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Enhance efficiency of blue and white organic light emitting diodes with mixed host emitting layer using TCTA and 3TPYMB

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ABSTRACT

A mixed host emitting layer consisting of TCTA and 3TPYMB can greatly increase the efficiency of blue and white organic light emitting diodes (OLED). The hole transport material TCTA can be used as a buffer layer and a hole-transport host emitting layer. Combining TCTA with electron-transport 3TPYMB produces a mixed host emitting layer that can effectively confine the charge carrier within luminous layer. The electron transport layer 3TPYMB reduces electronic injection energy barriers, improves charge balance, and reduces drive voltage to 4.38 V with proper adjustment to optimum thickness. The luminous efficiency of blue light OLED mixed with FIrpic can reach 36.0 cd/A, 27.5 lm/W, and luminous efficiency of white light OLED mixed with Os tangerine adulterant can reach 36.1 cd/A, 26.4 lm/W.

1. Introduction

White light organic light emitting diodes have superior properties such as high brightness, high quantum efficiency, thin and lightweight, low drive voltage, simple manufacturing process, and the ability of being large area light source [1]. As a result, there are great interests in adopting this technology in flat panel displays and illumination. Increasing luminous efficiency of OLED is one of the research topics that draw a lot of attention [2]. Luminous efficiency can be improved in many ways [3–9]. There are also researches focusing on reducing drive voltage [7], and avoiding luminous efficiency rolling off while minimizing color shifting. For example, double-layer composite structure [7,10], hosting emitting layer with extra large energy gap [8], and mixing with HTL can all realize carrier balance and confining combination carriers in luminous layers [6].

The luminous structure of white OLED can be done via triple-color [2,11] or two-color [4,7,10]. The two-color mechanism is generally achieved by mixing blue and orange light.

The 4,4′,4″-tris (*N*-carbazolyl)-triphenyl amine (TCTA) hole transport material is known to confine excitons and electrons in emitting layer and reported as a suitable host material for green phosphorescent OLEDs [12–14]. TCTA is only strong as hole transport material but poor as electron transport material [15]. To overcome low electron mobility property of host material, researchers mixed TCTA with high electron mobility electron-transport materials (ETM), such as, mixed spacer (MS) of TCTA with BAlq [bis-(2-methyl-8-quinolinolate)-4-(phenylpheno lato) aluminum] which exhibited a maximum luminance of 42,200 cd/m^2 at 8.5 V, external quantum efficiency (EQE) of 10.3% and power efficiency of 19.0 lm/W [16]. Zhao et al. mixed TCTA with Bepp2 [bis(2-(2-hydroxyphenyl)-pyridine) beryllium] as the host of phosphorescent EMLs as well as the spacer which exhibited a current efficiency of 30.2 cd/A, a power efficiency of 32.0 lm/W [17]. Lee et al. combined TCTA with UGH3 [*m*-bis-(triphenylsilyl) benzene] which obtained peak external quantum and luminance efficiencies of 22.9% and 39.2 lm/W, respectively [18]. Zhu et al. used TCTA/TPBi [1,3,5-tris (*N*-phenylben zimidazole-2-yl) benzene] as the cohost which obtained peak external quantum efficiency of 17.7% and a peak power efficiency of 45.7 lm/W [19]. Because of the advantages of the mixed layers, highly improved efficiencies can be obtained.

Tanaka et al. have reported that tris[3-(3-pyridyl)-mesityl]borane (3TPYMB) has a very high triplet energy of 2.98 eV and electron

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mobility of 10^{-5} $cm^2/V/s$ [8]. Additionally, it was used as a hole blocker to achieve efficient exciton confinement and good charge balance in the device [3]. Therefore, in this paper we try to inject more electrons into the EML region by mixing TCTA with 3TPYMB as EML, therefore the luminance efficiencies has been apparently promoted.

In this study, mixed emitting layer structure combined TCTA with 3TPYMB and used two color dopants consisting of blue phosphorescence dopant, FIrpic, and orange dopant, Os, for white OLEDs. The results show higher efficiency and lower driving voltage.

2. Experimental

An ITO substrate with a resistance of 13.59 ± 5 Ω/Sq is used for luminous phosphorescence devices. The substrate is first ultrasonic vibrated and washed using acetone, methanol and deionized water in sequence, and then its surface is cleaned via oxygen plasma. The organic and metal layers are thermal evaporated onto the substrate at vacuum pressure 2×10^{-6} Torr. The layers are coated in following order: EHI608 (produced by e-Ray Optoelectronics Tech. Co., Ltd.) as hole injection layer (HIL), 1,1-bis[(di-4-tolylamino) phenyl] cyclohexane (TAPC) as hole transmission layer (HTL), TCTA as host emitting layer (EML) with hole transmission property. The host emitting material of the blue emission layer is produced by mixing TCTA and TmPyPB at 1:1 ratio and doped with blue phosphor adulterant: iridium(III)bis((4,6-di-fluorophenyl)-pyridinato-N,$C^{2\prime}$) picolinate (FIrpic). The thickness of electron transport layer (ETL) 3TPYMB is controlled to observe the effects. The test piece is placed into metal evaporation cavity via robotic arm and metal cathode (CsF/Al) is coated through evaporation at vacuum pressure 4×10^{-6} Torr. Consequently, the white device is produced by co-doping blue with orange [Os $(bpftz)_2(PPh_2Me)_2$] in the front section of TCTA:3TPYMB mixed layer. The structure composition and parameters of the five manufactured devices are listed in Table 1. The luminous area is 35 mm^2 for all devices.

