viewing angle, high luminous efficiency and possibility of very thin devices. It is one of the most critical research issues to obtain appropriate device reliability and efficiency. To enhance electron injection, the use of low-work function metals and alloys is effective because of their low barrier heights for electron injection from the Fermi levels of the cathodes to the lowest unoccupied molecular orbitals (LUMOs) of the ETL materials [1-3]. However, OLEDs using low work function metal cathodes exhibited inferior stability [4]. In the same way as in electrochemical cells, a steep electrical potential change near the electrode surface is necessary for enhanced charge injection due to the decrease in the tunneling barrier thickness [5,6]. Recently, Kido and Matsumoto observed that the Li doping of Alq₃ at the cathode interface was effective for lowering the driving voltage and increasing EL efficiencies [6-7]. They attributed these improvements

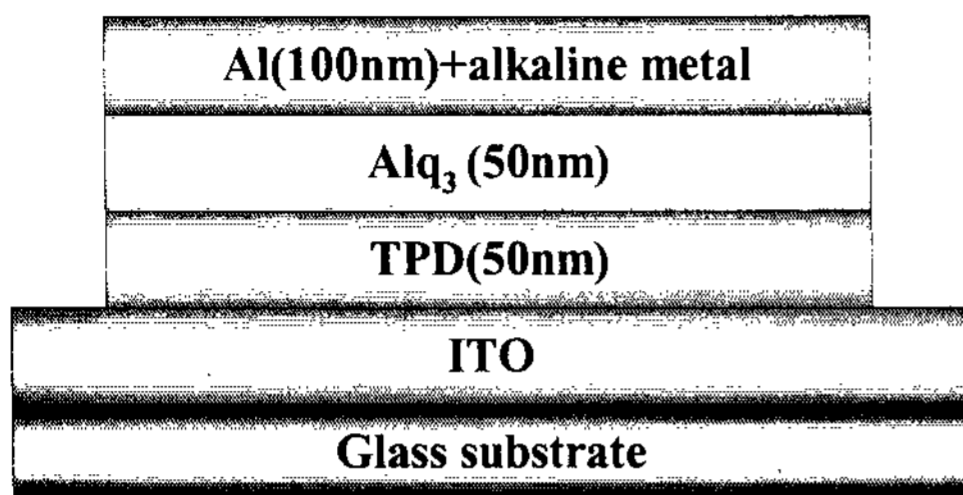
to the higher conductivity of the Li-doped Alq₃ layer. A number of groups have reported that electron injection can be significantly improved by inserting a thin layer of large band-gap inorganic and organic salts or insulators at the organic/metal interface. But it is difficult to control the thickness of insulating alkaline metals and make the inserting thin layer process reproducible. So we applied the co-evaporated cathode structure of alkaline metals (CsF, KF, and NaF) and Al to enhance OLEDs performances. Especially, CsF can be thermally deposited at lower temperature than is possible with LiF. Therefore, it can be expected that CsF can prohibit the heat exposure of the organic layers during the evaporation of cathode metals [8]. In this study, it has been investigated that the co-evaporated cathodes can improve the operational characteristics of the OLEDs.

2. Experimental details

Glass substrates coated with ITO (20Ω/ of the sheet resistance) were cleaned in ultrasonic baths of acetone, isopropyl alcohol, and D. I. Water in succession. The double-layer devices were fabricated, which consists of HTL and ETL. The HTL, 50nm thick N, N'-diphenyl-N,N'-bis(3-methylphenyl) -1,1'-biphenyl -4, 4'-diamine (TPD) and the ETL, 50nm thick tris(8-hydroxy-quinoline) aluminum (Alq₃) were deposited under the base pressure of 1.6×10⁻⁶ Torr, respectively. In depositing Al-CsF, Al-KF, and Al-NaF composite contacts, the mass ratio of alkaline metal is varied from 1 to 4wt%. The device structure is schematically presented in figure 1. The devices with both Al and Al-alkaline cathodes were fabricated to evaluate the effectiveness of the co-evaporated Al-alkaline cathodes. The current-voltage characteristics of the EL devices were measured using a Keithley 238 at room temperature under ambient atmosphere.



