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An efficient dual-emissive-layer white organic light emitting-diode: Insight into device working mechanism and origin of color-shift

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ABSTRACT

By using a single host for both blue and orange phosphorescent dopants, a simple and efficient white organic light emitting-diode is reported. The dual-emissive-layer white device achieves a peak external quantum efficiency of 16.9 ± 0.9% and power efficiency of 44.1 ± 2.3 lm/W without out-coupling enhancement. Analysis of the device working mechanism determines that the blue dopant molecules can form a bridge to facilitate electron transport into the adjacent orange emitting-layer. The orange emission originates from both the direct electron trapping by the orange dopant and incomplete blue–orange energy transfer mechanisms. The origin of the voltage-dependent color shift of the device is quantitatively determined according to the working mechanism. Possible solution to reducing the color-shift is also provided based on the calculation and analytical results.

1. Introduction

White organic light-emitting diode (WOLED) has attracted much attention in OLED research because it provides a great alternative for the current solid-state lighting source, e.g., inorganic LEDs [1]. Given the limited spectral bandwidth of an organic emitter generally used, multiple emitting species are often incorporated into one WOLED to realize a balanced white light. To achieve high efficiency in WOLEDs, using phosphorescent emitters is one effective method because phosphorescent dopants can convert both the singlet and triplet excitons into photons [2]. Recent conceptual advancement leads to many approaches to realize high-performance phosphorescent WOLEDs [3–15]. Among them, the single-host structure, i.e., using a single host for all of the phosphorescent dopants, has attracted more attention due to the following advantages [9–15]. First, it facilitates charge and exciton transport between different emission regions [9]. Second, it eliminates heterojunctions and therefore the interfacing energy barriers, thus favoring reduction of the operational voltage [12–15]. Finally, it offers a facile management of charge and exciton transport for a balanced white light and high efficiency in WOLEDs [9,10,12,15].

Today's state-of-the-art single-host WOLEDs often focus on primary colors combination, i.e., blue, green and red, because they can provide a wide coverage of the visible wavelength [9–15]. However, the structure of such

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devices is relatively complicated compared to WOLEDs with complementary colors, i.e., blue and orange/yellow [11]. Although complementary-color WOLEDs provide a simpler alternative, they have received less attention in single-host WOLEDs [10,11]. Furthermore, studies of the working mechanism for such WOLEDs, e.g., emission nature of each dopant, charge and exciton transporting behavior and their influence on device performance, are rare in previous literatures [9]. To resolve both issues, here we report a simple and efficient single-host WOLED with a dual-emissive-layer for both the blue and orange dopants. The white device achieves a forward viewing external quantum efficiency (EQE) of 16.9 ± 0.9% and power efficiency (PE) of 44.1 ± 2.3 lm/W. It is found that both the direct electron trapping by the orange dopant and incomplete blue–orange energy transfer mechanisms contribute to orange emission. The origin of the voltage-dependent color shift is quantitatively described according to the working mechanism.

2. Materials and methods

To illustrate the concept, a blue phosphorescent dye of iridium(III)[bis(4,6-difuorophenyl)-pyridinato-*N*,$C^{2\prime}$] picolinate (FIrpic) and an orange dye of bis(2-(9,9-diethyl-9*H*-fluoren-2-yl)-1-phenyl-1*H*-benzoimidazol-*N*,C^3) iridium(acetylacetonate) [$(fbi)_2Ir(acac)$] are selected [16,17]. A hole-transporting material 1,3-bis(9-carbazolyl)benzene (mCP) with a high triplet energy of 2.9 eV is introduced as the host for both the blue and orange dyes. To ensure blue emission, the FIrpic:mCP layer is placed near the main exciton formation zone in the device, as shown below [9,12,15]. The orange layer composed of $(fbi)_2Ir(acac)$:mCP is placed adjacent to the blue layer. The optimized structure of the WOLED is ITO/PEDOT:PSS/NPB (85 nm)/TCTA (5 nm)/3 wt.% $(fbi)_2Ir(acac)$:mCP (3.25 nm)/8.5 wt.% FIrpic:mCP (3.85 nm)/TPBi (50 nm)/LiF/Al. Here, NPB represents *N*,*N*′-diphenyl-*N*,*N*′-bis(1-naphthylphenyl)-1,1′-biphenyl-4,4′-diamine, TCTA 4,4′,4″-tri(*N*-carbazolyl)triphenylamine, TPBi 2,2′,2″-(1,3,5-Benzinetriyl)-tris(1-phenyl-1-H-benzimidazole). The device was fabricated on a pre-cleaned ITO substrate with a sheet resistance of 10 Ω per square. All of the layers except PEDOT:PSS were grown by thermal evaporation in a high vacuum (~2×10^{-4} Pa) system. The PEDOT:PSS layer was spin coated onto ITO and then heated under 120 °C for 2 h. The current–voltage–luminance characteristics were measured by using a Keithley source measurement unit (Keithley 2400 and Keithley 2000) with a calibrated silicon photodiode. The EL spectra were measured by a calibrated PR650 spectrophotometer. The active dimension of the device is 4×4 mm^2. All of the measurements were carried out in ambient atmosphere at room temperature.

