

## Improvement In recombination at a two-emission-layers interface For White-light-emitting organic electroluminescent device

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### Abstract

In order to realize full color display, two approaches were used. The first method is the patterning of red, green, and blue emitters using a selective deposition. Another approach is based on a white-emitting diode, from which the three primary colors could be obtained by micro-patterned color filters. White-light-emitting organic light emitting devices (OLEDs) are attracting much attention recently due to potential applications such as backlights in liquid crystal displays (LCDs) or other illumination purposes. In order for the white OLEDs to be used as backlights in LCDs, the light emission should be bright and have Commission Internationale d'Eclairage (CIE) chromaticity coordinates of (0.33, 0.33). For obtaining white emission from OLEDs, different colours should be mixed with proper balances even though there are a few different methods for mixing colors. In this study, we will report a white organic electroluminescent device using exciton diffusion length concept.

### 1. Introduction

Wide viewing angle, fast response, low power consumption, and the possibility of wide application has spurred interest in organic light emitting diodes (OLEDs) [1-3]. Since an organic light emitting was reported first by Tang and Vanslyke in 1987 [4], it has become an active field of research [5-7]. Several studies have been reported on white organic electro luminescent (EL) devices [1-8].

Two methods to modify the spectral characteristics of an OLED in order to achieve white emission have been demonstrated [9-11]. First, doping the emission layer with a luminescent dye as a dopant can result in energy transfer from the host to

the dopant or carrier trapping at the dopant site. This energy transfer is always incomplete and the incomplete energy transfer can then result in light emission from both the host and the dopant. This technique has been used to obtain white light emission from small-molecule-based multi-layer devices comprising two or three different layers, each emitting one color or a combination of three primary colors. Second, sandwiching a layer that preferentially blocks one type of carrier between the hole-transporting layers (HTL) and electron-transporting layers (ETL) can control the spatial location of the exciton recombination zone in order to achieve the white emission via direct color mixing [12]. It has been demonstrated to be possible to mix the different colors to generate white emission via controlling the thickness of the blocking layers, because it could change the spatial distribution of carriers across the blocking layers. Using three different color-emitting layers for the white emission is somewhat straightforward even though the structure should be more complicated. A pioneering work for obtaining the white emission has been first published by Kido *et al.* [7]. Recently, an improved method for the white-light emission was reported by Deshpande *et al.* [8]. They concluded that energy transfer occurs in a sequential manner between species in different layers across the thin hole blocking layer, so called, interlayer sequential energy transfer. In the studies using three different color emitting layers, the emitting color was tuned to white by controlling both the thickness of the blocking layer and the concentration of dopant. Therefore, the structure should be considered to not only use the carrier-blocking layer, but also the incompleteness of energy transfer between the host and dopant. But, using the

blocking layer has a drawback that it blocks the movement of carrier to reduce the power efficiency of the device.

In this experiment, we fabricated the white-light-emitting OLED using two methods. First is method by control the thickness of emitting-layer aside of electron transport layer to use an advantage of career trapping utility of rubrene. Second is the method by control the thickness of near emitting-layer from the hole-transport-layer to use exciton diffusion length concept.

In our previous work, we demonstrated white-light-emitting device with two emission layers. But this device has two problems. The first is low power efficiency. It cause by inserting of career blocking layer. Career blocking layer have role of energy barrier. In order to increase of power efficiency, we fabricated the devices without blocking layer. The second is hardship of control of doping rate and doping uniformity. In usual instance,, very small amount of dopant was used as compared to that of host materials. Therefore, there could be a lot more chance for the experimental errors to come in. So, we will propose the method to make white-light-emitting OLED without blocking layer and doping of dopant in this experiment that

## 2. Experimental

ITO-coated glass having a sheet resistance of  $10 \Omega/\square$  and 150nm thick, was cleaned by wet-cleaning method and photo-lithographically patterned to form the transparent anode. The wet cleaning method included sonification by de-ionized (DI) water, degreasing by flushing in warm TCE, rinsing in acetone and methanol, and finally rinsing in DI water. On top of the anode a buffer layer of phthalocyanine copper complex (CuPc) was deposited by vacuum sublimation in order to enhance the hole injection from the anode. We used 4,4'-bis[N-(1-naphthyl)-N-phenyl-amino]biphenyl ( $\alpha$ -NPD) as the HTL instead of TPD of which the glass transition temperature ( $T_g$ ) is about  $36^\circ\text{C}$  lower than  $\alpha$ -NPD ( $96^\circ\text{C}$ ). The low molecular weight organic materials used in this study were 4,4'-bis(2,2-diphenyl-ethen-1-yl)-biphenyl (DPVBi) as a blue emitting material, 5,6,11,12-tetraphenylnaphthacene (Rubrene) as a orange emitting material. A reason why we select DPVBi and rubrene-doped Alq<sub>3</sub> as emissive materials is that direct mixing of the two colors emitted from those materials could produce white emission at a certain balance. As

an ETL, Alq<sub>3</sub> was used on top of the emissive layers. All the organic layers were thermally deposited with an approximate growth rate of  $1\text{-}2\text{\AA}/\text{s}$ . For a cathode electrical contact, Al-LiF was finally capped over the organic layers that are thermally sublimated in a vacuum less than  $10^{-6}$  torr.

