# Enhanced efficiency of organic light-emitting diodes by doping the electron-transport layer

**Hyun Koo Lee***
**Dept. of Electrical Engineering and Computer Science, Seoul National University, Seoul, Korea**
**Do Sung Kwon, Chang Hee Lee**
**Dept. of Electrical Engineering and Computer Science, Seoul National University, Seoul, Korea**

## Abstract

*We present that the electroluminescence (EL) efficiency can be improved by doping an electron transport layer (ETL) with organic materials which can make electron current increase. The electron transport layer of aluminum tris(8-hydroxyquinoline) (Alq3) is doped with 2-(4-Biphenylyl)-5-(4-tert-butylphenyl)-1,3,4-oxadiazole) (butyl-PBD) to enhance the electron mobility of the ETL. The higher quantum efficiency of device having ETL using Alq3 doped with butyl-PBD can be attributed to the improved electron and hole balance.*

## 1. Introduction

Since the invention of efficient organic light emitting diode (OLED),[1] there are many studies to increase the efficiency of OLED. One way to increase the efficiency of OLED is to keep the balance of electrons and holes.[2-4]

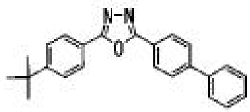
Basically, the operating mechanisms of OLED involve injection of electrons and holes to the organic emitter layers from the electrodes, and hole-electron recombination which generates molecular excitons.[5] Therefore, the balance of electrons and holes injected from electrodes is important for improving high recombination efficiency. One way to achieve the balance of electrons and holes is to control the mobility of electrons and holes.

Generally, the electron mobility is smaller than the hole mobility in organic material.[5] Thus, the hole current is larger than the electron current in OLED, causing the unbalance of electron and hole concentrations. We think that increase of electron mobility will improve the recombination efficiency.

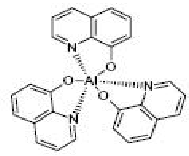
Alq3 is generally used for ETL.[6] However, the electron mobility of Alq3 is quite low, about $10^{-6}$ $cm^2/Vs$.[7] Butyl-PBD is well-known to have good electron transport property[8] and its electron mobility, about $10^{-5}$ $cm^2/Vs$,[9] is higher than Alq3's mobility. So it may be possible to increase the electron mobility of the ETL by doping butyl-PBD into Alq3 layer. We found that the EL efficiency is improved by doping Alq3 with butyl-PBD.

## 2. Experimental

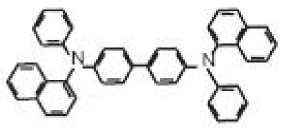
In our experiment, four green devices have been fabricated. First device is a standard green device without doping. Other devices are green devices



**butyl-PBD**



**Alq3**



a - **NPD**


**Figure 1. The material and device structure (doping concentration x varies 0, 25, 50, 100).**

*Corresponding author E-mail address: lhk108@snu.ac.kr

doped with butyl-PBD. The concentration of butyl-PBD is 10%, 25%, 100% for device, respectively.

The molecular structure and detail device structure is shown in figure 1. PEDOT:PSS[10] which was coated on the precleaned ITO glass substrate by spin coating process was used as the hole injection layer, α-NPD[11] as the hole transport layer, Alq3 as the emitting layer, butyl-PBD doped Alq3 as the electron transport layer and LiF[12]/Al as the cathode. Devices were fabricated under the base vacuum of about $3\times10^{-6}$ Torr by thermal evaporation. The active area of the EL device, defined by the overlap of the ITO and the cathode electrodes, was 1.96 $mm^2$. The current-voltage-luminance characteristics of the devices were measured with a calibrated silicon photodiode and photomultiplier tube (PMT) using a computer-controlled dc source (keithley 236 source measure unit).

## 3. Results and discussion

We compared the current-voltage-luminance (I-V-L) characteristics and the EL efficiency of the ETL doped devices with the undoped device.

Figure 2 shows the EL spectra of the devices with

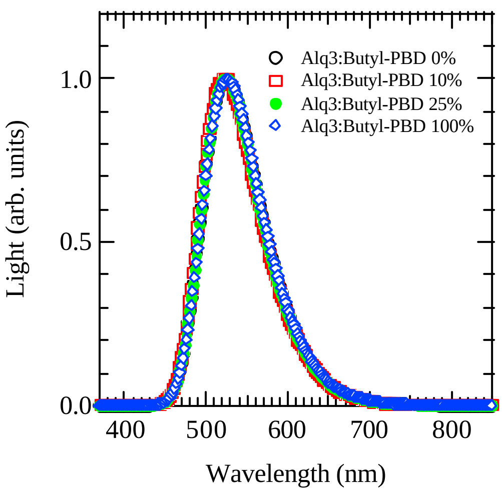



**Figure 2. EL spectra of the devices with different butyl-PBD concentration at a constant current density of about 20 $mA/cm^2$.**

different butyl-PBD concentration at a constant current density of about 20 $mA/cm^2$. The EL spectra are the same as the undoped device. Therefore, the butyl-PBD doping in the ETL layer doesn't affect the EL spectrum of the device and the light emission occurs from the recombination of electrons and holes in Alq3 layer.

