



Hybrid white organic light-emitting devices based on phosphorescent iridium–benzotriazole orange–red and fluorescent blue emitters

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ABSTRACT

We demonstrate that high color purity or efficiency hybrid white organic light-emitting devices (OLEDs) can be generated by integrating a phosphorescent orange–red emitter, bis[4-(2*H*-benzotriazol-2-yl)-*N,N*-diphenyl-aniline-*N*¹,*C*³] iridium acetylacetonate, Ir(TBT)₂(acac) with fluorescent blue emitters in two different emissive layers. The device based on deep blue fluorescent material diphenyl-[4-(2-[1,1';4',1'']terphenyl-4-yl-vinyl)-phenyl]-amine BpSAB and Ir(TBT)₂(acac) shows pure white color with the Commission Internationale de L'Eclairage (CIE) coordinates of (0.33,0.30). When using sky-blue fluorescent dopant *N,N'*-(4,4'-(1*E*,1'*E*)-2,2'-(1,4-phenylene)bis(ethene-2,1-diyl)bis(4,1-phenylene))-bis(2-ethyl-6-methyl-*N*-phenylaniline) (BUBD-1) and orange–red phosphor with a color-tuning phosphorescent material *fac*-tris(2-phenylpyridine) iridium (Ir(ppy)₃), it exhibits peak luminance yield and power efficiency of 17.4 cd/A and 10.7 lm/W, respectively with yellow-white color and CIE color rendering index (CRI) value of 73.

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1. Introduction

White organic light-emitting diodes (white OLEDs) have attracted much attention in recent years, owing to their potential use of backlight system in full color displays and solid-state lightings with low-cost and large-area alternatives [1]. White fluorescent OLEDs can be generated by many approaches such as using vertical red–green–blue (RGB) small-molecular organic emitters stacked with different layers comprising three primary colors or two complementary colors [2–6], polymers combining R, G, B dopants in a single layer [7], utilization of broad exciplex or excimer emission [8,9], and the application of microcavity [10]. However, many of these devices suffered from poor color purity and low power efficiency.

The efficiency of OLEDs can be greatly improved by incorporating a phosphorescent dopant in an appropriate host material as the emitting layer, because it captures the triplet state energy which is lost in conventional fluorescent OLEDs. As robust deep blue phosphorescence material is still not available, most high-efficiency white OLEDs are based on the combination of blue fluorescence and orange/red phosphorescence emitter in a single device architecture, which have been called hybrid white OLEDs [11–13].

Lately, we reported an orange–red emitting iridium (III) complex based on benzotriazole–iridium derivative bis[4-(2*H*-benzotriazol-2-yl)-*N,N*-diphenylaniline-*N*¹,*C*³]iridium acetylacetonate ([Ir(TBT)₂(acac)]) [14], which can be used as an efficient dopant in monochromatic orange–red OLEDs. The low driving voltage and high efficiency properties make this material a good candidate for the application in hybrid white OLEDs.

In this work, we integrated this orange–red phosphor with two fluorescent blue emitters as the emissive layers. High color purity or efficiency hybrid white OLEDs were achieved in the two type devices **A** and **B1**. Device **A** based on deep blue fluorescent material BpSAB and Ir(TBT)₂(acac) shows pure white color with the CIE coordinates of (0.33,0.30) at 10 mA/cm². However, the maximum luminance yield of device **A** is only 4.8 cd/A. While using the sky blue fluorescent dye BUBD-1 and co-doping a green phosphorescent Ir(ppy)₃ into orange–red phosphor Ir(TBT)₂(acac) layer, device **B1** exhibits greatly improved luminance yield of 17.4 cd/A with a red-shifted color (CIE_{x,y}: 0.47, 0.45).

2. Experimental details

The chemical structures of key materials and the device configuration of monochromatic PHOLED are shown in Fig. 1. The synthesis and characterization of Ir(TBT)₂(acac) have been published elsewhere [14,15]. Other materials were obtained commercially and used without further purification.