(a)



(b)

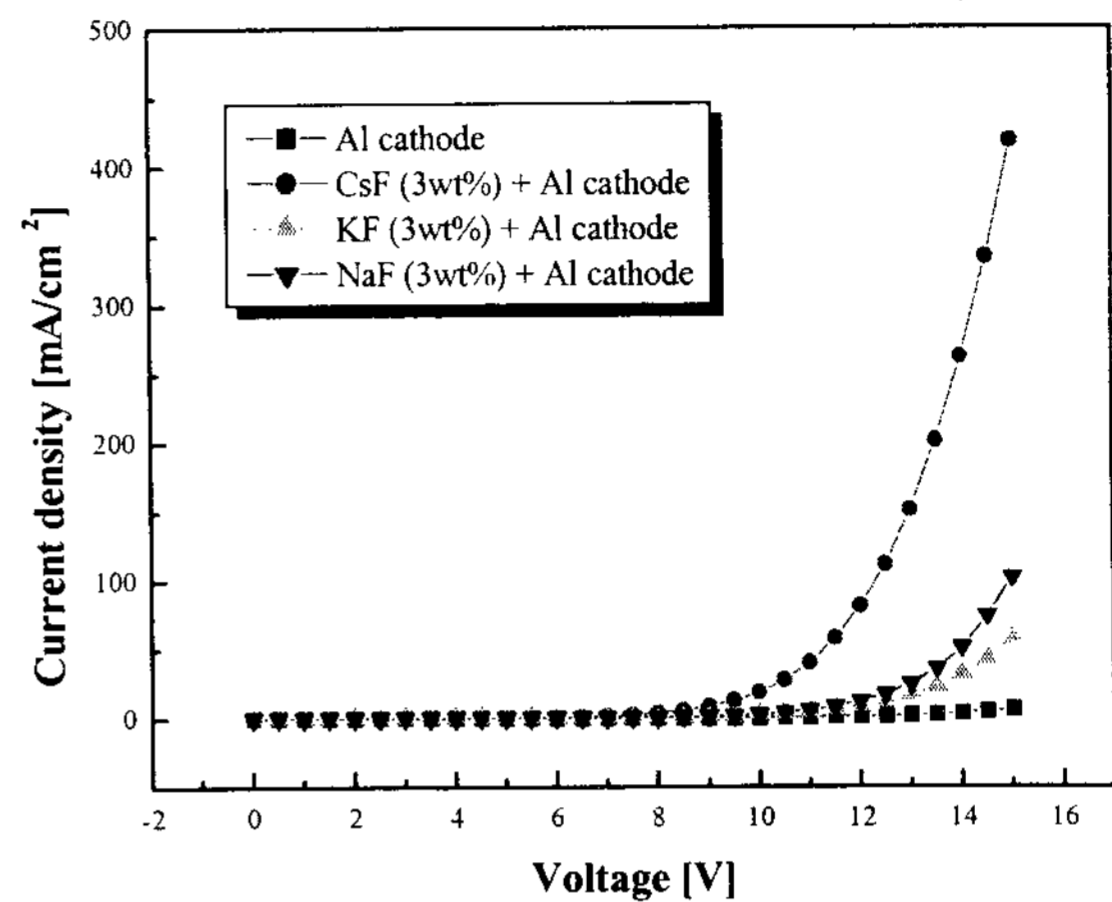
Figure 1. Configuration of organic EL device: (a) ITO/TPD/Alq₃/Al, ITO/TPD/Alq₃/Al+alkaline metal

