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Invited paper

Improved color stability of white organic light-emitting diodes without interlayer between red, orange and blue emission layers



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ABSTRACT

We demonstrated color stability improved white phosphorescent organic light-emitting diodes (WOLEDs) based on red, orange and blue emission layers. Iridium(III) Bis(3,5-difluoro)-2-(2-pyridyl)phenyl-(2-carboxypyridyl) was doped into red emission layer (R-EML) and orange emission layer (O-EML) to lower the electrons injection barrier and facilitate the ambipolar charge carriers balance. Consequently, the recombination region was extended to the R-EML and O-EML, leading to the excellently stable spectra and the reduction of triplet–triplet annihilation. Then the resulting device with a negligible Commission International de L'Eclairage coordinates shift of (0.003, 0.007) within a wide luminance range as well as a high color rendering index of 90 was gained, which was comparable to the profit caused by the conventional method of introducing the interlayer. And the emission mechanism of the WOLEDs was also discussed.

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1. Introduction

White organic light-emitting diodes (WOLEDs) have condensed great quantities of attentions in recent years owing to their great potential use in backlight, full color applications [1–5]. With the development of the WOLEDs, various configurations have been proposed to meet with the commercial fabrications, such as using multiple emission layers doped with different complementary colors respectively [6,7], using a single emission layer with two complementary colors doping in the corporate host [8], using a single material with broad emission wavelength, using stacked structure [9], using exciplex emission or excimer [10,11], and so on. Among all these approaches, the multiple emission layers structure exhibits a high efficiency and lower efficiency roll-off trait [12–15], which is the indispensable advantages for the performance of the WOLEDs. Meanwhile, good color stability except for high efficiency is indispensable for manufacture on a large scale [16]. Generally, the poor chromaticity stability often occurs in the WOLEDs with the multiple emitting structure due to the preferred holes or electrons transport property of the unipolar host, which leads to the relatively narrow exciton recombination region and serious triplet–triplet annihilation [17]. Up to date, many efforts have been made to gain color stable WOLEDs [18–20]. For example, the interlayer is introduced between the adjacent emission

layers to suppress the variation in color by redistributing the carriers or excitons in the respective emission zone [21–24]. However, the introduction of the interlayer frequently suppresses the power efficiency due to the voltage drop on the interlayer [25]. In addition, the codoped method was commonly proposed to manage the excitons and carriers distribution, leading to the broad recombination region. Hsiao et al. demonstrated efficient phosphorescence sensitization WOLEDs with excellent color stability by using the codoped method. The slight change in Commission International de L'Eclairage coordinates (CIE) coordinates was only (0.008, 0.006) within the luminance range from 1000 cd/m² to 4000 cd/m² [26]. Chang et al. demonstrated a novel method by doping a green phosphor with the highest exciton trapping capability into the yellow and red emission layers to fabricate the WOLEDs, and the white device achieved a significantly enhanced performance [27]. Lee et al. demonstrated a significant enhancement and reduced efficiency roll-off in blue and white phosphorescent devices based on a mixed host structure [28].

In this paper, we demonstrated a novel method by introducing blue dye of FlrPic as a favorite intermediate energy level into the red emission layer (R-EML) and orange emission layer (O-EML) to facilitate the electrons transportation across the total emission region, leading to the negligible dependence of the electron transporting property on the driving voltage. Then the resulting device with the recombination zone extending to R-EML and O-EML shows a negligible CIE coordinates shift of (0.003, 0.007) within a large luminance range from 1334 cd/m² to 15,000 cd/m².

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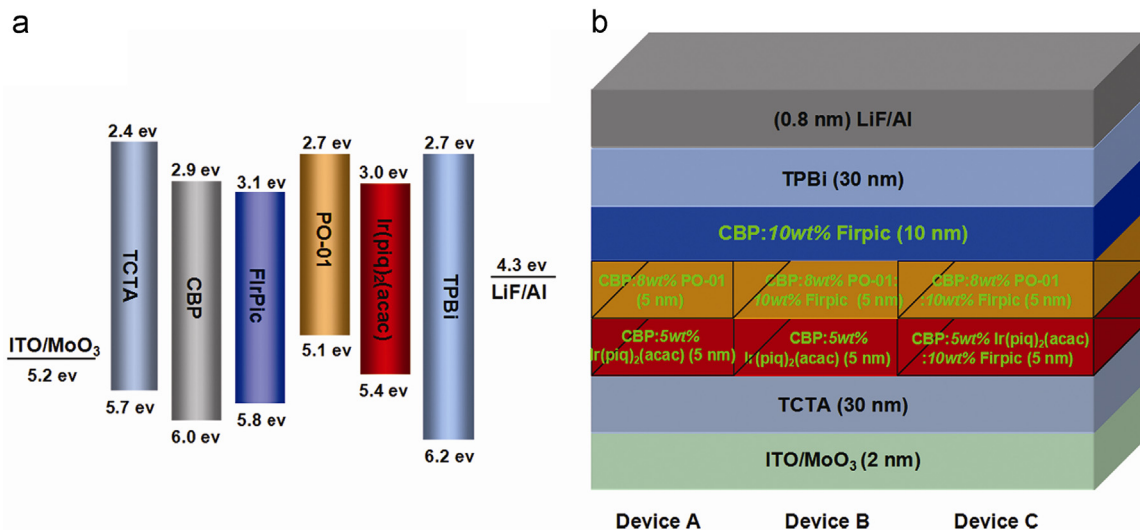


Fig. 1. The detailed energy level diagram of the materials (a) and the structures of devices A–C (b).

