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Luminescence characteristics of hybrid dual emitting layers in blue organic light-emitting diodes by controlling the fluorescent doping concentration

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ABSTRACT

We demonstrate blue organic light-emitting diodes (OLEDs) based on a host-dopant system with a dual emitting layer (EML) configuration consisting of variable concentration of fluorescent doped and fixed concentration of phosphorescent doped emitting materials. We also introduce two different device designs by switching the position of the fluorescent and phosphorescent EMLs. Because 4,4'-Bis(2,2-diphenylvinyl)-1,1'-biphenyl (BCzVBi), which is the blue fluorescent dopant, exhibits the highest occupied molecular orbital (HOMO) energy level compared to the neighboring layers, the fluorescent dopant is shown to strongly correlate with hole transport in the fabricated blue OLEDs. In this study, we show how the electrical and optical properties of devices are affected by different doping concentrations due to the hole-transport-related properties of dopant molecules.

1. Introduction

Ever since the first multilayered OLEDs were reported in 1987 by Tang and Van Slyke [1] OLEDs have been considered as an excellent candidate for solid-state light sources, and full color display applications [2,3] because OLEDs have several advantages such as low driving voltage, low power consumption, high contrast ratio, rapid respond time, wide viewing angle, and ultra-thin thickness [4–9]. The three primary colors, red, green and blue, are critical to creating white light sources or full color displays. There have been a variety of efficient and stable red and green emitting materials and devices reported; however, in the case of blue organic emitting materials and devices, there is still much research required to improve their luminous efficiency and color stability. To overcome the technological issues with achieving high quality blue emission, the key factors are to find the best emitting material with a wide energy gap and perfectly matched host and dopant materials with a large triplet energy state to prevent non-radiative quenching [10,11] and enhance quantum efficiency [12]. Phosphorescent materials have high efficiency; however, for blue emission, there only have been reported many non-saturated blue or sky blue devices with blue phosphorescent materials [13,14]. On the other hand, blue fluorescent materials generate better deep blue emission although they are still less efficient than phosphorescent materials due to only being able to collect singlet–singlet excitons. Therefore, with respect to these issues, further research is needed to optimize a trade-off between fluorescent and phosphorescent material characteristics. The incorporation of a host–dopant system in OLEDs has been considered one of the most important developments towards the achievement of high efficiency and the desired color [15]. The host–dopant system is capable of transferring the generated excitons to the highly emissive and stable dopant sites from the host material, which prevents non-radiative decay and improves device efficiency [16].

In this paper, we report on the design of blue OLEDs with dual EMLs by introducing fluorescent and phosphorescent dopants individually into the fluorescent and phosphorescent host materials. In addition, by switching the location of the fluorescent and phosphorescent EMLs and controlling the fluorescent doping concentration, we can investigate how the fluorescent and phosphorescent EMLs react with respect to the

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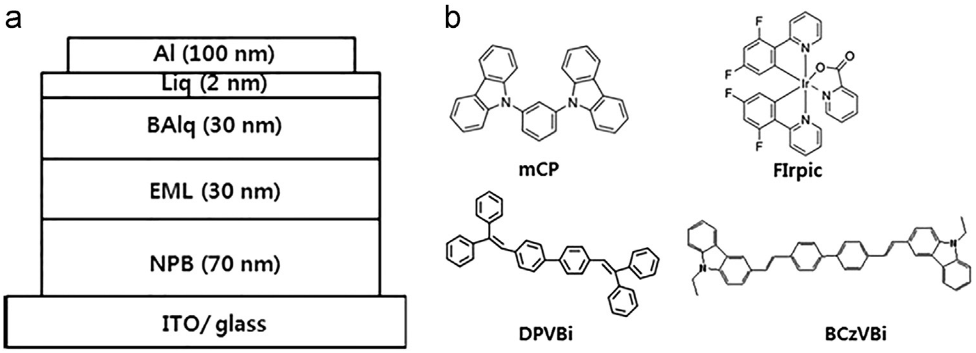

Fig. 1. Schematic diagram of the standard structure of blue OLEDs (a) and fluorescent and phosphorescent emitting materials (b).

Table 1
Device structures depending on the position of fluorescent (F) and phosphorescent (P) EMLs.

