

Highly efficient and color-stable white organic light-emitting diode based on a novel blue phosphorescent host



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ABSTRACT

Highly efficient phosphorescent white organic light-emitting devices (WOLEDs) have been fabricated by using two complementary blue and yellow emitting layers, in which the blue guest iridium(III) bis[(4,6-difluorophenyl)-pyridinato-N,C^{2'}] picolinate (Firpic) was doped in a novel blue phosphorescent host. The efficiencies and spectra of WOLEDs can be easily tuned by inserting an ultrathin interlayer between the two emitters and adjusting the thickness of the yellow emitting layer (Y-EML). The device with 1 nm thick interlayer and 3 nm thick (Y-EML) obtains very high efficiencies of 42.4 cd/A and 47.6 lm/W and a luminance of 1144 cd/m² was realized at a low voltage of 3.6 V. In addition, another device with 2 nm thick interlayer and 5 nm thick Y-EML exhibited nearly voltage-independent electroluminescent (EL) spectra. Commission International de L'Eclairage (CIE) coordinates of this device only changes from (0.333, 0.436) at a luminance of 100 cd/m² to (0.330, 0.434) at that of 10,000 cd/m², nearly independent of the driving voltage.

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1. Introduction

White organic light-emitting devices (WOLEDs) with homogeneous large-area emission, good color rendering and potential realization on flexible substrates have been recognized as one of the most promising candidate for future full-color display and the next generation of solid-state lighting [1–4]. Among the various methods that have been proposed to realize highly efficient WOLEDs [2,3,5–10], phosphorescent WOLEDs (PHWOLEDs) are deliberately exploited because they can harvest both singlet and triplet excitons which lead to the potential for achieving 100% internal quantum efficiency in comparison with fluorescent OLEDs [11]. White-light emission can be simply obtained by mixing of two complementary colors (blue and yellow or orange) or three primary colors (red, green and blue) by stacking multiple emitting layers (MEML) [3,12] or by co-doping several dopants in a single emitting layer [9]. Compared with other WOLED structures, the MEML is less complicated in fabrication process and more flexible in color tuning through optimizing doping concentration or layer thickness. However, the

undesirable movement of the exciton recombination zone, which leads to the variation of emission color [13], is often observed in WOLED employing MEML structures.

For commercial use, the low operating voltage is of great importance for improving power efficiency and realizing portable applications. However, the blue-phosphorescent dopants usually doped into wide band-gap host materials with high triplet energy level [14,15], which inevitably increases the injecting barrier and therefore the operating voltages. Blue fluorescent emitters may be an alternative way to solve this problem. However, the utilization of fluorescent emitters remarkably reduces the quantum efficiency of the devices. Therefore, highly efficient and low operating voltage WOLEDs with good color stability is still a challenge that limits the practical applications of WOLEDs.

Toward this end, we presented our effort in achieving highly efficient and color stable WOLEDs, based on complementary blue and yellow phosphors doped into different hosts to form MEML structure. We tailored the efficiencies and spectra of WOLEDs by simply adjusting the thickness of yellow emitting layer (Y-EML) and inserting an ultrathin interlayer between the two emitting layers (EMLs). The influences of the interlayer and the thickness of (Y-EML) on the dynamics of charges/excitons are investigated. In this contribution, we provided a new way to achieve highly efficient

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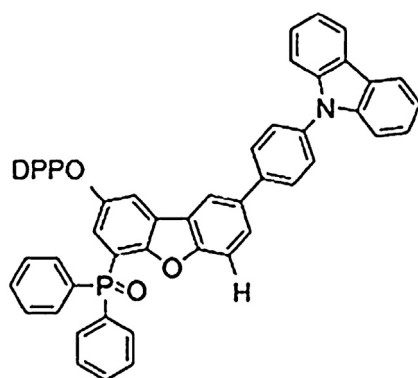


Fig. 1. The molecular structure of DBFDPOPhCz.

and color stable WOLEDs with low driving voltage, which would be beneficial to portable applications.

2. Experimental

Prior to the device fabrication, the indium tin oxide (ITO)-coated glass substrates were scrubbed and sonicated consecutively with acetone, ethanol, and deionized water, respectively. To reduce the ohmic loss, a molybdenum oxide (MoO_x) buffer layer and a p-doping layer 4,4',4''-tris-(3-methylphenylphenylamino)triphenylamine (m-MTDATA): MoO_x [16], were directly deposited onto the ITO substrate for each samples. 4,7-diphenyl-1,10-phenanthroline (Bphen) serve as the electron transporting layer (ETL), while the hole-transporting layer (HTL) is composed of m-MTDATA and tris(phenylpyrazole)iridium ($\text{Ir}(\text{ppz})_3$). Moreover $\text{Ir}(\text{ppz})_3$ also serve as electron/exciton blocking layer (EBL) due to its higher triplet energy (3.1 eV). Iridium(III) bis[(4,6-difluorophenyl)pyridinato-N,C2'] (Flrpic) was doped into a new host DBFDPOPhCz with the doping concentration of 10 wt.% [17] as the blue emitting layer (B-EML). DBFDPOPhCz is a donor (D)- π -acceptor (A)-type phosphine-oxide hosts, which were composed of phenylcarbazole, dibenzofuran (DBF), and diphenylphosphine-oxide (DPPO) moieties. The molecular structure of DBFDPOPhCz is shown in Fig. 1. While the Y-EML is composed of bis(2-(9,9-diethyl-fluoren-2-yl)-1-phenyl-1H-benzod[j]imidazolato)actylacetate)iridium(III) ($(\text{Fbi})_2\text{Ir}(\text{acac})$) or Iridium(III) bis(4-phenylthieno[3,2-c]pyridinato-N,C2') acetylacetate (PO-01) doped 4,4'-bis(carbazol-9-yl)biphenyl (CBP) with a doping concentration of 6 wt.%. All the organic layers were thermally deposited in a 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 the cathode buffer layer LiF, the samples were transferred to metal chamber and suffered from a vacuum break due to the change of the shadow mask for determining the active areas. The current voltage luminance characteristics were measured with a PR650 spectrascan spectrometer and a Keithley 2400 programmable voltage-current source. The efficiencies were calculated from the luminance, current density, and EL spectra. All the samples were measured directly after fabrication without encapsulation in ambient atmosphere at room temperature. Note that the efficiencies showed here are determined without any specific out-coupling enhancement technique.

