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Efficiency enhancement of blue phosphorescent organic light-emitting diodes using mixed electron transport layer

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ABSTRACT

Blue phosphorescent organic light-emitting diodes (OLED) using mixed electron transport layer (ETL) were fabricated with the device structure of ITO/NPB/mCP:Firpic-8%/TPBi:BCP or TPBi:3TPYMB/Liq/Al to observe mixed ETL's influence on their electrical and optical characteristics. OLED device with mixed ETL of TPBi with BCP or 3TPYMB significantly improved its current efficiency to 30.4 and 34.2 cd/A comparing to 19.8 cd/A of single ETL with BCP only. We examined mixed ETL's capability of electron transport and triplet exciton confinement enhancing phosphorescent OLED's luminance and luminous efficiency.

1. Introduction

In recent years, many interests in phosphorescent organic light emitting devices (PHOLEDs) have resulted in a number of studies and developments for much better performances [1–3]. Especially for the development of white light and full-color displays, highly efficient red, green, and blue OLEDs are required. Red and green PHOLEDs with high efficiency and long lifetimes have been demonstrated for the lighting and display applications [4,5]. However, achieving high efficiency and long lifetime blue PHOLEDs still remains as a technical challenge.

There are several methods to build highly performed blue PHOLED devices. One of them is to render energy level of carrier transport material similar with that of host material in the emissive layer (EML) minimizing energy barrier for moving electrons from electron transport layer (ETL) to EML [6,7]. The other is to select carrier transport materials with higher triplet energy blocking triplet excitons diffusing from EML to ETL [7–9]. Also ETL mixed with host material of EML has been used for obtaining higher efficiency to lower injection barrier of EML [10].

In this paper, we fabricated blue PHOLED with mixed electron transport layer (M-ETL) which is composed of 1,3,5-tris(N-phenylbenzimiazole-2-yl)benzene (TPBi), 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP) and Tris(2,4,6-trimethyl-3-(pyridin-3-yl)phenyl)borane (3TPYMB) to investigate effects of M-ETL resulted in improvement of luminance and luminous efficiency. TPBi, BCP, 3TPYMB were selected as ETL material because of their different energy states such as LUMO, HOMO, triplet energy level (T_1) and electron mobility, which were summarized in Table 1.

2. Experimental

Indium Tin Oxide (ITO) coated glass was cleaned in an ultrasonic bath by the regular cleaning sequence: in deionized water, isopropyl alcohol, acetone, deionized water, isopropyl alcohol. Thereafter, the pre-cleaned ITO was treated with an O_2 plasma, under vacuum conditions of 5.0×10^{-2} Torr at 100 W for 2 min. Blue PHOLED devices were fabricated by thermal evaporation under high vacuum conditions of 5.0×10^{-7} Torr. We fabricated two type blue OLEDs. First type of PHOLEDs with M-ETL were composed of N,N′-bis-(1-naphyl)-N,N′-diphenyl-1,1′-biphenyl-4,4′-diamine (NPB) (T_1 = 2.3 eV) [11] as hole transport layer (HTL)/3,5-*N*,*N*-dicarbazolebenzene (mCP) (T_1 = 2.9 eV) [12] as host material and bis[2-(4,6-difluorophenyl)pyridinato-C2,N](picolinato)iridium(III) (FIrpic) (T_1 = 2.7 eV) [13] as blue dopant/TPBi

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Table 1
Electrical properties of electron transport layer materials.

Characteristics	BCP	TPBi	3TPYMB
LUMO	3.0 eV	2.7 eV	3.3 eV
HOMO	6.5 eV	6.2 eV	6.8 eV
Triplet energy level	2.6 eV	2.7 eV	3.0 eV
Electron mobility	5.5×10^{-6} cm^2/Vs	3.3×10^{-5} cm^2/Vs	$\sim 1.0 \times 10^{-5}$ cm^2/Vs

(T_1 = 2.7 eV) [14] and BCP (T_1 = 2.6 eV) [15] as mixed electron transport layer (M-ETL1)/8-Hydroxyquinolinolato-lithium (Liq) as the electron injection layer(EIL), /aluminum(Al) as cathode (see Fig. 1). The other type PHOLEDs used only different M-ETL composed of TPBi and 3TPYMB (T_1 = 3.0 eV) [16] under same structure. The electro-optical properties of the blue PHOLED devices were measured and analyzed using a Keithley 238, LMS PR-650 spectrophotometer, colorimeter and the *I–V–L* system.

3. Results and discussion

Compositions of the blue PHOLED device A with different ratio of TPBi and BCP in ETL are summarized in Table 2. M-ETL 1 using TPBi and BCP was deposited with the ratio of 10:0, 5:5, 2:8 and 0:10 after EML to investigate the electron transport mechanism according to ETL materials with different LUMO energy level (see Fig. 2). Also, in the device As, triplet exciton confinement is not considered due to lower triplet energy of TPBi and BCP than that of FIrpic.