Fig. 3 shows the current-voltage (I-V) and luminance-voltage (L-V) characteristics for the devices with various butyl-PBD doping ratios in Alq3 at room temperature. The current at low bias voltage, which is dominated by the hole current, is similar for all devices.

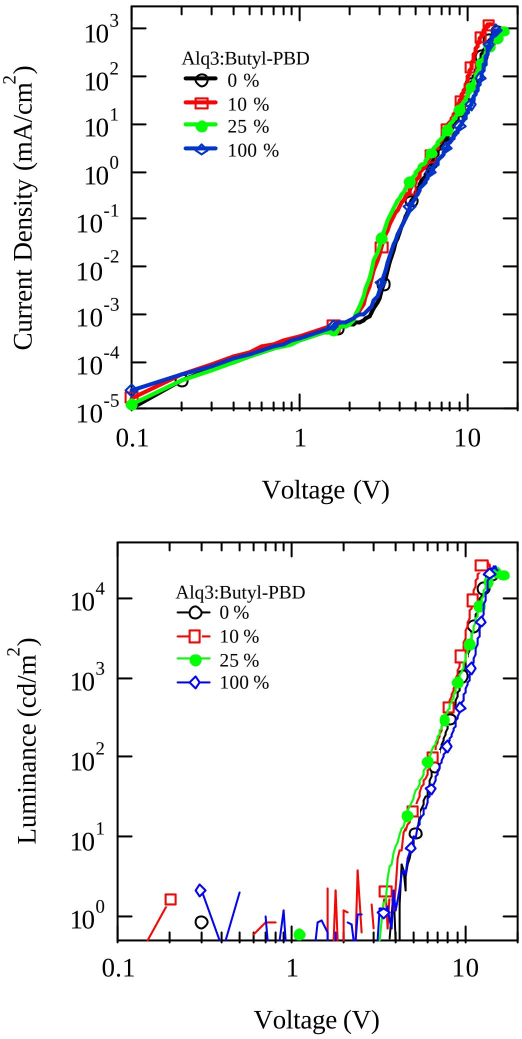



**Figure 3. The current-voltage (I-V) and luminance-voltage (L-V) characteristics for the devices with various butyl-PBD doping ratios in Alq3 at room temperature.**

However, the turn-on voltage ($V_{on}$) for light emission decreases and the current above $V_{on}$ is higher for the devices with butyl-PBD doped Alq3. This result implies that the electron current increases by doping the Alq3 layer with higher electron mobility material of butyl-PBD[9].

Figure 4 compares the external quantum efficiencies (QE) of devices with doped ETL and the undoped ETL. The external QE of devices with doped ETL are higher than the undoped device regardless of doping concentration. The highest QE is obtained with 25 % butyl-PBD ratio to Alq3. The enhanced QE is attributed to the improved electron and hole balance[2-4] for the doped ETL devices.

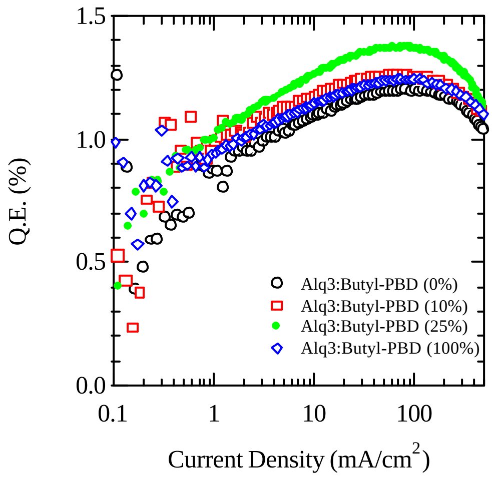



**Figure 4. The external quantum efficiency of each device.**

## 4. Conclusion

The balance of holes and electrons[2-4] is considered to be one of the important factors that determine the external quantum efficiency of OLEDs. Here, we have showed ETL doping which can efficiently control the electron mobility in order to achieve a hole-electron balance. Improvement in the hole-electron recombination efficiency of the device with butyl-PBD doped Alq3 ETL was demonstrated by the high external quantum efficiency compared to that of undoped device. Under our experimental conditions, the device with 25 % butyl-PBD doped ETL has the highest external quantum efficiency.

## 5. Acknowledgements

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