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High efficiency and simplified white organic light-emitting diode based on a single-host emission layer

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ABSTRACT

Efficient white organic light-emitting diodes (WOLEDs) with high stability are highly desired nowadays to produce devices that meet the commercial illumination requirement. WOLEDs based on single-host emission layer, is a preferred route to simplify device structures and thus lower the production cost. In this work, we report on single-host WOLEDs based on bipolar material, 2,6-bis[(3-carbazol-9-yl)phenyl)] pyridine (26DCzPPy), as the host, and Iridium (III)bis[(4,6-difluorophenyl)-pyridinato-N,$C^{2'}$] (FIrpic), [3,2-c]pyridinato-N,$C^{2'}$) acetylacetonate (PO-01), as blue and yellow dopants, respectively. The devices exhibit not only higher efficiency, but also superior stability compared to the conventional devices and doping-free devices. Detailed analysis is conducted to clarify the underlying reasons. This work enriches the mechanism understanding of single-host devices and paves the way for development of high performance WOLEDs.

1. Introduction

White organic light-emitting diodes (WOLEDs) have promising applications as next generation flat-panel displays and solid-state light sources because of its unique merits of spatially homogeneous white emission across the surface of large-area, high external quantum efficiency (EQE), flexibility and eco-friendly, etc. [1–4]. Up to now, although various products based on WOLEDs technology have entered the commercial markets, the high price restricts its popularization among the consumers. Thus, further improvement is required to simplify the device structure in order to reduce the fabrication costs, and promote the commercialization of WOLEDs. Among approaches to simplify the device structure, adopting the same host material for different emitters to construct a single white emission layer (SWEML) is attractive, since it not only lower the driving voltage due to the reduction of structural heterogeneity, but also yield high brightness because of easier charge injection and transport to the emitting layers (EMLs) [5–7]. However, one of the challenges of such a device architecture is to acquire a host which is suitable for both blue and yellow emitters to simultaneously realize high efficiency. In general, the host selection for the blue emitter should be first considered since it has to provide wide band-gap (E_g) with high lowest triplet-excited states (T_1) to ensure exothermic energy transfer to the blue emitter [8,9]. In addition, blue host with higher glass transition temperature (T_g) is preferred. Since hosts with low T_g, such as the most popular used *N*,*N*′-dicarbazolyl-3,5-benzene (mCP), will deteriorate device operational stability [10]. Hence, the key to obtain high performance SWEML WOLEDs is actually to i) select a blue host with high T_g; and ii) more importantly, find a strategy to improve the energy transfer efficiency from the blue host to the complementary color (yellow or red) emitters.

In this work, we use 2,6-bis(3-(carbazol-9-yl)phenyl)pyridine (26DCzPPy) [11], which has high T_1 (2.71 eV) and T_g (>200 °C), as the common host for both blue (Iridium (III)bis[(4,6-difluorophenyl)-pyridinato-*N*,$C^{2'}$] (FIrpic)) and yellow ([3,2-c]pyridinato-N,$C^{2'}$) acetylacetonate (PO-01)) phosphorescent materials. The bipolar nature of 26DCzPPy also allows a balanced carrier injection into the EMLs. We have obtained high efficiency simplified SWEML WOLED based on 26DCzPPy by utilizing FIrpic as assistant dopant to boost energy transfer from 26DCzPPy to PO-01. Compared with the reference devices (conventional devies and doping-free devices), our SWEML device shows excellence in terms of both efficiency and color stability. The optimized device,

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without any out-coupling enhancements, obtains a current efficiency (CE) of 39 cd/A and power efficiency (PE) of 30 lm/W at 4 V (431 cd/m^2).

2. Experimental section

The materials used in the experiments are purchased from Luminescence Technology Corporation. In advance of thermal vapor deposition process, the ITO-coated glass substrates were scrubbed and sonicated consecutively with acetone, ethanol, and deionized water, respectively. All the organic layers were thermally deposited in vacuum ($\sim 4.0 \times 10^{-4}$ Pa) at a rate of 0.1–0.2 nm/s monitored in situ with the quartz oscillator. After the deposition of Cs_2CO_3, the samples were transferred to the metal chamber, and suffered from a vacuum break for ~10 min due to the change of the shadow masks to define the active area. The current density-voltage-forward luminance characteristics, electrolumiance (EL) spectra and Commission Internationale de L'Eclairage (CIE) coordinates were measured with a Keithley 2400 programmable voltage-current source and a PR655 Spectrascan spectrometer. All the samples were measured directly after fabrication without encapsulation in ambient atmosphere at room temperature.

3. Results and discussion

High efficiency has already been achieved by using 26DCzPPy as the host for the FIrpic-based blue phosphorescent OLEDs [16,17]. However, the suitability of 26DCzPPy for the yellow phosphorescent emitter, PO-01, has not been addressed yet. Aiming to investigate the performance of PO-01 in 26DCzPPy, we first fabricated yellow OLEDs with the structure of ITO/MoO_x(10 nm)/TcTa(50 nm)/26DCzPPy:x% PO-01 (10 nm)/Bphen(50 nm)/Cs_2CO_3(1 nm)/Al, and x is 3 for device Y1, 0.5 for device Y2. We note that the device with higher doping concentration (Y1) produces higher CE (26 cd/A at 140 cd/m^2, EQE of 8%), but it is still much lower than the device using other traditional hosts (e.g., CBP) for PO-01 (ca. 43.6 cd/A) [18], indicating 26DCzPPy is not an ideal host for PO-01. Then we co-doped FIrpic into the EML, and fabricated devices Y3 and Y4. Fig. 1 shows the energy level diagram of the materials used in this paper (the energy levels are extracted from literatures [11–15]) and the schematic configuration of the yellow OLEDs. For all devices, MoO_x is served as anode buffer layer for hole injection and Cs_2CO_3 is served as cathode buffer layer for electron injection. 4,4′,4″-tris(*N*-carbazolyl)triphenylamine (TcTa) is hole transport layer (HTL) and 4,7-diphenyl-1,10-phenanthroline (Bphen) is electron transport layer (ETL).