Types	Device structures	
F–P EML	ITO/NPB/DPVBi:BCzVBi (*x*%)/mCP: FIrpic (10%)/BAlq/Liq/Al	Devices A–D
P–F EML	ITO/NPB/mCP: FIrpic (10%)/DPVBi:BCzVBi (*x*%)/BAlq/Liq/Al	Devices E–H

* '*x*' indicates the fluorescent doping concentration (15%, 12%, 8% and 5%).

various fluorescent doping concentrations and how they relate to the devices' performance and more specifically, carrier transport and electroluminescence (EL) mechanisms.

2. Experiments

Prior to organic material deposition, indium tin oxide (ITO) coated glass was cleaned in an ultrasonic bath in the order of acetone, methanol, diluted water and isopropyl alcohol. Thereafter, the pre-cleaned ITO was treated by O_2 plasma under the conditions of 2.0×10^{-2} Torr, 125 W for 2 min. After oxygen plasma treatment to clean the substrate surface, the substrates were loaded into the thermal evaporator under high vacuum (1.0×10^{-7} Torr) to deposit organic thin films.

The molecular structures for the EMLs and the schematic of the standard device structure used in this study are shown in Fig. 1. As seen in Fig. 1(a), the device structures of the blue OLEDs are as follows: ITO/N,N'bis-(1-naphthl)-diphenyl-1,1'-biphenyl-4,4'-diamine (NPB) (70 nm) as a hole-transport layer (HTL)/dual EMLs/Bis(2-methyl-8-quinolinolato-N1,O8)-(1,1'-Biphenyl-4-olato)aluminum (BAlq) (30 nm) as an electron transport layer (ETL)/Lithium quinolate (Liq) (2 nm) as an electron injection layer (EIL)/aluminum (Al) (100 nm) as a cathode. The emitting region is composed of dual EMLs divided into two parts: one layer fluorescent doped and the other phosphorescent doped onto two different host materials. Each EML thickness is 15 nm. To be specific, the fluorescent EML is formed by 4,4'-Bis(2,2-diphenylvinyl)1,1'-biphenyl (DPVBi) doped with BCzVBi and the phosphorescent EML is created by 1,3-bis(carbazol-9-yl)benzene (mCP) doped with iridium(III) bis[(4,6-difluorophenyl)-pyridinato-N,C2'] picolinate (FIrpic). Depending on the position of the fluorescent and phosphorescent EMLs, we have differentiated our devices between F–P EML and P–F EML structures. The two different device structures are shown in Table 1. The BCzVBi doping concentrations used are 15%, 12%, 8% and 5% and the doping concentration of FIrpic is fixed at 10%.

With various DC bias voltages, the optical and electrical properties of blue OLEDs such as the current density, luminance, luminous efficiency, Commission Internationale de L'eclairage (CIE_{xy}) Coordinates and EL characteristics were measured with a Keithley 236, LMS PR-650 spectrophotometer and colorimeter and the IVL system, respectively.

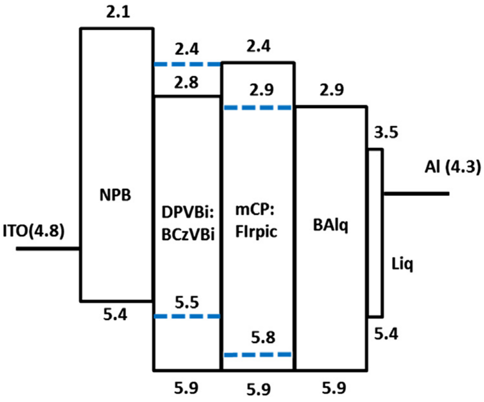

Fig. 2. Energy level diagram of F–P EML structure (the dotted line indicates the HOMO/LUMO energy level of the dopant materials).

3. Results and discussion

The schematic energy level diagram in Fig. 2 indicates that the energy barrier between NPB and DPVBi is 0.5 eV where the large HOMO energy barrier results in degradation of hole injection into the DPVBi. From the hole injection point of view, holes are favorably injected through the BCzVBi molecules, since the energy barrier between NPB and BCzVBi is low, only 0.1 eV. The current density–voltage–luminance (*J–V–L*) of the blue OLEDs of the F–P EML structure with different fluorescent doping concentrations are plotted in Fig. 3(a) and Table 2 summarizes the performance of the devices at a given condition. Since dopant sites in a host material can influence the carrier transport characteristics either by trapping carriers or by providing additional carrier transport channels [17,18], the *J–V–L* characteristics of our devices are strongly dependent on the BCzVBi doping concentration, specifically, the current