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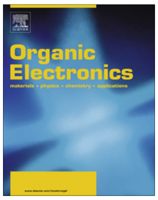

High efficiency and non-color-changing orange organic light emitting diodes with red and green emitting layers

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ABSTRACT

We report a high performance orange organic light-emitting diode (OLED) where red and green phosphorescent dyes are doped in an exciplex forming co-host as separate red and green emitting layers (EMLs). The OLED shows a maximum external quantum efficiency (EQE) of 22.8%, a low roll-off of efficiency with an EQE of 19.6% at 10,000 cd/m^2, and good orange color with a CIE coordinate of (0.442, 0.529) and no color change from 1000 to 10,000 cd/m^2. The exciplex forming co-host system distributes the recombination zone all over the EMLs and reduces the triplet exciton quenching processes.

1. Introduction

Recently, the extent of the applications of organic light emitting diodes (OLEDs) has been increasing, and these applications now range from mobile displays to large size televisions and solid-state lighting using white OLEDs. However, there are significant difficulties in achieving both high efficiency and long device lifetimes in white OLEDs using all phosphorescent dopants due to difficulties in finding a stable deep blue phosphorescent emitting material. One of the alternative ways to overcome the difficulties is to use a hybrid white OLED in which a blue fluorescent and a green/red phosphorescent emitting system have been combined [1–4]. These hybrid white OLEDs take advantages of a stable fluorophor with a long device lifetime and high efficiency green and red phosphors. One difficulty in the creation of hybrid white OLEDs is the triplet exciton quenching by fluorescent blue materials, since many commercially available high efficiency and long device lifetime fluorescent blue materials have a lower triplet energy compared to green phosphors. Therefore, the combinations of low triplet energy fluorescent materials with phosphorescent materials in the adjacent emitting layers can reduce device efficiency.

There are two possible ways to overcome the triplet quenching problem in hybrid white OLEDs: (1) inserting a high triplet energy buffer layer between the blue fluorescent EML and the red/green phosphorescent EMLs [3], and (2) the use of a tandem OLED where a fluorescent blue emitting OLED and a phosphorescent red/green emitting OLED are stacked with a charge generation unit (CGU) between them [1]. Even though device construction by using a buffer layer is simple, it is difficult to fabricate a high efficiency device using this system [3]. The tandem OLEDs of phosphorescent red/green emitting units and fluorescent blue emitting units connected by a CGU lead to white OLEDs with high efficiencies and long device lifetimes. In

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hybrid tandem white OLEDs, two emitting units are separately optimized that are then easily connected with each other using an efficient CGU with a negligible voltage drop [5] by considering the electrical balance and optical interference effects simultaneously. Efficient blue fluorescent OLEDs have been developed for two decades [6–14]; however, there are only a few efficient orange OLEDs using red and green phosphorescent dopants to the authors' knowledge [4,15,16].

In 2009, Yook et al. demonstrated an orange device with an EML containing two dopants which was achieved by the co-doping of two iridium complexes: ($Ir(ppy)_3$ [iridium(III) tris(2-phenylpyridine)] and ($Ir(phq)_2(acac)$ [iridium(III) bis(2-phenylquinoline) acetylacetonate]. They reached a maximum EQE of 13.8% [15]. Schwartz et al. reported a device with very good performances and relatively low roll-off characteristics by doping $Ir(ppy)_3$ and $Ir(MDQ)_2(acac)$ [iridium(III)bis(2-methyldibenzo-[f,h]quinoxaline) acetylacetonate] into TCTA [4,4′,4″-tris(N-carbazolyl)-triphenylamine], which serves as the host material. The orange device achieved a maximum EQE of 17.6% and an EQE of 16.7% at 1000 cd m^{-2} [4]. In 2011, Steinbacher et al. examined the behavior of co-evaporation of $Ir(ppy)_3$ and $Ir(MDQ)_2(acac)$. Without any device improvements the maximum EQE was as high as 5.2% [16].