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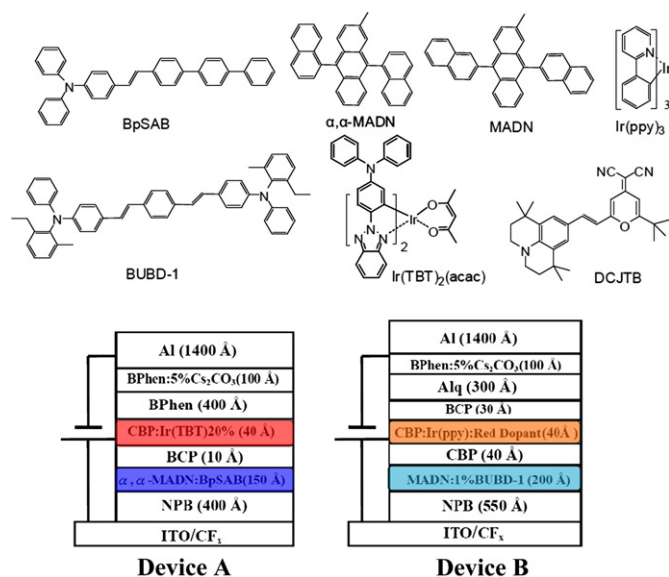


Fig. 1. Chemical structures of key materials and the configuration of two hybrid white OLEDs (devices **A** and **B**).

Prior to the deposition of organic materials, indium–tin–oxide (ITO)/glass was cleaned with a routine cleaning procedure and pretreated with oxygen plasma. Devices were fabricated under about 10^{-4} Pa base vacuum in a thin-film evaporation coater following a routine protocol. The current–voltage–luminance characteristics were measured with a diode array rapid scan system using a Photo Research PR650 spectrophotometer and a computer-controlled, programmable, direct-current (DC) source.

3. Results and discussion

According to our previous investigation, the optimized doping concentration of Ir(TBT)₂(acac) is 20 wt% in single emitting layer devices. A two-element WOLED was fabricated with the device structure **A**: ITO/CF_x/NPB (400 Å)/ α,α -MADN:3% BpSAB (150 Å)/BCP(10 Å)/CBP:20% Ir(TBT)₂(acac) (40 Å)/Bphen(400 Å)/Bphen:Cs₂CO₃(100 Å)/Al(1400 Å) as shown in Fig. 1 (ITO = indium tin oxide, NPB = 4,4-bis[N-(1-naphthyl)-N-phenyl amino]biphenyl, Bphen = 4,7-diphenyl-1,10-phenanthroline, α,α -MADN = 2-methyl-9,10-di(1-naphthyl)anthracene, BpSAB = diphenyl-[4-(2-[1,1';4',1'']terphenyl-4-yl-vinyl)-phenyl]-amine, CBP = 4,4'-N,N'-di(carbazolyl)-biphenyl, and BCP = 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline). CF_x acts as the hole injection layer, NPB is the hole-transporting layer (HTL), CBP:Ir(TBT)₂(acac) is the orange–red emissive layer, BPhen is the electron transporting and hole blocking layer (ETL/HBL), BPhen:Cs₂CO₃ is the n-doping layer, BCP is the exciton blocking layer, which prevents the triplet excitons of phosphorescent dopants being quenched by fluorescent non-radiative energy transfer, α,α -MADN is the host for deep blue dopant BpSAB, and the optimal doping concentration is \sim 3% [16].

