

# A Study on Electron Injection Characteristics of Organic Light Emitting Diodes with Doped Cathodes of Organic Light Emitting Diodes

Yun Hee Kwak\*, Yong Soo Lee\*, Jae Hoon Park\*, Yeon Ju Kim\*, and Jong Sun Choi\*

**Abstract** - The co-evaporated cathodes composed of Al and CsF is adopted to enhance the electrical and the optical properties of organic light emitting diodes (OLEDs). The hole transport layer (HTL), made of 50nm thick N,N-diphenyl-N,N-bis(3-methylphenyl)-1,1-biphenyl-4,4-diamine (TPD), and the electron transport layer (ETL), made of 50nm thick tris(8-hydroxy-quinoline) aluminum (Alq<sub>3</sub>), were deposited under the base pressure of  $1.6 \times 10^{-6}$  Torr. In depositing Al-CsF, the mass ratio of CsF is varied between 1 and 10wt%. OLEDs with co-evaporated cathodes have luminance of about 35,000cd/m<sup>2</sup>, and external quantum efficiency of about 1.38%. Cs tends to diffuse into the organic layer and then reforms Cs<sup>+</sup> cation and free electron with the Cs-doped surface region.

**Keywords:** OLEDs, Co-evaporated cathodes, CsF

## 1. Introduction

The organic Electroluminescence (OEL) display technology has many advantages over other types of flat panel displays. The performance of OEL devices is critically dependent on the efficient injection of electrons from the cathode into the organic semiconductor. To enhance electron injection, the use of low-work function metals and alloys is effective because of their low barrier heights against electron injection [1-3]. However, OLEDs using low work function cathodes have some problems such as inferior stability [4]. As in buffer layers, a steep electrical potential change near the electrode surface is necessary for enhancing charge injection by decreasing the tunneling barrier thickness [5-6]. Recently, Kido and Matsumoto observed that the Li-doped Alq<sub>3</sub> at the cathode interface was effective for lowering the driving voltage and increasing EL efficiencies [6-7]. These results are attributed to the higher conductivity of the Li-doped Alq<sub>3</sub> 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 controlling the thickness of insulating alkaline metals and reproducing the inserting thin layer process is difficult.

In this study, the OLEDs with co-evaporated cathode structure of CsF and Al were adopted to investigate the performance enhancement. CsF can be thermally deposited

at a lower temperature than can LiF, and the use of CsF can be expected to prohibit the heat exposure of the organic layers during the evaporation of cathode metals [8]. The co-evaporated cathodes have been confirmed to improve the device performance of the OLEDs.

## 2. Experimental Details

Glass substrates coated with ITO (the sheet resistance of  $20 \Omega$  /square) were cleaned in an ultrasonic bath of acetone, followed by isopropyl alcohol, and then Deionized water. The fabricated devices have a double layer structure, which consists of a hole transport layer (HTL) and an electron transport layer (ETL). The 50nm thick TPD (HTL) and the 50nm thick Alq<sub>3</sub> (ETL) were deposited under the base pressure of  $1.6 \times 10^{-6}$  Torr. In depositing the Al-CsF composite contacts, the mass ratio of CsF was varied from 1 to 10wt%. The device structures are schematically presented in Fig. 1. The current-voltage characteristics of the EL devices were measured using a Keithley 238 unit at room temperature under ambient atmosphere.

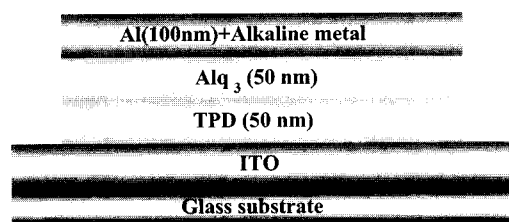


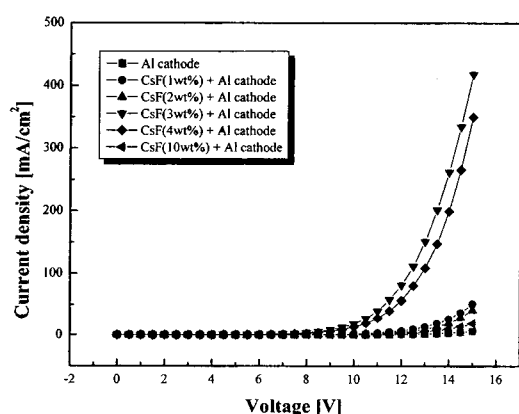
Fig. 1 Configuration of the fabricated organic light-emitting device.

