Realization of improved efficient White-Organic Light Emitting Diodes with a Thin Electron Blocking Layer

Jung Soo Park[1, 2] Joo Won Lee[1], Young Min Kim[1] and Jai Kyeong Kim[1]

[1] Opto-Electric Materials Research Center, Korea Institute of Science and Technology.

Hawolgok-dong, Seongbuk-gu, Seoul, 136-791, Korea

E-mail: jspark@kist.re.kr ,Tel: 82-2-958-5773, Fax: 82-2-958-5692

Jin Jang[2]

[2] Departments of Physics, Kyung Hee University, Seoul, Korea

Byeong Kwon Ju[3],

[3] Departments of Electrical Engineering, Korea University, Seoul, Korea

Abstract

We have fabricated white organic light emitting diodes. To obtain balanced white emission and improve the efficiency of devices, thin electron blocking layer (TEBL) was inserted between the emitting layers. We showed that the effective injection of electrons through the optimization of TEBL (a -NPD) embodied the balance of spectra and had a possibility of getting white emission. In a device with 0.3 nm a-NPD, it had a maximum power efficiency of 3.80 lm/w at 250 cd/m^2, a luminance of 1200 cd/m^2 at 100 mA/cm^2 , and the CIE coordinates were (0.353, 0.357).

1. Objective and Background

As the next generation flat-panel displays, organic light emitting diodes (OLEDs) have studied. Because their several advantages such as thinness, light-weight, low driving voltage, fast response time, and the wide viewing angle. So, the application for the various displays is possible. Even from in that, white-OLEDs will be able to embody large-area and full-color display and they can also serve as a backlight of liquid crystal display (LCD) and illumination light source as the as an illuminant. White is the most important color in the lighting industry. So white-OLEDs have attracted particular attention due to their potential. A variety of methods have been proposed to achieve white emission. One approach is using a multilayer device in which three different color lights such as red, green, and blue are emitted from each layer and combined to give the white emission.[1-5] Another is use of a complementary color relation.[6] For applying white-OLEDs to general illumination light source, the white light with high efficiency, stability, high brightness, and the Commission Internationale de l'Éclairage (CIE) coordinates near (0.33, 0.33) through controlling the emission intensity for balanced emission must be required.

In this study, we have fabricated the white-OLEDs using the method of Red-Green-Blue stacked multilayer and improved the efficiencies of the devices. To obtain balanced white emission, thin electron blocking layer (a -NPD) which form interfacial barrier for controlling electron injection was inserted between the emitting layers with the knowledge of energy band diagram. Then we took control of a -NPD' s thickness and embodied balanced white emission.