In this work, we report highly efficient orange OLEDs with low roll-offs and no color change with increasing luminance by using $Ir(ppy)_2(acac)$ [iridium(III) (bis(2-phenylpyridine) acetylacetonate)] and $Ir(mphq)_2(acac)$ [iridium(III) (bis(2-(3,5-dimethylphenyl)quinoline acetylacetonate)] as the green and red dopants, respectively. The green and red phosphorescent dyes are doped in an exciplex forming co-host [17] as separate red and green EMLs. The high efficiency orange OLEDs can be combined with high efficiency blue fluorescent emitting units to produce high color rendering index (CRI), high efficiency, and low efficiency roll-off hybrid tandem white OLEDs.

2. Experimental section

The OLEDs were fabricated by thermal evaporation onto cleaned glass substrates pre-patterned with 150 nm-thick indium thin oxide (ITO) at a base pressure of $<5 \times 10^{-7}$ Torr without breaking the vacuum. Before the deposition of the organic layers, the ITO substrates were exposed to an ultraviolet-ozone flux for 10 min, following degreasing in acetone and isoprophylalcohol. The current density, the luminance and the EL spectra were measured using a Keithley 2400 programmable source meter and a SpectraScan PR650 (Photo Research). The angular distribution of the EL intensity was measured using a Keithley 2400 programmable source meter, a rotation stage and an Ocean Optics S2000 fiber optic spectrometer. The EQE and power efficiency of the OLEDs were calculated from the current density, the luminance, the EL spectra, and the angular distribution of the EL intensity data. The transient EL measurements were obtained by applying voltage pulses to the device corresponding to 30 mA/cm^2 for the red and green emissions with a 100 μs width using an 8114A pulse generator (Agilent), and detecting the emission using an ACTON spectrometer (SpectraPro-300i) connected with a photomultiplier tube (Acton Research, PD-438). The detection wavelengths were 524 and 616 nm for the green and red emissions, which corresponded to the peak wavelengths of the $Ir(ppy)_2(acac)$ and $Ir(mphq)_2(acac)$ emissions, respectively. All signals were detected and integrated 1000 times by a 54642A oscilloscope (Agilent). The voltage applied to the OLEDs was measured over a 1 MΩ resistance parallel to the OLED.

3. Results and discussion

Fig. 1 shows a schematic diagram of the device structure and the energy levels and the molecular structure of the consisting layers. The device has a very simple structure consisting of three charge transporting materials and green and red phosphors. The HOMO and LUMO levels of the organic materials have been obtained from the published literature [17,18] Co-deposited TCTA and B3PYMPM [bis-4,6-(3,5-di-3-pyridylphenyl)-2-methylpyrimidine] doped with the red and the green dopants side by side form the emitting layers. TCTA and B3PYMPM are chosen as the exciplex forming co-host for the EMLs because this co-host shows a broad emission zone, and the exciplex has a higher triplet energy (2.5 eV) [17] than green ($Ir(ppy)_2(acac)$, $T_1 = 2.4$ eV) and red ($Ir(mphq)_2(acac)$, $T_1 = 2.0$ eV) phosphorescent dopants. In addition, the electrons and holes in the co-host are well confined inside the EML due to very high injection barriers between the hole transporting layer (HTL)/EML (0.86 eV) for electrons and the EML/electron transporting layer (ETL) (0.94 eV) for holes, while the triplet energies of the HTL (TCTA,

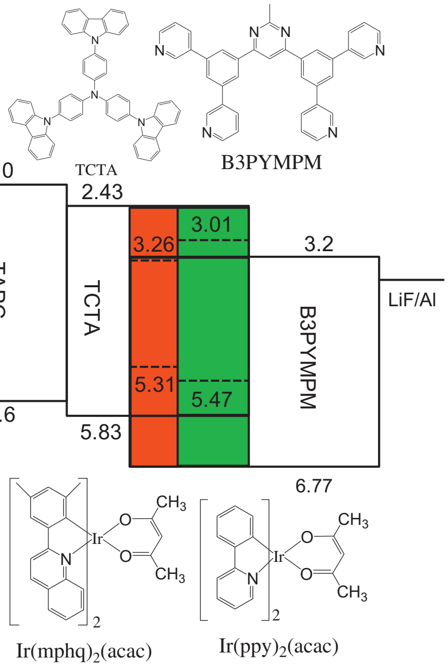

Fig. 1. The molecular structure of TCTA, B3PYMPM, $Ir(ppy)_2(acac)$, and $Ir(mphq)_2(acac)$ and the device structure and energy level of the OLEDs.