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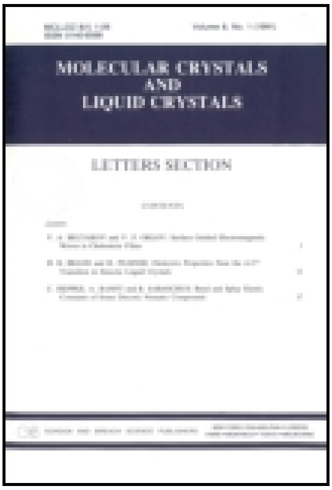

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A Comparative Study on the Optical Properties of Single-Layered White OLED Based on Multi-Host, Dopant System

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Two color white EML is proposed by using blending and spin-coating method through a co-host/dopant system. Device performances were systematically compared based on the optical property of with/without interlayer PVK. When 1-[1,1';3',1"]Terphenyl-5'-yl-6-(10-[1,1′;3′,1′′] terphenyl-5′-yl-anthracen-9-yl)-pyrene (TP-AP-TP) is a blue emitter with high luminance and external quantum efficiency, NPB is used as a co-host material which has HTL property and wide band gap like a blue emitter. DPAVBi and Rubrene were each used as blue dopant and yellow dopant. Luminance efficiency of the device used interlayer was 4.31cd/A, a value 30% higher than without interlayer (3.31 cd/A) at 10 mA/cm^2.

Keywords white organic light-emitting diodes; WOLEDs; co-host; solution process

Introduction

Organic light emitting diodes (OLEDs) are optoelectronic devices based on the photoluminescence (PL) properties of π-conjugated organic materials that are used in mobile displays and are expected to be useful in future flat panel displays as well as lighting applications. As for white OLED (WOLED), since Kido and his team at Yamagata university fabricated emitting layers (EML) with red, green, and blue light emitters and reported a white light emitting property in 1995, much research has been conducted to develop materials and devices that have high efficiency, long life and excellent color purity[1]. In particular, it is expected that WOLED is applied to full-color displays, illuminators, backlights, and opto-electronic devices [1–3].

It is possible to fabricate WOLED by using vacuum evaporation or solution process. With the vacuum evaporation method, it is available to realize high color purity by using the multi-layered structure. But evaporation method involves drawbacks such as high process cost, difficulties in large scaling, and difficulties in adjusting doping concentration [4, 5]. Thus, in order to solve these disadvantage, solution process method for WOLED such

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as spin-coating, ink-jet printing and nozzle printing is being considered and developed. However, the solution process method also has the difficulties; in case of fabrication of a multi-layered structure, the previous layer can be removed due to the solvent of next layer. In order to overcome the disadvantages of solution processed OLED introduced above, methods such as reducing solubility by adding a crosslinkable unit to material and using HTL or ETL soluble in water / alcohol have recently been attempted. Among these methods, the methods of developing crosslinkable unit in material or water / alcohol material have difficulty in designing and synthesizing molecules [6, 7]. Recently, studies that obtain high efficiency of single layer through simple blending of hole / electron transporting material or host material with different properties in the EML layer are being actively conducted [8]. However, there is lack of systematic studies on the host materials. Accordingly in this study, as for new dual core chromophore, 1-[1,1′;3′,1″] terphenyl-5′-yl-6-(10-[1,1′;3′,1″]terphenyl-5′-yl-anthracen-9-yl)-pyrene (TP-AP-TP)[9] developed by our group was used as a blue emitter and the two host materials including N,N′-Bis(naphthalen-1-yl)-N,N′-bis(phenyl)-benzidine (NPB) were blended to create a co-host/dopant system. The system was manufactured by spin-coating, the representative solution method using low molecular two-color white EML. Also, device performance was systematically compared by inserting PVK as the interlayer between PEDOT:PSS, the HIL of co-host, and EML. This was intended to help understand the role of interlayer in the co-host system.