2. Results

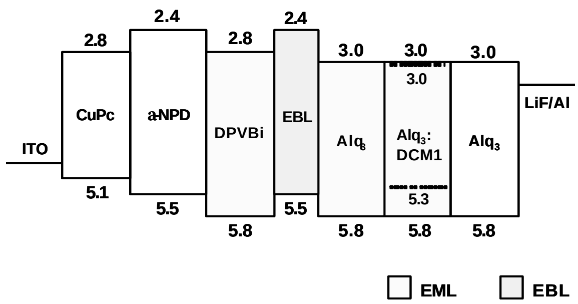


Figure 1. The schematic energy band diagram of white-OLEDs

The basic structure of the device configuration used in this study is shown in figure 1. Copper Phthalocyanine (CuPc) was used as a hole injection layer (HIL), [N,N'-di(naphthalene-1-yl)-N,N'-diphenyl-benzidine] (a-NPD) was as a hole transporting layer (HTL) and a electron blocking layer (EBL), 4,4'-bis(2,2' diphenylvinyl)-1,1'-biphenyl (DPVBi) was as a blue emitting material, tris-(8-hydroxyquinoline)aluminum (Alq_3) was as a green emitting material and a electron transporting layer (ETL). 2wt% red-emitting 4-(dicyano-methylene)-2-methyl-6-(p-dimethyl aminostyryl)-4H-pyran (DCM1)-doped tris-(8-hydroxyquinoline) aluminum (Alq_3) was as a red emitting material. A bilayer of 1 nm lithium fluoride (LiF) and aluminum (Al) was used as an efficient cathode. Light emitting area is 10×10 mm^2. In our experiment, devices stacked with RGB materials were constructed for white emission and relative contribution of red, green and blue emission can be controlled by changing the thickness of each emitting layer. The optimal thickness of each emitting layer was 7 nm so that the total thickness of three different emitting layers was 21 nm. Through the optimization of the thickness of all organic layers, white emission could be obtained. The CIE coordinates of (0.327, 0.353) were well within the white region.

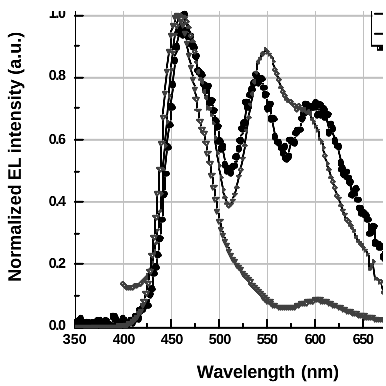
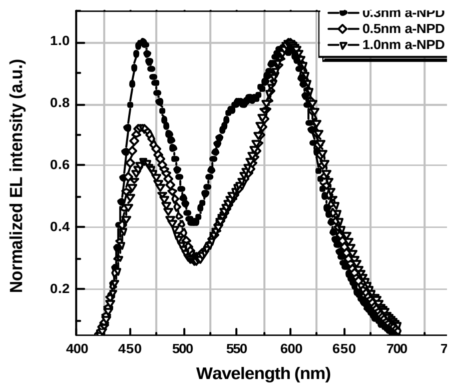
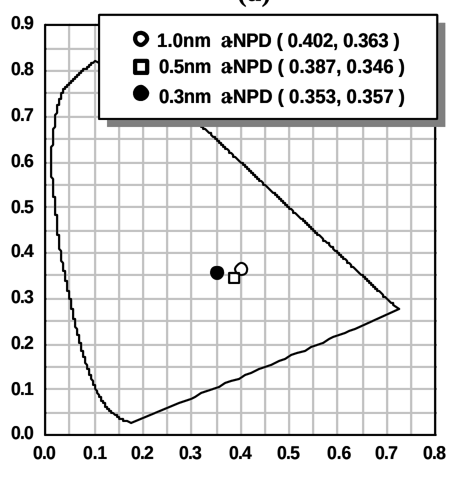


Figure 2. The normalized EL spectra of the RGB stacked OLED under different thickness of each emitting layer.

In figure 2, EL spectra showed a broadband covering the range of 400~700 nm but the red emission intensity was relatively weak compared to blue and green emission intensity. A greater contribution from the red is needed to obtain the pure white emission. Instead of increasing the red emission intensity, we reduced the contribution from blue emission. So we decided to control the blue emission peak by using the electron blocking layer in order to reduce the blue emission layer. We fabricated devices by using ITO / CuPc (3nm) / a -NPD (40 nm) / Blue (7 nm)/ a -NPD (0.3, 0.5, 1 nm) / Green (7 nm) / Red (7 nm) / Alq_3 (25 nm) / LiF:Al (150 nm) structure. To limit the electron transport into the blue-light-emitting layer, a-NPD is inserted between blue-light-emitting layer and green-light-emitting layer. Because the lowest unoccupied molecular orbital (LUMO) of a-NPD is higher than that of the blue-light-emitting layer (figure 1). As a result, electron could not easily be hopped into the blue-light-emitting layer, and recombination rate decreased inside the blue-light-emitting layer.



(a)



(b)

Figure 3. (a) The normalized EL spectra and (b) CIE chromaticity diagram under different thickness of TEBL (a-NPD).