Current-voltage characteristics and luminescence intensity were measured with a Kethley 236 measure unit and a silicon photodiode calibrated with a luminance meter (Minolta CS-100). And electroluminescent spectra were measured with a fiber optic spectrometer (Ocean optics S2000). Current-voltage characteristics, luminance intensity and spectra were measured at the same time.

## 3. Results and discussion

The organic light-emitting-device (OLED) structures studied in this work are shown in Fig. 1 schematically.

	thickness
Cathode(Al:Li)	100nm
ETL(Alq)	50nm
Orange(Rubrene)	1nm
Blue(DPVBi)	5,7,10,15 nm
HTL( $\alpha$ -NPD)	50nm
CuPc	15nm
Anode(ITO substrate)	

Fig. 1. Structure of OLED in this report

In this experiment, we used DPVBi as blue light-emitting layer and rubrene as orange light-emitting layer. In general, it is hard to achieve the white-light-emission in case of simply arranging the emitting-layers. This is due to the mobility difference between holes and electrons.

Because of the mobility of electron is faster than mobility of hole, the recombination zone is formed at the interface between the hole transport layer and emitting layer. With the increase of the applied voltage, the electron density increases rapidly at the interface. If the incoming electron flux is much higher than the removal flux of electrons via recombination, the electrons should accumulate around the interface. When the electron density becomes too high, the electrons tend to diffuse out toward the cathode direction.

We located the two emitting layers in exciton diffusion length for achieving the balanced white-light-emitting. But the one close to the hole transport

layer should emit light more efficiently than the other layer. It can be proved experimentally by the fact that a device consisted of rubrene at the hole transport layer and DPVBi at the electron transport layer emits mostly orange light. In case of the order reversed, however, the device emits the orange and blue light at the same time.

In order to compare with the device described above, a white-light-emitting OLED was fabricated using a rubrene-doped Alq<sub>3</sub> layer instead of a thin rubrene layer.

	thickness
Cathode(Al:Li)	100nm
ETL(Alq <sub>3</sub> )	50nm
Orange(Alq <sub>3</sub> : Rubrene, 5wt%)	20nm
Blue(DPVBi)	5nm
HTL( $\alpha$ - NPD)	50nm
CuPc	15nm
Anode(ITO substrate)	

Fig. 2. Structure of OLED with dopant doping

Fig. 2 shows the device that has Alq<sub>3</sub> as host material and rubrene as a dopant for orange-light emission. For the device, it is possible to obtain white-light emission by way of controlling the thickness of DPVBi blue emitting layer. As the result, the white emission was obtained such as shown in Fig. 3.

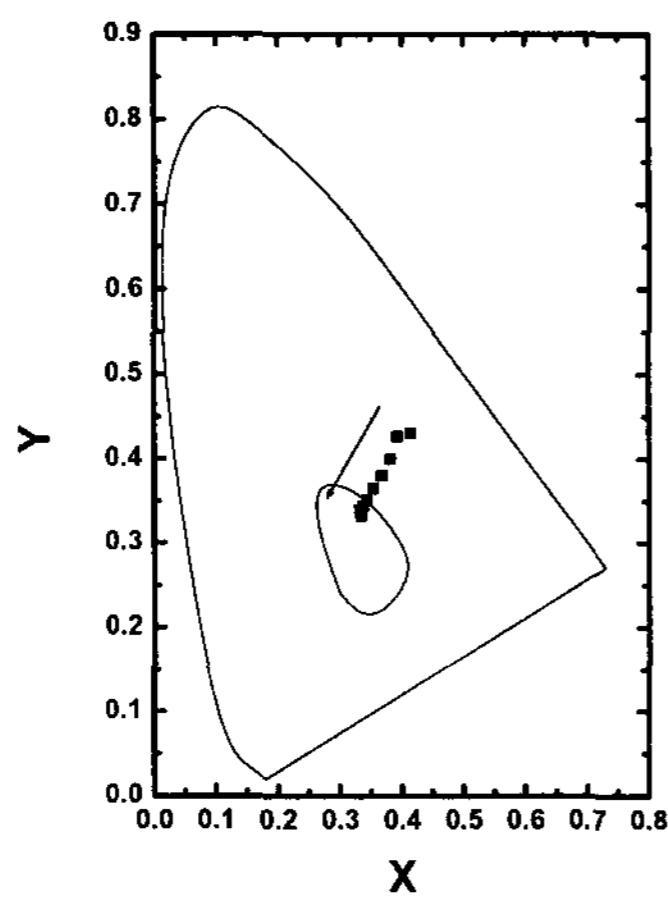


Fig. 3. CIE coordinates of OLED with dopant doping

This type of device has the inherent disadvantage of large swing on the CIE coordinate, depending on the driving voltage.