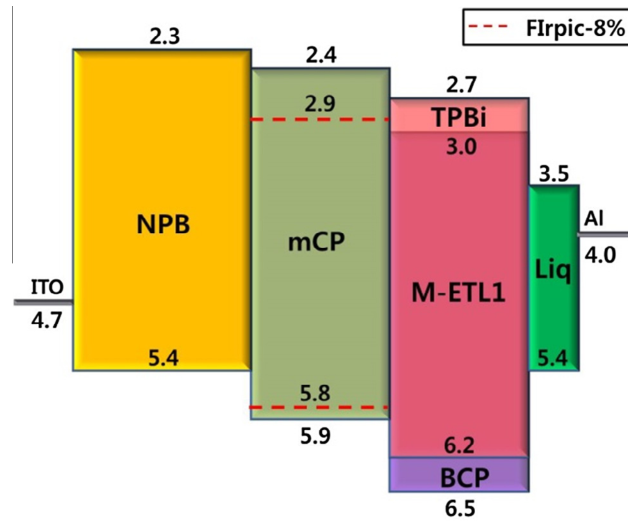

Fig. 2. Energy band diagram of blue PHOLED device A.

Fig. 3 shows the *J–V–L* characteristics and plot of luminous efficiency-current density for the blue PHOLED with M-ETL1. Current densities of the devices A-1, A-2, A-3 and A-4 were 1.78, 1.39, 1.26 and 1.21 mA/cm^2 at 6.5 V, respectively. Current density of the devices shows similar pattern due to the two to three orders of magnitude higher in hole mobility than the electron mobility [17,18]. Thus, it is not electrically influence on the devices in Fig. 3(a) but when compared in detail, we can find trend about

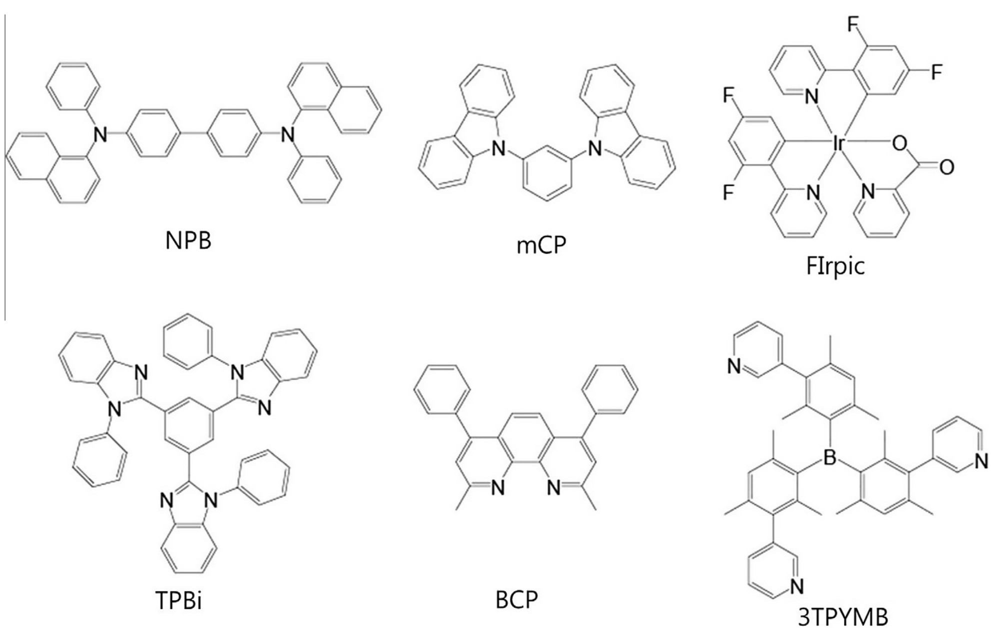

Fig. 1. Molecular structures of NPB, mCP, FIrpic, TPBi, BCP and 3TPYMB.

Table 2
Blue PHOLED device A's composition with various ratio of TPBi:BCP in ETL (unit = Å).

	HTL	EML	M-ETL1	EIL	Cathode
Device A-1	NPB (700)	mCP:Firpic – 8% (300)	TPBi:BCP (10:0) (300)	Liq (20)	Al (1200)
Device A-2	NPB (700)	mCP:Firpic – 8% (300)	TPBi:BCP (5:5) (300)	Liq (20)	Al (1200)
Device A-3	NPB (700)	mCP:Firpic – 8% (300)	TPBi:BCP (2:8) (300)	Liq (20)	Al (1200)
Device A-4	NPB (700)	mCP:Firpic – 8% (300)	TPBi:BCP (0:10)	Liq (20)	Al (1200)