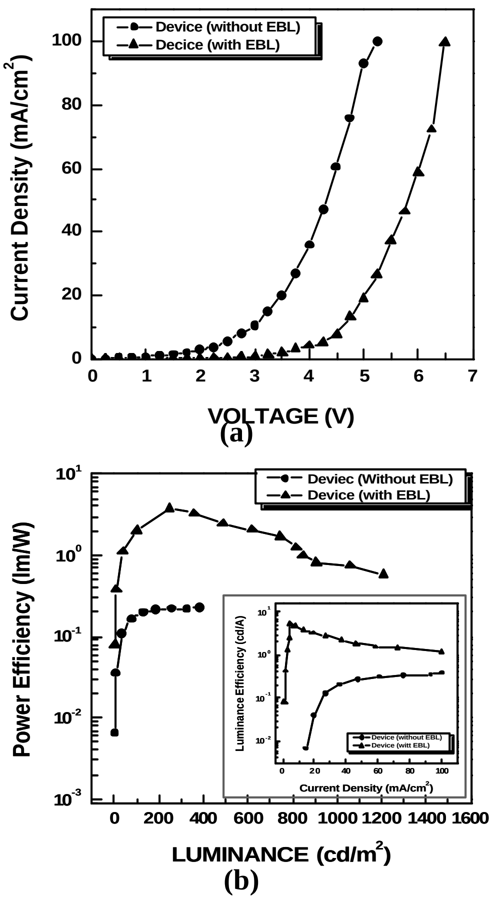


Figure 4. (a) Current density vs. applied voltage characteristics and (b) Power efficiency vs. luminance characteristics (Inset: Luminance efficiency versus current density) between the device with TEBL and without TEBL

The EL spectra of devices for different thickness of a-NPD are shown in figure 3. We observed that the blue emission intensity weakened and that emission of Alq_3 contributed to the broad tail at long wavelength region when a -NPD was inserted. As the thickness of the a-NPD layer increases from 0.3 nm to 1 nm, the blue emission intensity decreases. The CIE coordinates shift from red to white when the thickness of a -NPD was decreased. It may result from the effective trapping of electron by a–NPD, and the variation of the blue emission intensity could be understood as the result of a-NPD. That is, the thicker of the electron blocking layer, the more effective for the electrons blocked by the electron blocking layer, hence the blue emission intensity decreases.

It can be concluded that the a-NPD layer should be an effective electron-blocking layer and change the emission intensity. So the matching blue contribution relative to the red contribution can be achieved by controlling the thickness of a-NPD. From these results, we showed that the balanced white emission was tailored by using thin electron blocking layer (a-NPD) and controlling its thickness effectively.

Figure 4 shows current density (J) vs. applied voltage (V) characteristics of devices in which the electron blocking layer was inserted with 0.3 nm thicknesses and was not. Turn-on voltage increased from 3 to 3.25 V when the electron blocking layer was inserted in the device. It indicated that the current density was influenced by the electron blocking layer and that that a-NPD effectively interrupted the transport of electron. The efficiency was influenced by the electron blocking layer too. The device without the electron blocking layer had a maximum power efficiency of 0.2~0.22 lm/w at 142~255 cd/m^2, a luminance of 300~400 cd/m^2 at 100 mA/cm^2 but in a device with 0.3 nm a -NPD, it had a maximum power efficiency of 3.80 lm/w at 250 cd/m^2, a luminance of 1200 cd/m^2 at 100 mA/cm^2. It closely matched the CIE coordinates (0.353, 0.357) of balanced white emission.

3. Conclusion

We have demonstrated high-efficient white-OLEDs using thin electron blocking layer (a -NPD). TEBL played an important part in controlling the balanced emission. As the thickness of the electron blocking layer increases, the blocking of the electron happens effectively, hence emission intensity decreases. We showed that controlling the thickness of thin electron blocking layer (a-NPD) results in effective control emission intensity and the possibility of making the balanced white emission. TEBL will be a good means to obtain balanced emission and realize high-efficient white-OLEDs.

References

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