Fig. 4 shows the CIE coordinate for the emission from the devices shown in Fig.1. As

shown in the figure, the white emission can be obtained at a proper thickness ratio of the two emitting layers.

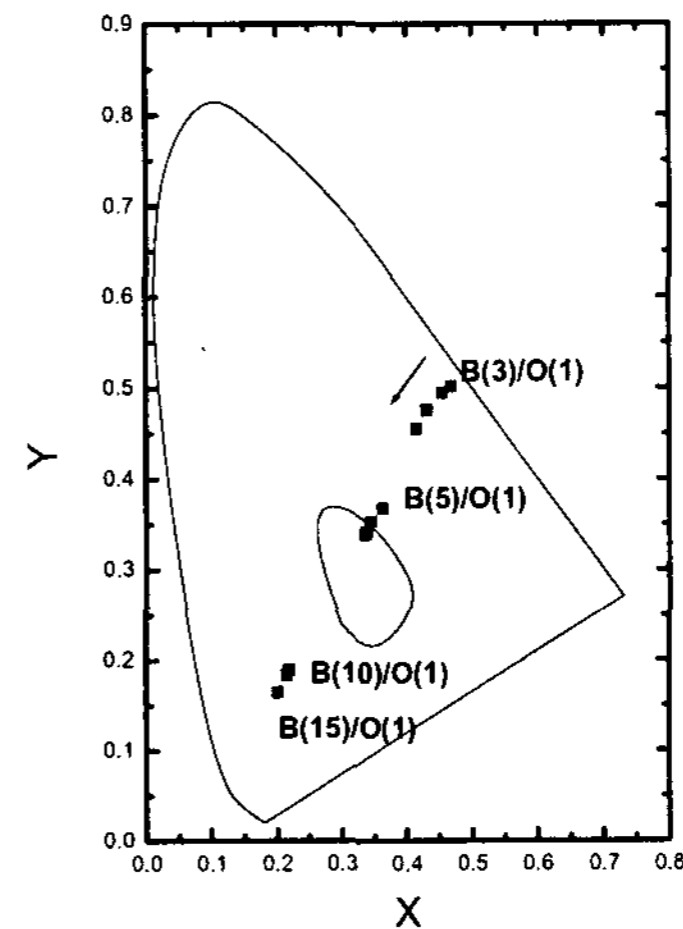


Fig. 4. CIE coordinates of OLED

The CIE coordinate is not changing as much as the device in Fig.2 as the driving voltage increases, and the variation in the coordinate decreases significantly as the thickness of blue emitting layer increases. At a suitable thickness ratio of 5:1 in thicknesses of blue and orange light emitting layers, a device emits balanced white light.