Experimental

Fabrication of OLED

Device configuration is ITO/ PEDOT:PSS (40 nm)/ interlayer_PVK (10 nm)/ TP-AP-TP + NPB + dopants (50 nm)/ TPBi (20 nm)/ LiF (1 nm)/ Al. The device was fabricated with a hybrid configuration structure which includes a solution process of HIL inter-layer(PVK) and EML(co-host) as well as a vacuum deposition process of ETL and cathode[8]. A water-dispersed PEDOT: PSS mixture (Baytron PVP CH8000, H. C. Starck GmbH) was spin-coated on top of indium tin oxide (ITO) in air to make film (40 nm). The spin-coated film was heated on a hot plate at 110 °C for 5 min. in air and 200 °C for 5 min. in nitrogen atmosphere. PVK film as an interlayer was prepared by spin coating of 1.5 wt% in 1 mL toluene solution. As for the materials used in the emitting layer, TP-AP-TP and NPB were used as host materials, 4,4′-bis[4-(di-p-tolylamino)styryl]biphenyl (DPAVBi) and (5,6,11,12)-tetraphenylnaphthacene (Rubrene) were used as blue and yellow dopants. For the host material, TP-AP-TP and NPB were mixed at the mass ratio of 60:40. For dopant materials, DPAVBi and Rubrene were mixed at 4% and 0.2% of the mass of co-host. Chlorobenzene was used as solvent. The solution-processed films were baked on a hot plate (80 °C, 30 min) in an N_2 glove box. Electron-transporting layer (2,2′,2″-(1,3,5-benzinetriyl)-tris(1-phenyl-1-H-benzimidazole), TPBi) with a thickness of 20nm was deposited by vacuum evaporation(at a pressure about 10^{-6} torr). LiF (1 nm) and Al films were sequentially deposited on the electron-transporting layer under vacuum (at a pressure about 10^{-6} torr).

Measurements

The optical absorption spectra were obtained by HP 8453 UV-VIS-NIR spectrometer. Perkin Elmer luminescence spectrometer LS50 (Xenon flash tube) was used for photoluminescence (PL) spectroscopy. The current–voltage-luminance (I-V-L) characteristics of

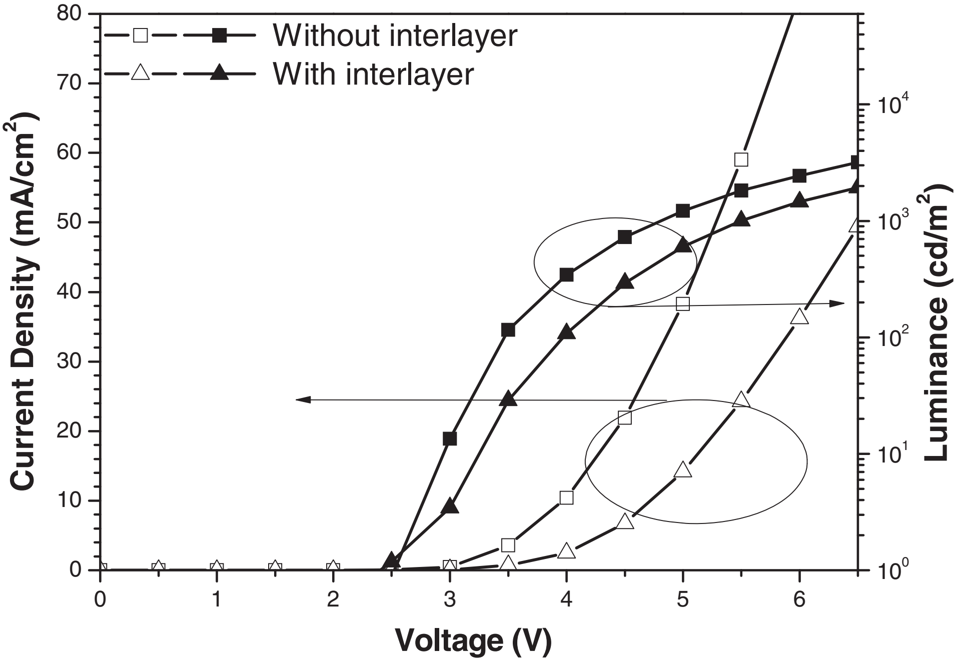


Figure 1. I-V-L characteristics of OLED devices.

the fabricated EL devices were obtained by Keithley 2400 electrometer and light intensity was obtained by Minolta CS-1000A.