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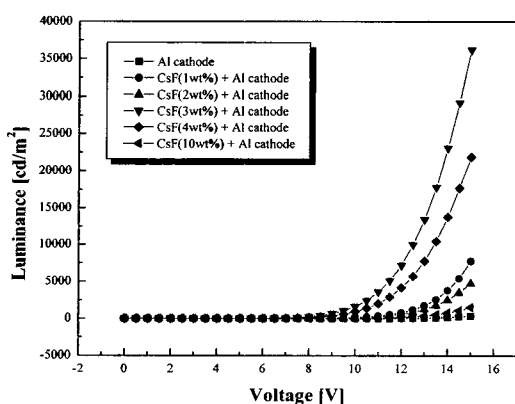
### 3. Results and Discussions

The current density and luminance intensity of the devices with different cathode compositions are shown in Fig. 2. The devices with co-evaporated cathodes show superior performance to the device with the Al cathode. The device with the Al-CsF (3wt%) cathode shows the best performance with the lowest turn-on voltage. Greczynski reports that Cs atoms evaporated onto Alq<sub>3</sub> uniformly diffuse into Alq<sub>3</sub> layer, and the Fermi level of Alq<sub>3</sub> moves towards its LUMO level [9]. The depletion of electrons near the cathode results in the accumulation of the ionic space charge of Cs<sup>+</sup> cations. The extent of the effectiveness of the alkaline salts for co-evaporated cathodes depends on the order of the decrease in the barrier heights against the electron injection into the ETL [6].

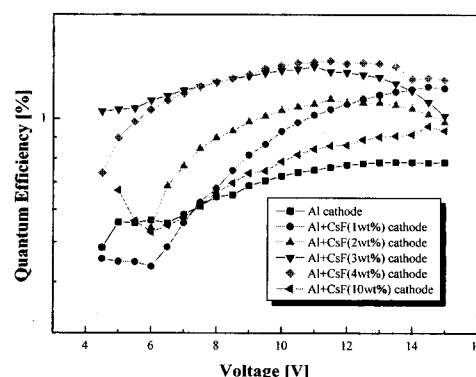
The device with the co-evaporated Al-CsF (3wt%) cathode has the luminance of 10,000 cd/m<sup>2</sup> at a 100mA/cm<sup>2</sup>. As compared in Fig. 3, a significant difference in luminance intensity exist between the device with the Al cathode and the device with the Al-CsF (3wt%) cathode.



**Fig. 2** Current density vs. voltage characteristics of OLEDs with co-evaporated CsF-Al cathodes of various CsF contents.



**Fig. 3** Luminance vs. voltage characteristics of OLEDs with co-evaporated CsF-Al cathodes of various CsF contents.



**Fig. 4** External quantum efficiency of OLEDs with coevaporated CsF-Al cathodes of various CsF contents.

Higher power efficiencies were also observed for OLEDs with co-evaporated cathodes compared with devices using Al cathode as shown in Fig. 4. The highest external quantum efficiency of 1.38% was obtained from the device with co-evaporated Al-CsF (4wt%) at 11 V. Jabbour reports that the CsF evaporated with Al, forming the Cs-doped surface region within the Alq<sub>3</sub> layer improves electron injection and device performance [10]. Therefore the operating voltage of the device with a co-evaporated cathode is lower than that of the device with a Al cathode. Ganzorig shows that durability was also improved by the enhanced electron injection [11], which is important in their practical application of these devices along with their stability.

Two electron-only devices were fabricated to study the Alq<sub>3</sub>-cathode interface properties: Mg:Ag/Alq<sub>3</sub> (50nm)/Al (Device 1) and Mg:Ag/Alq<sub>3</sub>(50nm)/Al-CsF (3wt%) (Device 2). The device structures are shown in Fig. 5. The I-V characteristics of the devices are presented in Fig. 6. Device 2 has higher conductivity (0.26 S/m) than Device 1(34.84 S/m) The displayed equation was used to estimate the effective trap density in the Alq<sub>3</sub> and Alq<sub>3</sub>-cathode interface [13]:

$$V_{\Omega} = \frac{qd^2 H_b}{\epsilon} \left( \frac{n_0}{N_c} \right)^{1/1} \left( \frac{l+1}{l} \right) (l+1)^{2l+1} l^{l+1/1}$$