3. Results and discussions

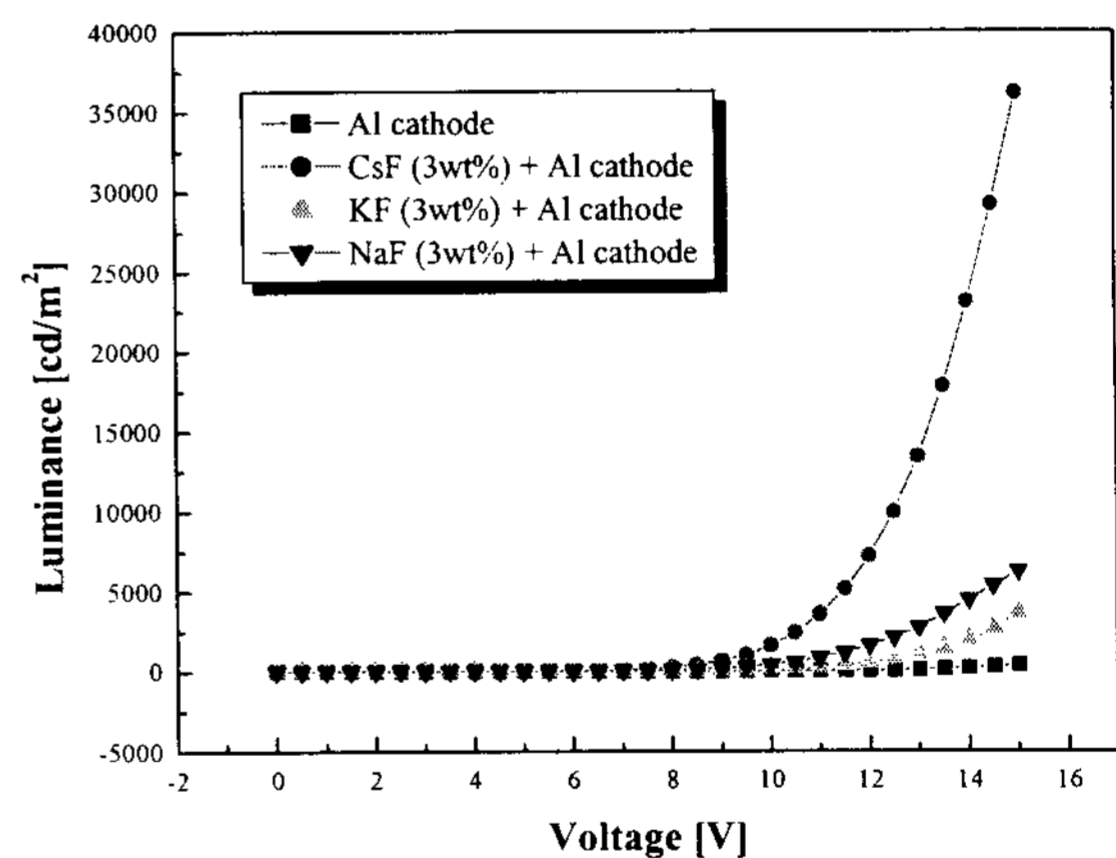
3.1 J-V characteristics

The current density and luminance intensity of the devices with different cathode compositions are shown in figure 2. The devices with co-evaporated cathodes show superior performance to the devices with Al cathode. The device with the Al-CsF cathode shows the best performance with the lowest turn-on voltage, which is attributed to the efficient charge injection into the ETL. It is reported that Cs, K, and Na atoms evaporated onto ETL uniformly diffuse into Alq₃ layer, and the Fermi level of Alq₃ moves towards the LUMO level of Alq₃ [9]. Negative charges on the cathode repel electrons toward Alq₃ radical anions to form neutral Alq₃ molecules and Cs⁺ (K⁺, Na⁺) cations. The depletion of electrons near the cathode results in the accumulation of the ionic space charge due to the Cs⁺ (K⁺, Na⁺) cations. The order of the effectiveness of the alkaline salts as a co-evaporated cathode depends on the order of the decrease in the barrier heights against the electron injection [6], which can balance the electron injection from the cathode with the hole injection from the anode. The device with the co-evaporated Al-CsF cathode has the luminance of 7,000cd/m² at a 100mA/cm². As compared in figure 3, there is a significant difference

in luminance intensity between the device with Al cathode and the device with Al-CsF(3wt%) cathode. The EL intensity of the devices with co-evaporated cathode shows the unique wavelength comparing which of Al cathode device. And the result of the EL intensity corresponds with the current-voltage characteristic. Thus, it can be stated that the co-evaporated cathodes of the device do not have an effect on the color purity [6].



(a)



(b)

Figure 2. (a) Current density vs. bias (J-V) characteristics and (b) luminance vs. bias (L-V) characteristics with 3wt% mass ratio alkaline metals.