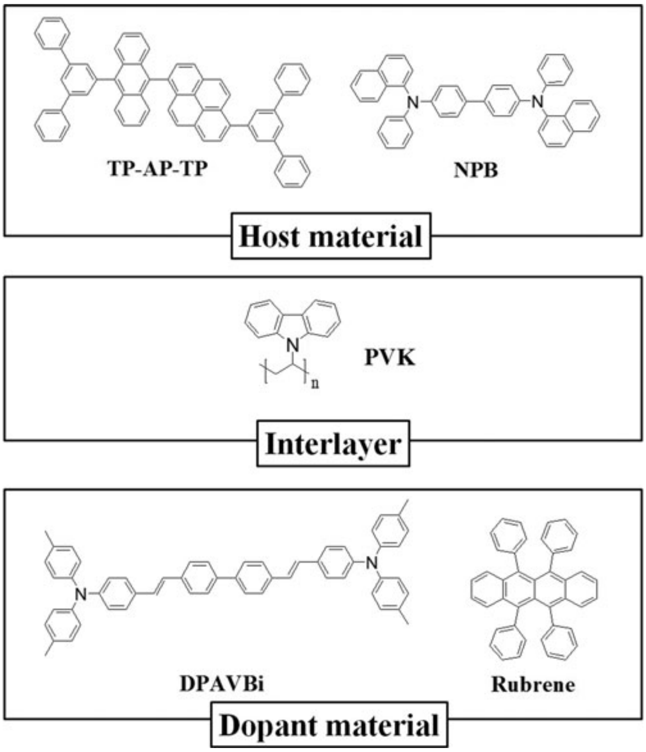
Results and Discussion

In this study, PEDOT:PSS, interlayer and emitting layer were prepared by spin-coating and ETL layer and electrode were prepared through evaporation method. As shown in Figure 1, host material of the emitting layer was a double host composed of TP-AP-TP, a blue fluorescent material with high quantum efficiency, and commercial compound NPB. DPAVBi and Rubrene were respectively used as a blue dopant and a yellow dopant. Scheme 1 and 2 show chemical structures of all materials and energy diagram in this study. The results of the OLED device with and without interlayer PVK were summarized in Table 1and Figures 1, 2, 3, and 4.

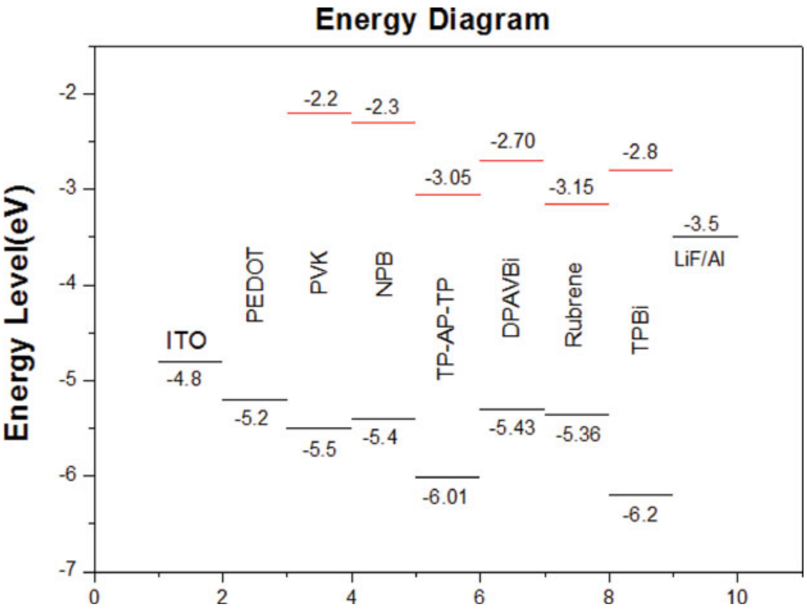
Table 1. EL performances : ITO/PEDOT (40 nm)/Emitting layer (50 nm)/TPBi (20 nm)/LiF (1 nm)/Al (200 nm) at 10 mA/cm^2

Host of Emitting Layer	Turn-on Voltage[a] (V)	Operating Voltage (V)	L. E.[b] (cd/A)	P. E.[c] (lm/W)	CIE (x, y)
With PVK	2.92	4.71	4.31	3.18	(0.37,0.46)
Without PVK	2.73	3.97	3.31	2.89	(0.36, 0.43)

a) turn-on voltage measured at 3 cd/m^2, b) luminance efficiency, c) power efficiency



Scheme 1. Chemical structures of materials.



Scheme 2. Energy diagram of the compounds.