After doping FIrpic into the EML, the performance of the device is improved. Fig. 2 shows the absolute irradiance spectra of devices Y1, Y3 and Y4 at a same voltage of 5 V. Surprisingly, we noted that addition of FIrpic into the EML only harvest a little blue emission, but, contrarily, remarkably enhanced PO-01 emission. Moreover, under the same voltage (5 V), the brightness of the co-doped devices (Y3 and Y4) is much higher than that of the solely PO-01 doped control devices (Y1) (see upper inset of Fig. 2), and the efficiency improved remarkably (see lower inset of Fig. 2). A maximum CE of 48 cd/A at 447 cd/m^2 is obtained for Y3 (corresponding to an EQE of 14.6%), which is even higher than the device using classic CBP host (CE of 43.6 cd/A) [18].

In order to reveal the underlying mechanism of the above phenomena, the following hole-only and electron-only devices are fabricated as follows:

Hole-only devices: MoO_x(10 nm)/TcTa(50 nm)/M (10 nm)/TcTa (50 nm)/MoO_x(10 nm)/Al;

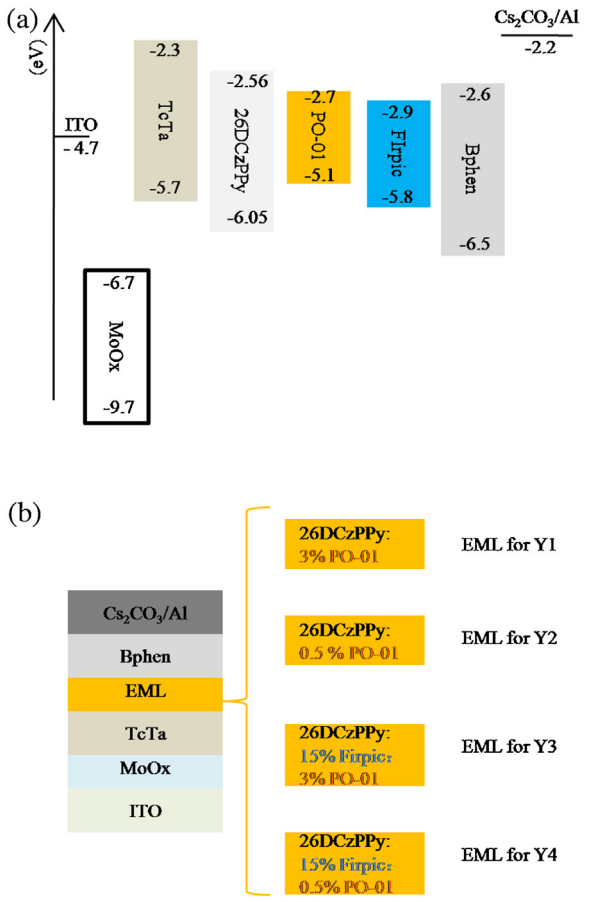

Fig. 1. (a) The energy level diagram of the materials used in this paper, (b) the schematic configuration of yellow OLEDs.

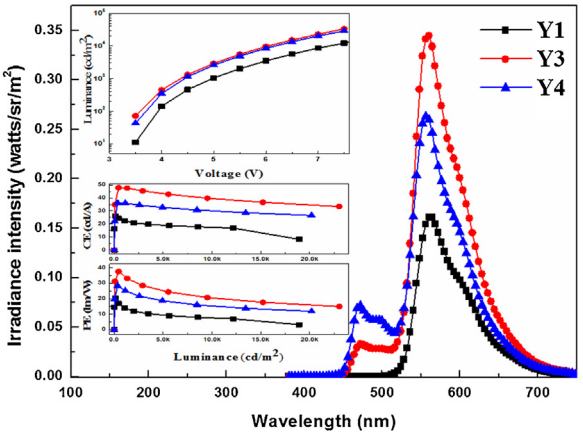

Fig. 2. Absolute irradiance spectra of devices Y1, Y3 and Y4 at the same voltage of 5 V. Luminance versus voltage characteristics (upper inset), CE and PE versus luminance characteristics of devices Y1, Y3 and Y4 (lower inset).

Electron-only devices: Cs_2CO_3(1 nm)/Bphen(50 nm)/M (10 nm)/Bphen(50 nm)/Cs_2CO_3(1 nm)/Al.

Here M refers to 26DCzPPy for h1 and e1, 26DCzPPy:3% PO-01 for h2 and e2 and 26DCzPPy:15% FIrpic for h3 and e3. (h1, h2 and h3 denote hole-only devices, e1, e2 and e3 denote electron-only devices)