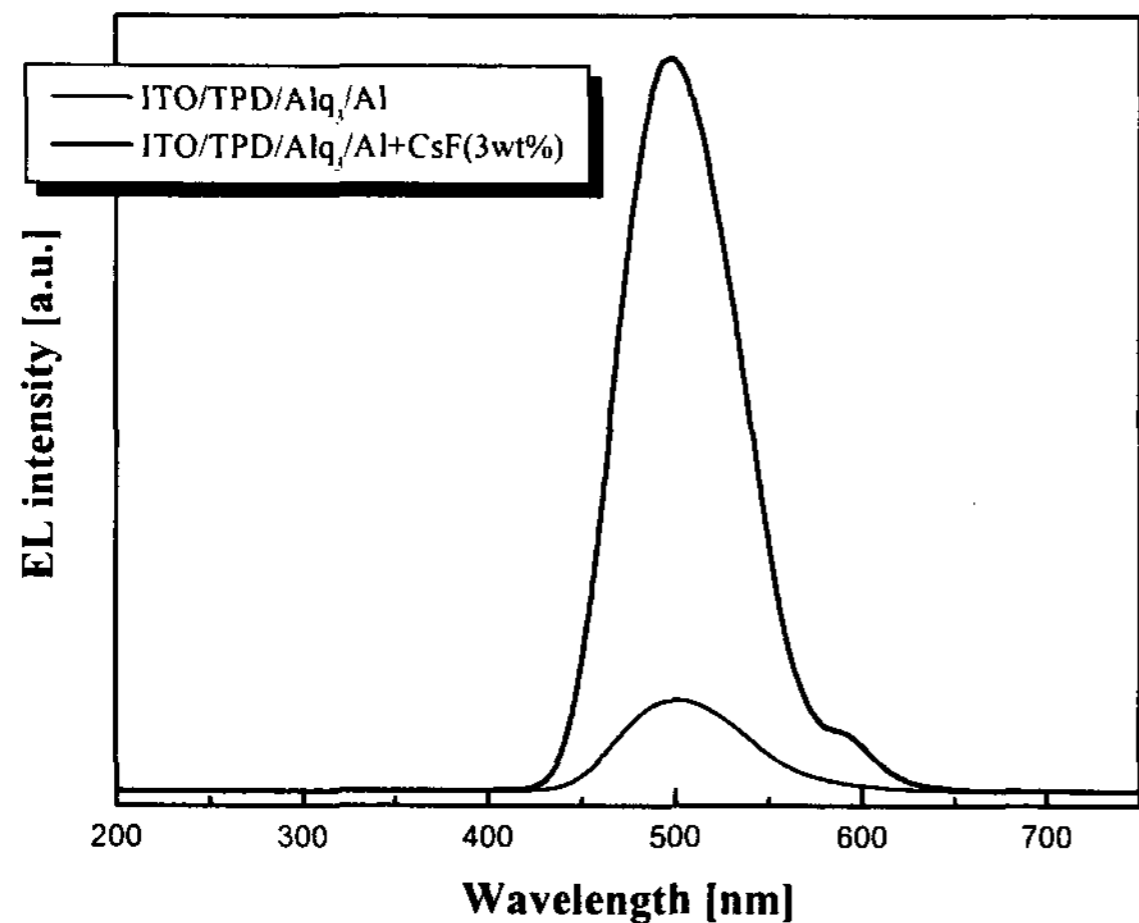
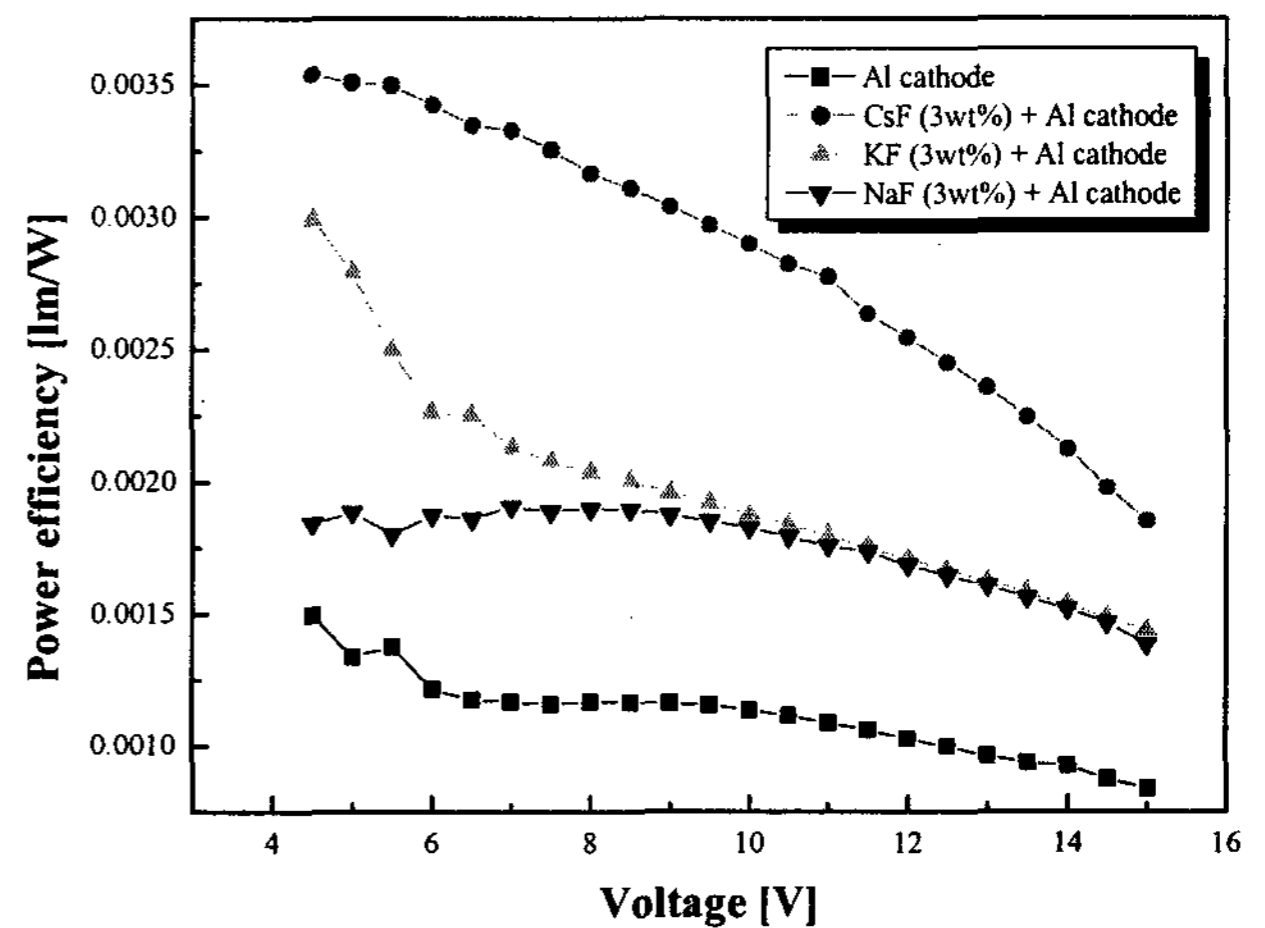


