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Highly efficient white organic light-emitting diodes based on broad excimer emission of iridium complex

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ABSTRACT

By utilizing the relatively broad orange-red excimer emission of an iridium complex $(DMBA)_2Ir(acac)$ (DMBA = 5,6-dihydro-9,10-methylenedioxy-benzo[c]acridine, acac = acetylacetonate) together with an efficient blue phosphorescent iridium complex FIrpic, two types of efficient white organic light-emitting diodes were fabricated. Through the optimization of the thickness, location, and doping concentration of each emitting layer, both of the two types of devices exhibited pure white emission with CIE coordinates close to the ideal white emission (0.33, 0.33). Compared with the double-emitting-layer structure, a triple-emitting-layer device structure with a blue-emitting layer sandwiched between two orange-red-emitting layers led to more stable white emission at different biases/brightnesses with maximum efficiencies of up to 12.2%, and 27.0 cd A^{-1} for the forward viewing direction, corresponding to the total efficiencies of 19.7%, 45.9 cd A^{-1} and 32.1 lm W^{-1}. At a high brightness of 1000 cd m^{-2}, the EL efficiencies remained high at 8.8% and 19.2 cd A^{-1}.

1. Introduction

White organic light-emitting diodes (WOLEDs) can be as high efficient large-area light sources that may play an important role in solving the global energy crisis due to the continuously improved efficiencies. On the other hand, their use in displays also becomes increasingly attractive. Full-color displays incorporating high efficient WOLEDs with color filters can circumvent issues of high-resolution shadow masking for fine patterning the organic thin films, making it more feasible for fabrication of large-area OLED displays [1–4]. With high internal efficiencies of organic triplet emitters approaching 100% theoretically, WOLEDs incorporating phosphorescent emitters are most promising to meet the efficiency requirements in all these applications [5–14]. Up to date, the highest efficiencies were achieved by incorporating all-phosphor doped WOLEDs [15]. Forrest and Sun demonstrated highly efficient WOLEDs composed of three separate phosphorescent emission layers [16]. Through controlling the recombination current within individual organic layers by introducing charge-blocking layers, varying layer thicknesses and adjusting doping concentrations, emission from red-, green-, and blue-light-emitting layers was balanced to obtain white light emission. Recently, Wong and co-workers reported color stable four-emission-layer phosphorescent WOLEDs incorporating four iridium complexes with red, yellow, green, and blue emission, respectively [17]. The most significant disadvantage of this type of structure is its complexity in device fabrication process and relatively high operating voltage due to the combined thicknesses of many emissive layers. One effective strategy used to solve this problem is to incorporate phosphor excimer emission, thus white light can be produced by using fewer dopant

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emitters with simpler device structures, which might eventually replace the existing illumination sources [18,19]. Up to date, almost all phosphor excimer based WOLEDs utilized Pt complexes as dopant emitters [18–22]. In our insight, no Ir complex has been applied in this technique.

Recently, we reported highly efficient orange-red OLEDs based on a new iridium complex $(DMBA)_2Ir(acac)$ (DMBA = 5,6-dihydro-9,10-methylenedioxy-benzo[c]acridine, acac = acetylacetonate) with relatively broad excimer emission [23]. In the present work, we report the first example of WOLEDs incorporating the complex $(DMBA)_2Ir(acac)$ in combination with an efficient blue iridium complex bis(4′,6′-difluorophenylpyridinato) iridium (III) picolinate (FIrpic). Through adjusting the doping concentration, varying the thicknesses and locations of emission layers, pure white emission and high luminescent efficiencies were achieved.

2. Experimental

2.1. Materials

The complex $(DMBA)_2Ir(acac)$ was synthesized as we reported before [23]. Other materials were purchased and all compounds used were subject to temperature-gradient sublimation under high vacuum before fabrication of the devices.

Selected spectroscopic data of $(DMBA)_2Ir(acac)$: ^1H NMR ($CDCl_3$, 400 MHz) δ: 8.08 (s, 2 H), 7.71 (s, 2 H), 7.01 (s, 2 H), 6.64 (d, J = 7.2 Hz, 2 H), 6.56 (t, J = 7.2 Hz, 2 H), 6.33 (d, J = 7.6 Hz, 2 H), 6.04 (s, 2 H), 6.00 (s, 2 H), 4.90 (s, 1 H), 3.26–3.30 (m, 2 H), 3.04–3.15 (m, 6 H), 1.60 (s, 6 H). Anal. Calcd for $C_{41}H_{31}IrN_2O_6$: C, 58.63; H, 3.72; N, 3.34. Found: C, 58.48; H, 3.85; N, 3.48.