Moreover, the white device has a high color rendering index of 90.

2. Experimental

The detailed energy level diagram of the materials (a) and the structures of devices (b) are shown in Fig. 1. We used the patterned indium tin oxide (ITO) coated glass with a sheet resistance of 20Ω as the transparent anode. MoO_3 and 4,4',4''-tri(N-carbazolyl)-triphenylamine (TCTA) were used as hole-injection layer (HIL) and hole-transportation layer (HTL), respectively. A bipolar transport organic material 4,4'-N,N'-dicarbazole-biphenyl (CBP) was served as the host of red, orange, and blue emission layers. Iridium(III) bis(-phenylquinoline) acetylacetonate $[\text{Ir}(\text{piq})_2(\text{acac})]$, iridium(III) bis(4-phenylthieno [3] pyridinato-N,C2') acetylacetonate (PO-01), and iridium (III) Bis(3,5-difluoro)-2-(2-pyridyl)phenyl-(2-carboxypyridyl) (FirPic) were used as red, orange, blue phosphorescent dyes, respectively. 2,2',2''-(1,3,5-Benzotriazolyl)-tris(1-phenyl-1-H-benzimidazole) (TPBi) acted as electron-transportation layer (ETL). Then, 0.8 nm LiF covered by 100 nm Al was used as cathode. All organic layers were grown in succession by high vacuum (3×10^{-4} Pa) thermal evaporation, and the ETL or HTL were evaporated at a rate of 0.1–0.2 nm/s, the phosphorescent dyes were evaporated at a rate of 0.05–0.1 Å/s, and the cathode was at a rate of 0.5 nm/s. The layer thickness and the deposition rate of materials were monitored in situ by an oscillating quartz thickness monitor. Electroluminescence (EL) spectra and CIE coordinates of the devices were measured by using a PR650 spectrosan spectrometer. The luminance–voltage and current–voltage

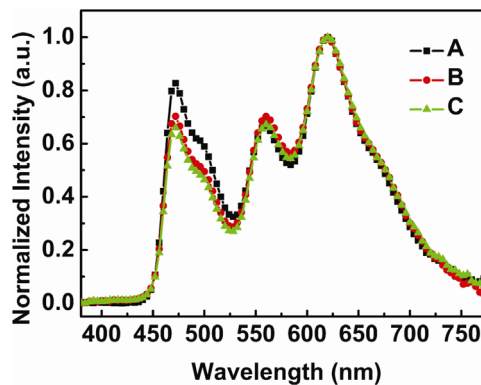


Fig. 3. Normalized EL spectra of devices A–C at the voltage of 8 V.

characteristics were measured simultaneously with the measurement of the EL spectra by combining the spectrometer with a programmable Keithley 2400 voltage–current source.

3. Results and discussion

Firstly, we fabricated three WOLEDs based on red, orange and blue doping emission layers, and the structures are as follows. Device A: ITO/ MoO_3 (2 nm)/TCTA (30 nm)/CBP: 5 wt% $\text{Ir}(\text{piq})_2(\text{acac})$ (5 nm)/CBP: 8 wt% PO-01 (5 nm)/CBP: 10 wt% FirPic (10 nm)/TPBi (30 nm)/LiF (0.8 nm)/Al (100 nm); Device B: ITO/ MoO_3 (2 nm)/TCTA (30 nm)/CBP: 5 wt% $\text{Ir}(\text{piq})_2(\text{acac})$ (5 nm)/

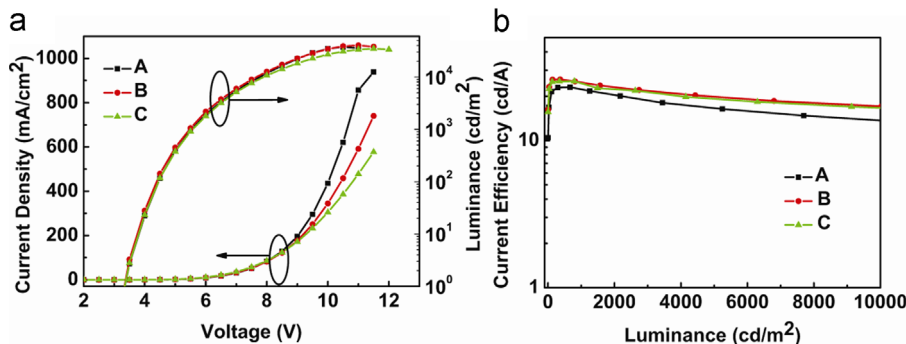


Fig. 2. The current density–voltage–luminance characteristics (a) and the current efficiency–luminance characteristics of devices A–C (b).

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