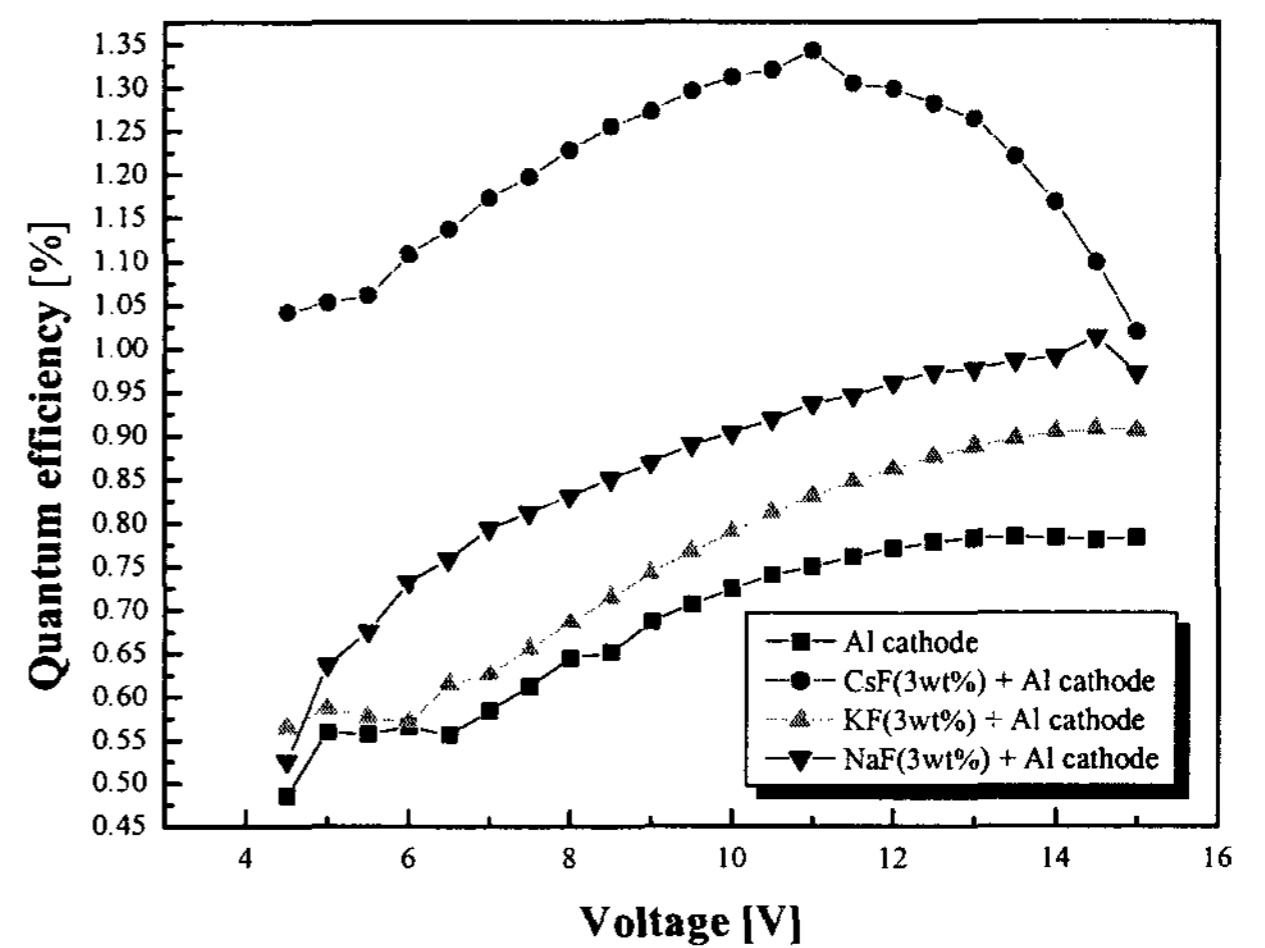
Figure 3. EL intensity of the fabricated devices: ITO/TPD/Alq₃/Al(dash line), ITO/TPD/Alq₃/Al-CsF (solid line).