3. Results and discussion

Fig. 1 shows the electroluminescence (EL) performance of the WOLED. As shown in Fig. 1a, the WOLED achieves a forward viewing EQE and PE of 16.9 ± 0.9% and 44.1 ± 2.3 lm/W, respectively. The turn-on voltage of the

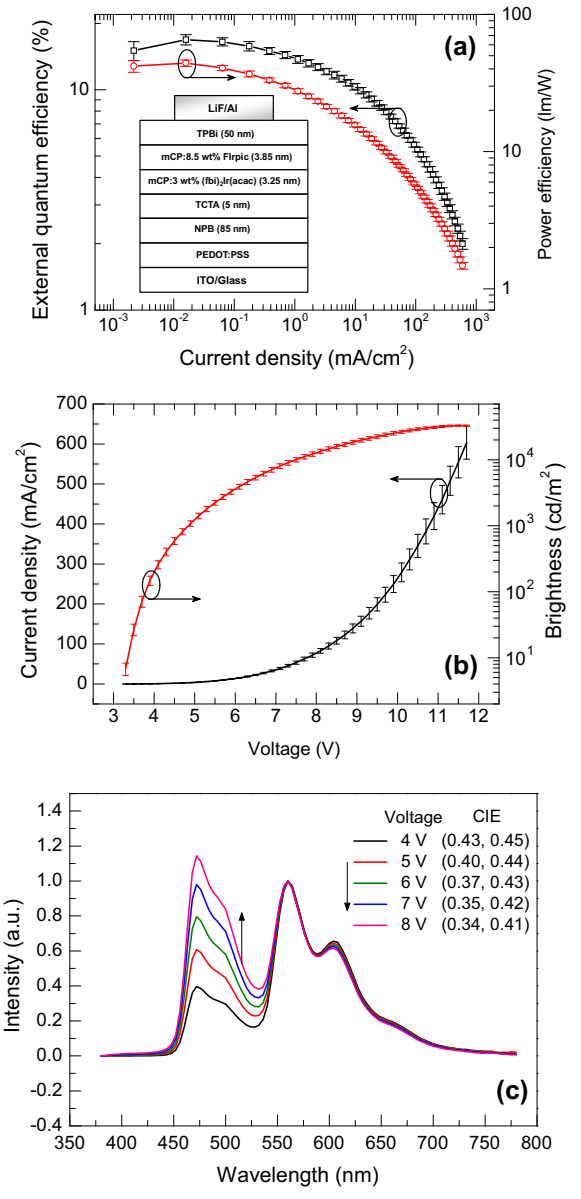

Fig. 1. (a) External quantum efficiency and power efficiency of the optimized WOLED. Inset: structure of the white device. (b) Voltage–current density-brightness characteristics of the device. (c) Electroluminescent (EL) spectra of the WOLED from 4 to 8 V. The Commission Internationale de L'Eclairage coordinates (CIE) of the device are shown on the top-right.

device is 3.2 V, as shown in Fig. 1b. The voltages at the brightness of 500 and 1000 cd/m^2 are 4.41 and 4.85 V, respectively. At a brightness of 500 cd/m^2, the EQE and PE of the device still reach 13.7 ± 0.6% and 27.6 ± 1.1 lm/W, respectively. Fig. 1c shows the EL spectra of the device at different voltages. The Commission Internationale de L'Eclairage coordinates (CIE) of the device at voltages from 4 to 8 V are shown in Fig. 1c. The color-rendering index (CRI) of the device is from 62 to 68, and the correlated color temperature (CCT) of the device is from 3468 to 5372,