where  $V_{\Omega}$  is the set-on voltage for the transition from ohmic to space-charge limited conduction,  $q$  is the electronic charge,  $d$  is the thickness of Alq<sub>3</sub> layer,  $H_b$  is the density of traps,  $\epsilon$  is permittivity of Alq<sub>3</sub>,  $n_0$  is the density of thermally generated free carriers,  $N_c$  is the LUMO density of states of Alq<sub>3</sub> and  $l$  is the characteristic constant of the distribution ( $T_c$ ) over temperature ( $T$ ). The trap density of Device 1 was calculated as  $3.27 \times 10^{19} \text{ cm}^{-3}$ , while that of Device 2 is  $8.66 \times 10^{18} \text{ cm}^{-3}$ . The higher conductivity of Device 2 may be attributed to Cs atoms' diffusing into and filling up the traps of Alq<sub>3</sub>. To understand the overall reactions at the interface, which are still considerably exother-

mic and consistent, readers can refer to Mason's work [12]. CsF molecules undergo decomposition when they contact hot Al atoms during evaporation. The energy level of the Alq<sub>3</sub> layer depends on the quantity of cesium's diffusion into the Alq<sub>3</sub> layer. The diffusion depth of Cs into Alq<sub>3</sub> is about 25nm in Fig. 7. The contact formed at the organic/cathode interface becomes ohmic. As a result, the device with the co-evaporated cathode has enhanced electrical properties [8].

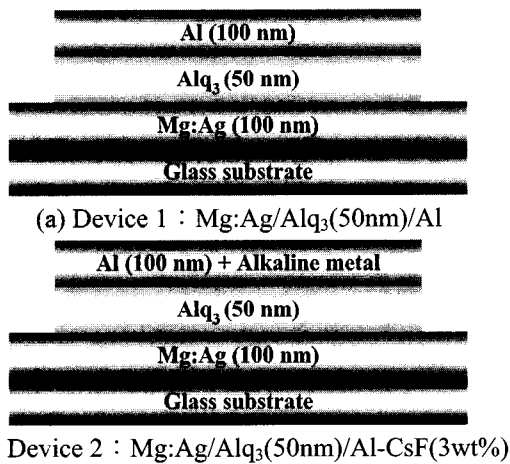


Fig. 5 Configuration of the devices with a single Alq<sub>3</sub> layer.

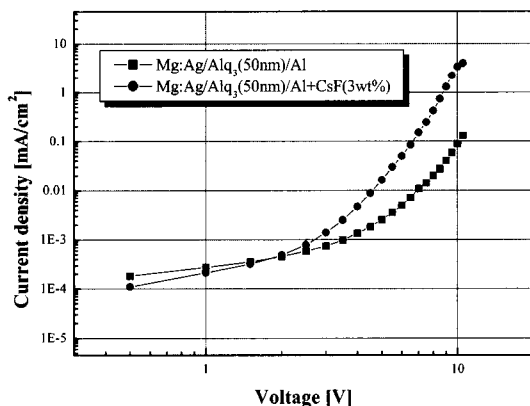


Fig. 6 The current density vs. voltage of Device 1 and Device 2 in Fig. 5.

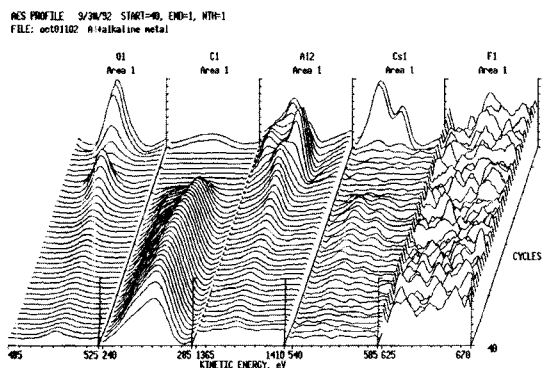


Fig. 7 AES characteristic.

## 4. Conclusion

In this work, the electrical properties of the co-evaporated cathodes of the multi-layer OLEDs have been investigated. Upon the investigations, the co-evaporated cathodes are found to enhance the electron injection and improve the luminance intensity. Cs atoms tend to diffuse into Alq<sub>3</sub> and then reform the Cs-doped Alq<sub>3</sub> region. The depletion of electrons near the cathode results in the accumulation of the ionic space charge due to the Cs<sup>+</sup> cations. The contact formed at the organic/cathode interface becomes ohmic [9]. Consequently, the co-evaporated cathode is confirmed to be suitable for enhancing the OLED performances.

## Acknowledgements

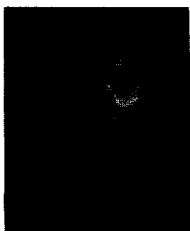
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