3.3 Power efficiency and external Q.E.

The power efficiencies of the devices with the different cathode compositions are shown in Figure 4. Higher power efficiencies for OLEDs with co-evaporated cathodes were observed compared with devices with Al cathode. Respectively, best performance be showed the device of using alkaline metal co-evaporated cathode in current-voltage characteristic and Luminance characteristic. Using Al-CsF co-evaporation cathode, we get the highest external quantum efficiency of 1.35% at 11V. The CsF evaporated with Al, likely forming AlF₃ with the Cs-doped surface region, is likely to improve electron injection and device performance [10]. To interpret our previous enhanced electron injection by using co-evaporated cathode, we proposed that the enhancement can be attributed to lowering of the work function of the Al cathode and doping of Alq₃ with alkaline metal that was formed by the reaction with hot Al atoms impinging on alkaline material during the vapor deposition [6]. Therefore the operating voltage of the device using co-evaporated cathode is lower than that of the device of Al cathode. Not only the power efficiency, but also the stability and durability are important in their practical application of theses devices. Preliminary results show that durability was also improved by the enhanced electron injection [11].



(a)



(b)

Figure 4. (a) Power efficiencies and (b) external quantum efficiencies of the devices.

4. Conclusion

In this work, the electrical properties of the co-evaporated Al-alkaline metal cathodes of the multi-layer OLEDs have been investigated. Upon the investigations, it is revealed that co-evaporated cathodes can enhance the electron injection, improve the luminance intensity, and reduce the driving voltage of the multi-layer OLEDs. Alkaline metal tends to diffuse into organic layer and then form AlF₃ in the alkaline metal-doped surface region. And negative charges on the cathode repel electrons on Alq₃ radical anions to form neutral Alq₃ molecules

and Cs⁺(K⁺, Na⁺) cations. The depletion of electrons near the cathode results in the accumulation of the ionic space charge due to the Cs⁺(K⁺, Na⁺) cations. It could be suggested that the characteristic enhancements are attributed to lowering of the electron injection barrier of the Al cathode, and doping of Alq₃ with alkaline metal that was formed by the reaction with hot Al atoms impinging on alkaline material during the vapor deposition and forming the ohmic contact at the organic/metal interface [9]. Consequently, it is confirmed that co-evaporated cathode is suitable for enhancing the OLED performances.

Acknowledgement

This work was supported by the Korea Ministry of Commerce, Industry, and Energy.

5. References

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