Fig. 1 is the Material Energy Band Diagram. Photoelectric property measurements of manufactured devices are done in atmospheric environment. Luminous brightness and spectrum are measured with SpectraScan PR-650, and Keithley 2400 is used as both power supply and current/voltage meter.

3. Results and discussion

Fig. 2 shows the relationships between luminous brightness and current of blue light devices. Device B, which has mixed host emitting layer consisting of TCTA and TmPyPB, has much better characteristics than those of Device A, which has single main luminous layer TmPyPB. The reason is that TCTA provides hole transport and TmPyPB provides electron transport. Device B

Table 1
Parameters for different devices.

#	HTL	Buff. layer	Mixed-EML	ETL-1 (nm)	ETL-2 (nm)
	TAPC	TCTA	Cocen. (10 nm)	TmPyPB	3TPYMB
A	10	10	TCTA:Fir. 1:0.17	15	20
B	25	5	TCTA: Tm:Fir. 1:1:0.17	5	20
C			TCTA:3 TP:Fir. 1:1:0.17		50
D			TCTA:Tm.:FIr:Os 1:1:017:0.02	5	45
E			TCTA:TP:FIr:Os 1:1:0.17:0.02		50

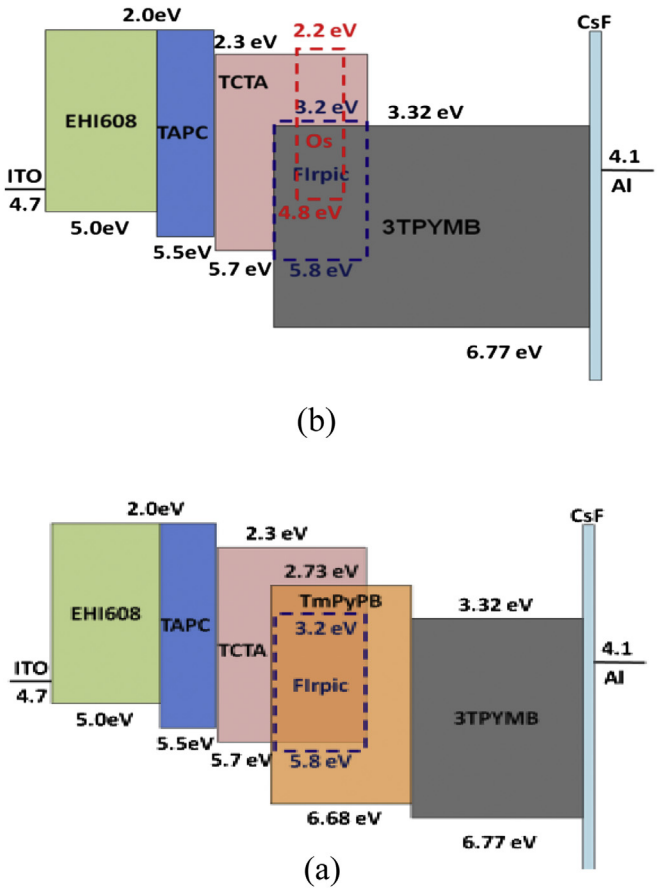

Fig. 1. The Energy Band Diagram of the mixed host structure, (a) the blue light (b) the white light.

presents a current efficiency of 19.6 cd/A and power efficiency of 14.3 lm/W at 4.33 V. Since the mixed host emitting structure has better performance [2,4], HIL (EHI608) and electronic injection layer (CsF) are used together to increase luminous and power efficiency. In Device C, 3TPYMB is used to replace TmPyPB to constitute a mixed host emitting layer along with TCTA. The luminous efficiency and power are boosted to 36.0 cd/A and 27.5 lm/W individually (Fig. 2), and drive voltage and drive current respectively drop to 4.15 V and 2.98 mA, as shown in Table 2. 3TPYMB lowers electronic injection energy barrier by 0.59 eV, therefore electron injection efficiency and drive voltage are increased.

Because the electronic mobility of TAPC is much higher than that of 3TPYMB, the injection current is mainly based on holes and electrons are the minority. As a result, the thickness of the 3TPYMB electron transport layer should be increased (see Table 1) for better electron injection efficiency under relatively low drive voltage and better balance of hole–electron carrier, which in turn increases luminous and power efficiency, as shown in Table 2. We found that a mixed host structure was effective to control the charge carrier injection and transportation in the EML.

Device D and E mix Os dopant into blue light luminous devices (Device B, C, see Table 1.). Blue light luminous devices generate blue light and transfer part of the energy to Os dopant, which in turn emits orange light and the two colors are combined into white light [20,21]. Because LUMO energy level of Os is much lower than those of TCTA, TmPyPB, and 3TPYMB, Os dopant can trap electron holes and reduce input current (see Table 2). Controlling the doping position by mixing Os dopant in the middle of the luminous layer (Fig. 1), excitons are effectively confined in the carrier