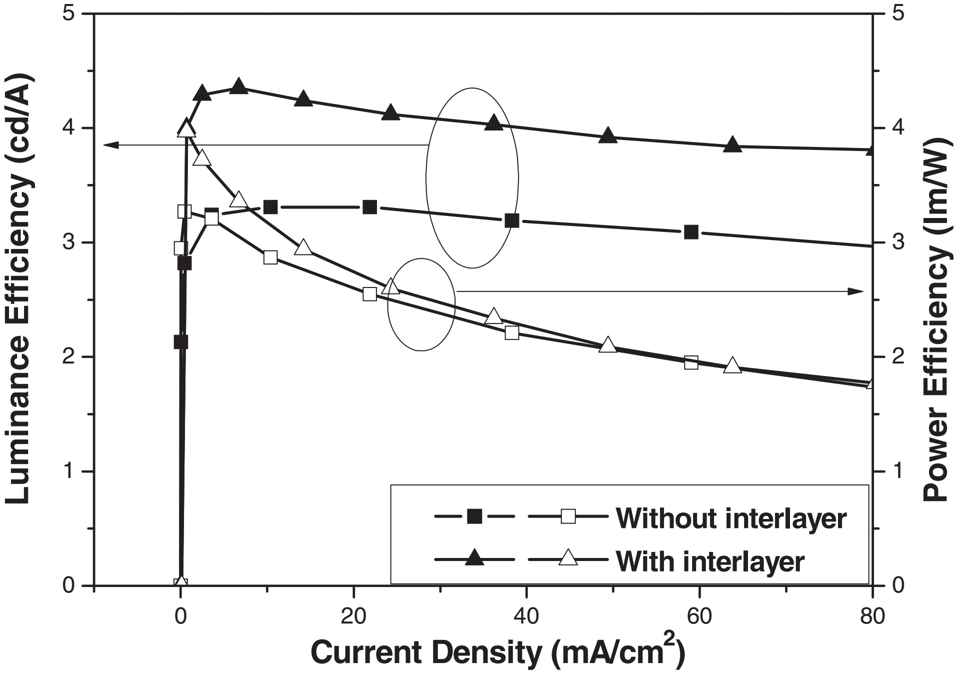


Figure 2. Luminance efficiency and power efficiency according to current density.

At first, as in Table 1 and Figure 1, turn-on voltage and operating voltage of the device that used PVK as the interlayer were 2.92 V and 4.71 V. When PVK was not used, operating voltage was about 2.73 V and 3.97 V. Though turn-on voltage was similar, operating voltage was greatly increased by insertion of the interlayer. This can be interpreted as a phenomenon which occurs due to increase in thickness of the device with insertion of the interlayer. However in case of luminance efficiency, the device using PVK as the interlayer showed efficiency of 4.31 cd/A and the device without the interlayer was 3.31 cd/A. Luminance efficiency of the device with PVK was 25% higher. PVK is well known as the buffer layers in opto-electronic devices such as OLED and OPV (organic photo-voltaic cell) [10, 11]. Accordingly, despite the fact that voltage was increased by increase in thickness, power efficiency was increased by 10% in the device with the interlayer (3.18 lm/W) compared to the device without the interlayer (2.89 lm/W). Also, CIE values of the devices with and without the interlayer were (0.37, 0.46) and (0.36, 0.42) and those are similar values. As shown in Figure 3, although the 470nm region on the EL graph was slightly reduced when the interlayer was used, CIE values were almost same.

Therefore, higher device efficiency was shown when PVK was used as the interlayer on the device. The reason for similar turn-on voltage can be explained by similar HOMO/LUMO and band gap in the device structure [12]. On top of hole transporting property, PVK is also known to help the interaction with EML (emitting layer) and HIL (hole injection layer) [13]. By inserting PVK, the phenomenon in which voltage is slightly shifted on the I-V-L graph can be verified as in Figure 1. However, as the graph of luminance efficiency and power efficiency in Figure 2 shows, the device with PVK showed higher luminance efficiency than the device without PVK. Since voltage is somewhat increased but definitely higher efficiency is shown with addition of PVK in I-V data, power efficiency