3. Results and discussion

To reveal the influence of an interlayer on the WOLED performance, we fabricated first batch of four devices. The configuration of device A1 is as follow: ITO/ MoO_x (2 nm)/m-MTDATA: MoO_x (30 nm, 15 wt.%) /m-MTDATA (10 nm)/ $\text{Ir}(\text{ppz})_3$

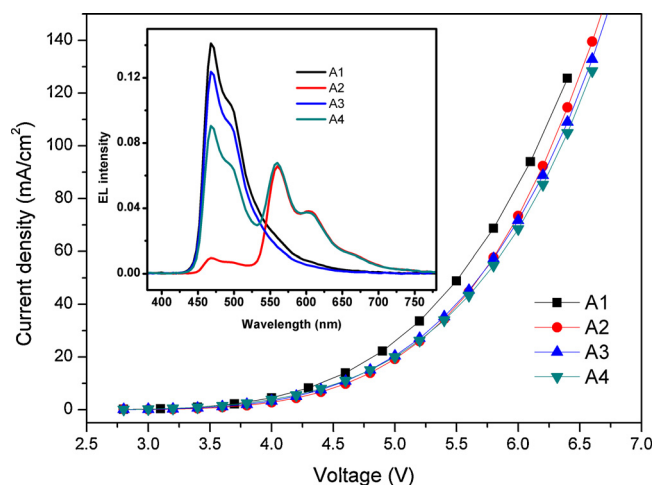


Fig. 2. Current density–voltage characteristics of devices A1–A4. The inset shows the EL spectra of devices A1–A4 at the same driving voltage of 5V.

(10 nm)/DBFDPOPhCz: 10 wt.% Flrpic (10 nm)/CBP: 6 wt.% $(\text{Fbi})_2\text{Ir}(\text{acac})$ (5 nm)/Bphen (35 nm)/LiF (1 nm)/Al, and then we exchange the position of B-EML and Y-EML to form device A2, while in device A3 and A4, 2 nm thin interlayer of $\text{Ir}(\text{ppz})_3$ is inserted between B-EML and Y-EML, respectively, compared to that of device A1 and device A2. Fig. 2 plots the current density–voltage characteristics of the four devices. As it can be seen that, at the same driving voltage, device A1 has the highest current density among the four devices and the current densities of devices A3 and A4 with the additional interlayer are lower than those of devices A1 and A2, respectively. The inset of Fig. 1 shows the EL spectra of the four devices at the same driving voltage of 5V, in which the EL peak with a wavelength of 468 nm corresponds to Flrpic emission, and the peak at 560 nm corresponds to $(\text{Fbi})_2\text{Ir}(\text{acac})$ emission. It is interesting that devices A1 and A3 with the B-EML adjacent to the HTL exhibits only the emission from Flrpic. In contrast, as the position of B-EML and Y-EML is exchanged, both the emissions from Flrpic and $(\text{Fbi})_2\text{Ir}(\text{acac})$ are observed in devices A2 and A4.

Fig. 2 shows the energy level diagrams of device A1 (a) and A2 (b), where the highest occupied molecular orbital (HOMO) level and the lowest unoccupied molecular orbital (LUMO) level for each material are obtained from the literature [9,17,18]. As shown in Fig. 3(a), the HOMO–HOMO offset (1.19 eV) between $\text{Ir}(\text{ppz})_3$ and DBFDPOPhCz in devices A1, indicates the possibility of holes accumulation at the interface and the accumulated holes will subsequently directly injected into Flrpic emitters in the DBFDPOPhCz layer. Different from device A1, the yellow dopant $(\text{Fbi})_2\text{Ir}(\text{acac})$ tends to severing as hole-trapping site in CBP layer [9], due to the big HOMO offset (1.0 eV) between $(\text{Fbi})_2\text{Ir}(\text{acac})$ and CBP. Therefore, it is understandable that the current density of device A1 is higher than that of device A2. As the higher LUMO level of $\text{Ir}(\text{ppz})_3$, the insertion of $\text{Ir}(\text{ppz})_3$ will block part of electrons at the EML adjacent to Bphen layer, which will reduce the current densities, compared to those without this layer. For the four devices, as the big difference of the HOMO level between $\text{Ir}(\text{ppz})_3$ and hosts (i.e., DBFDPOPhCz or CBP), the excitons recombination zone is mainly located at the interface of $\text{Ir}(\text{ppz})_3$ /EML. For devices A1 and A3, the 10 nm thick blue EML make it possible that few excitons can diffuse into yellow EML. Thus only emission from Flrpic is observed.

Fig. 4 shows the normalized EL spectra of devices A2 and A4 at different voltage. In device A2, the blue portion was much weaker than the yellow counterpart at low voltage as most of the holes are trapped in the yellow emitters. Furthermore the exciton diffusion from the higher energy triplet (blue) to the lower one (yellow) may be a reason to the unbalanced white emission.

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