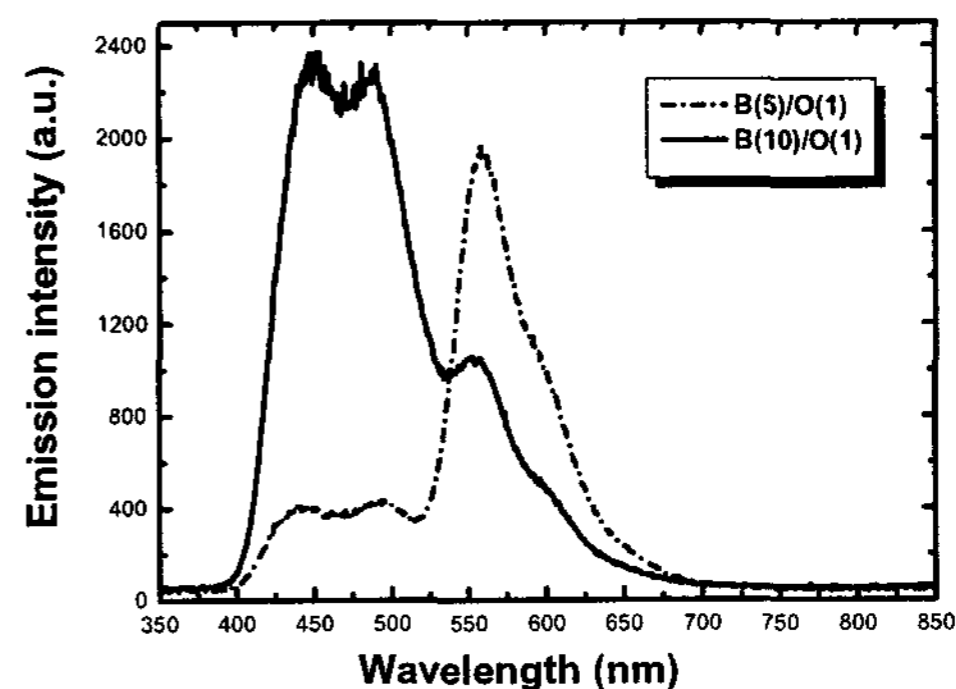


Fig. 5. Emission Spectrum of OLED

As shown in Fig. 5, the solid line represents an emission spectrum from the device that has a thicker blue emitting layer compared to an optimum thickness giving white emission. In this case most of emission comes from the blue emitting DPVBi layer and  $\alpha$ -NPD. On the other hand, when the thickness of blue emitting layer is reduced, the blue emission spectra weakens and orange light emission get stronger. At

this thickness ratio, the balanced white light can be obtained.

The efficiency of the devices was compared in Fig. 6.

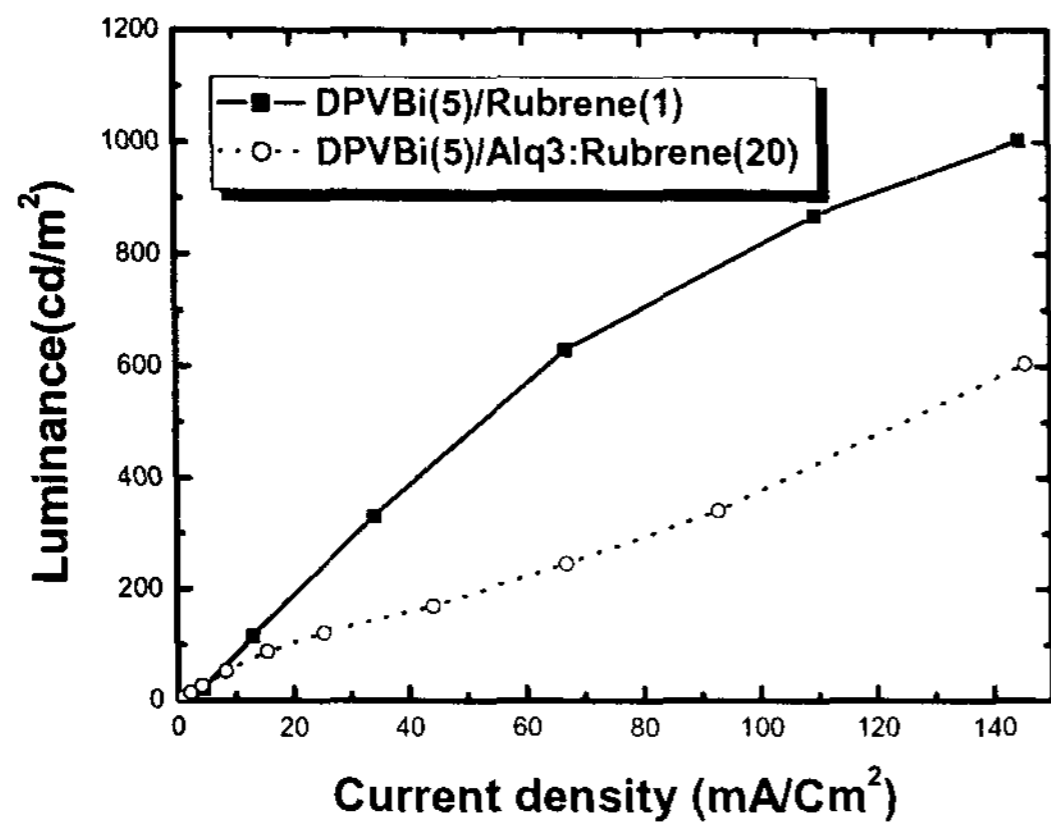


Fig. 6. Efficiency of OLED

This figure shows that the emission efficiency is much higher when the orange light-emitting material is incorporated with the device as a form of thin film, rather than being used as a dopant in a host material.

#### 4. Conclusion

In this report, we propose the structure that can emit the white-light by controlling the thickness of the emitting layer in the range less than the exciton diffusion length. And, the result was compared with a case that the same amount of orange light-emitting material is used as a dopant in a host material. It shows the proposed device has better luminescence efficiency and less variation in CIE emission coordinate depending on the driving voltage. The proposed white-light-emitting OLED shows an emission in the CIE coordinate of (0.34, 0.33) with an efficiency of 1030Cd/A at 9V.

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