2.2. OLED fabrication and measurement

The EL devices were fabricated by vacuum deposition of the materials at 10^{-4} Pa onto a clean glass sheet that was pre-coated with a layer of indium tin oxide with a sheet resistance of 10 Ω square^{-1}. The deposition rate for the organic compounds was 0.1–0.2 nm s^{-1}. The cathode of LiF/Al was deposited by first evaporating LiF (1 nm) at a deposition rate of 0.01 nm s^{-1} and then evaporating aluminum (100 nm) at a rate of 0.1–0.2 nm s^{-1}. The cathode was then capped with silver metal (100 nm) by evaporation silver at a rate of 0.3 nm s^{-1}. Current, voltage, and light-intensity measurements were made simultaneously using a Keithley 2400 source meter and a Newport 1835-C optical meter equipped with a Newport 818-ST silicon photodiode.

3. Results and discussion

As described in our previous report [23], the complex $(DMBA)_2Ir(acac)$ had been used to fabricate highly efficient orange to red phosphorescent OLEDs with an external quantum efficiency of 17.7% and maximum brightness of 66,312 cd m^{-2}. An additional benefit of the complex $(DMBA)_2Ir(acac)$ is its relatively broad emission band with an emission peak at 620 nm and a shoulder at 572 nm covering the spectral range from yellow to saturated red. On the other hand, the well known complex FIrpic have been used widely for the fabrication of WOLEDs due to its very high photoluminescence (PL) quantum efficiency in wide gap host and high EL efficiencies [12,13]. Thus the orange-red phosphorescent iridium complex $(DMBA)_2Ir(acac)$ and the blue phosphorescent iridium complex FIrpic were selected in this work for the fabrication of WOLEDs. The molecular structures of the two Ir complexes and the related materials are shown in Fig. 1.

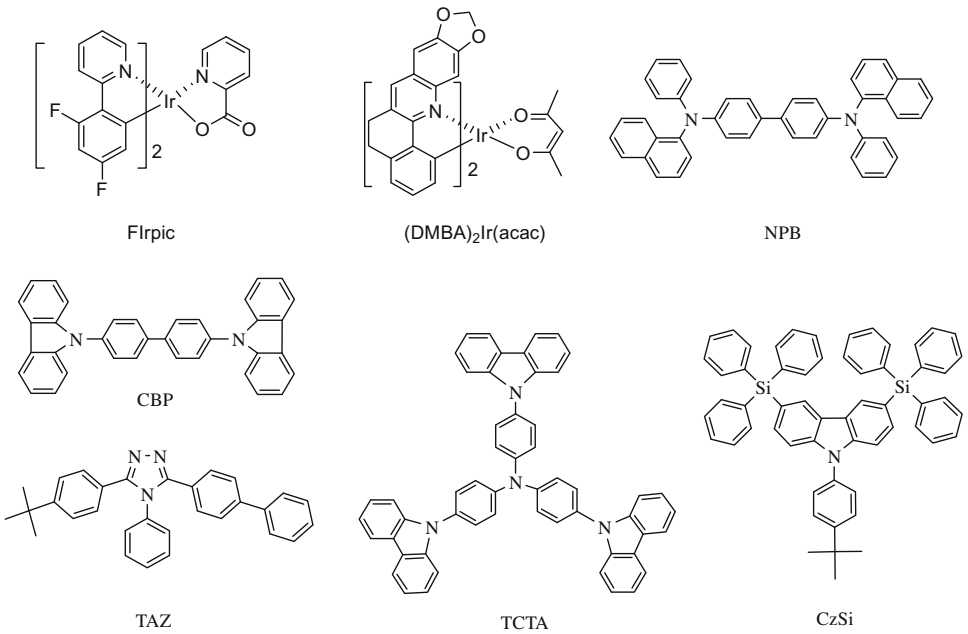

Fig. 1. Molecular structures of compounds used in EL devices.