The electroluminescence spectra of device **A** at different current densities are shown in Fig. 2. Two blue emission peaks at 456 nm and 476 nm are from the fluorescent dopant BpSAB and the orange–red peak at 588 nm comes from the phosphorescent dye. The relative intensity of blue emission increased slightly under low current densities (from 0.5 mA/cm² to 10 mA/cm²). At high current density, the intensity of the blue peaks was about 50% higher than that of the normalized orange–red one. The color shift could be attributed to the hole blocking effect of BCP insertion layer. In device **A**, there is a large energy barrier (\sim 0.6 eV) of hole injection from α,α -MADN host (HOMO:

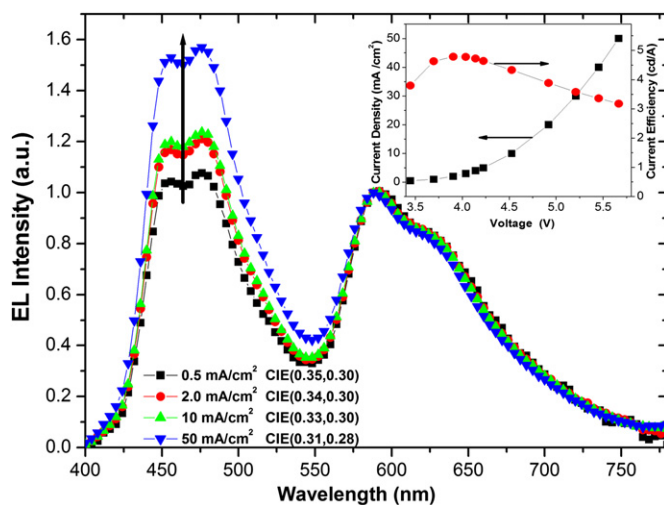


Fig. 2. EL spectra of device **A** (normalization on orange–red peak) at various current densities. Inset: the current density–voltage (*J*–*V*) and current efficiency characteristics of device **A**.

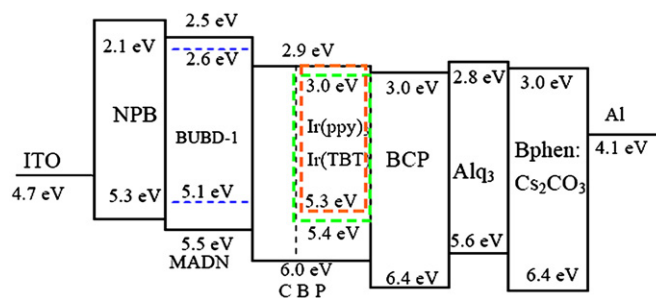


Fig. 3. Energy level diagram and the structure of device **B1**.

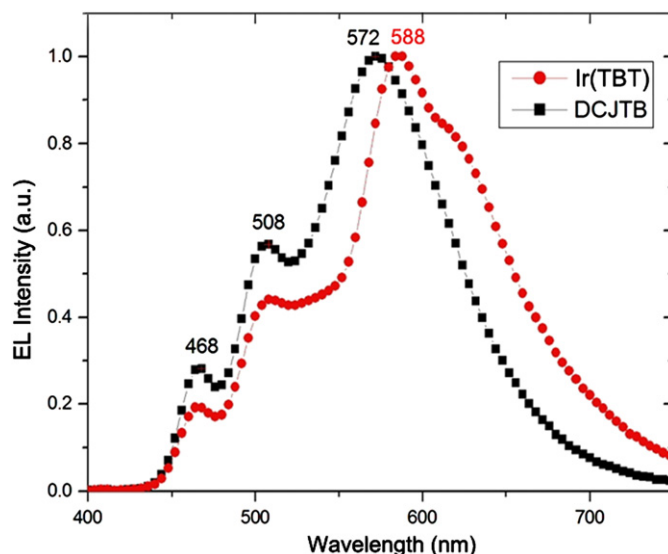


Fig. 4. Normalized EL spectra of devices **B1** and **B2** (DCJTb as the orange–red dopant) at the current density of 10 mA/cm².

–5.8 eV) to BCP (HOMO: –6.4 eV) layer. Apparently large amount hole carriers are accumulated around α,α -MADN/BCP border at high driving voltage; then more excitons are generated around α,α -MADN host layer for increasing blue fluorescent emission. It is worth mentioning that the CIE value (0.33,0.30) is

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