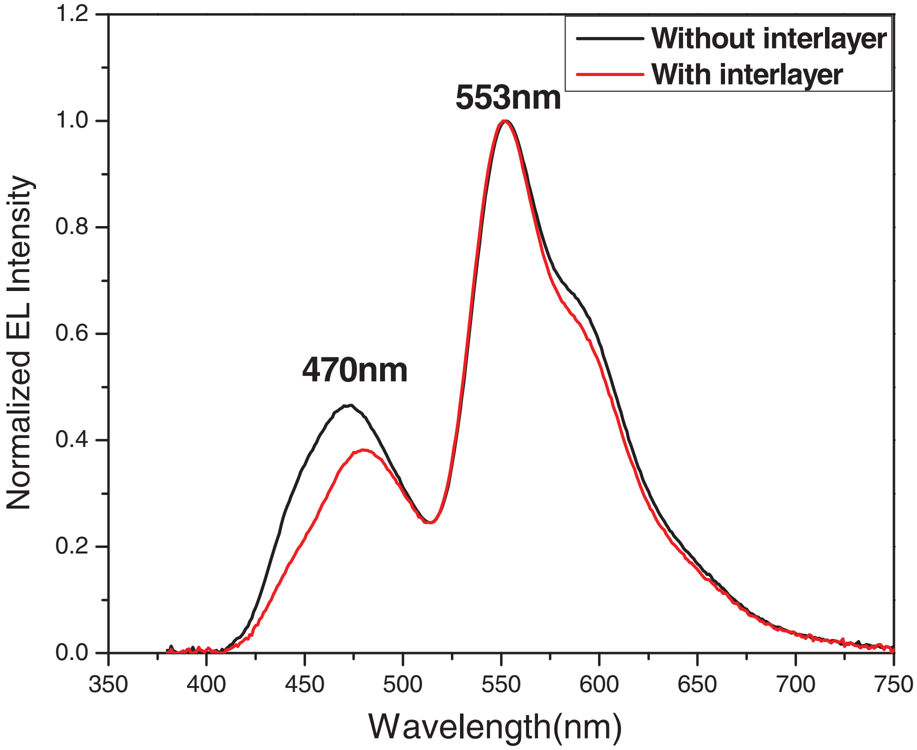


Figure 3. EL spectra of the related OLED device with/without interlayers.

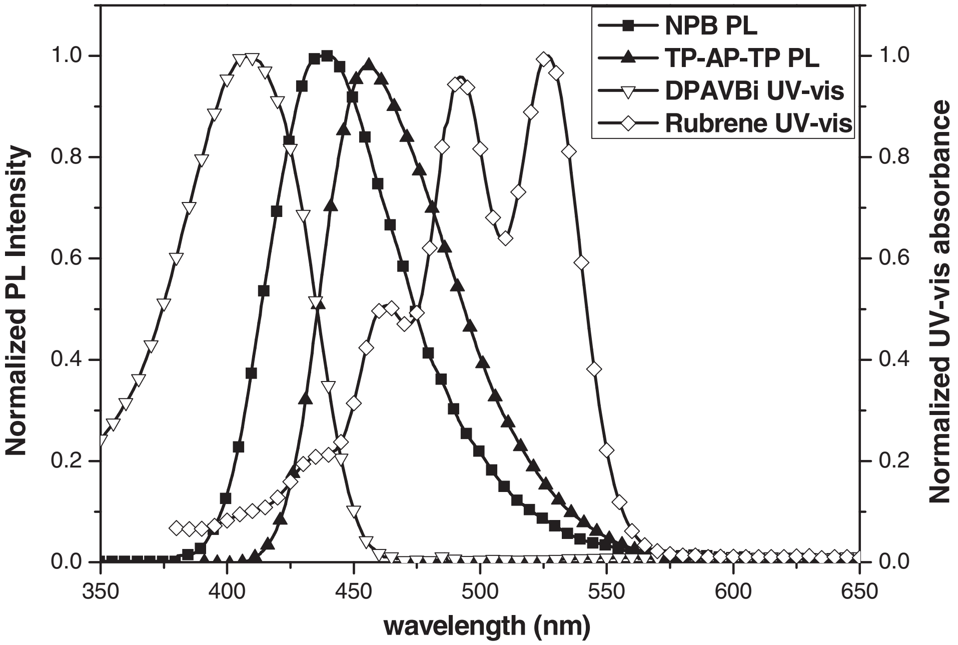


Figure 4. UV-Visible absorption of Rubrene and DPAVBi in toluene solution and PL spectra of TP-AP-TP, NPB in film states.

was increased from 2.89 lm/W to 3.18 lm/W. To explain operation of the device based on co-host, the PL spectra of the host material used in the emitting layer and the UV-visible (UV-Vis.) spectra of the dopant materials were summarized in Figure 4. As a result, PL of TP-AP-TP and NPB as the host materials and UV-Vis. of DPAVBi and Rubrene as dopants are shown. As shown in the graph, energy from the two hosts are transferred to the two dopants, namely DPAVBi and Rubrene.

Conclusions

In this study, the solution process method was used to prepare a two-color white light emitting device with PVK as the interlayer, TP-AP-TP/NPB as the co-host, DPAVBi as the blue dopant, and Rubrene as the yellow dopant. Devices with CIE values of (0.37, 0.46) and CIE (0.36, 0.43) were obtained. As a result of experiment, the device that used PVK as the interlayer showed an efficiency of 4.31 cd/A (at 10 mA/cm^2), which was 30% higher than the device that did not use PVK.

In order to explain the efficiency of the device, the PL spectra of TP-AP-TP and NPB used as the host materials and the UV absorption spectra of DPAVBi and Rubrene used as the dopants were examined. Based on this, energy transfer from TP-AP-TP and NPB to the dopants was found to be efficiently carried out. As PVK helped the interaction with EML and HIL, the device with PVK showed higher efficiency than the device without PVK.

Acknowledgment

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