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High-color rendering index white organic light-emitting diodes based on exciplex forming blue emitters

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ABSTRACT

A novel emitting layer structure of white organic light-emitting diodes (WOLED) was developed using exciplex-forming two blue emitters, 2,3,4,5,6-penta(9H-carbazol-9-yl)benzonitrile (5CzCN) and tris(2-(1-(2,4-diisopropyldibenzo[b,d]furan-3-yl)-1H-imidazol-2-yl)phenyl)iridium (Ir(dbi)$_3$). The 5CzCN blue delayed fluorescence material and Ir(dbi)$_3$ phosphorescent emitter partially formed a red exciplex in the mixed film. Combination of blue emission from the blue emitters and red emission from the exciplex provided white emission in the blue emitting 5CzCN and Ir(dbi)$_3$ co-doped device. The WOLED fabricated using the blue emitting 5CzCN and Ir(dbi)$_3$ emitters achieved high color rendering index of 90.8 at 100 cd/m^2.

Introduction

There have been a lot of research activities in the development of white organic light-emitting diodes (WOLEDs) technology to use it for solid-state lighting applications and backlights for flat-panel display [1–9]. For the solid-state lighting, the color rendering index (CRI) is important because the object under different light sources may look different due to different color of the reflected light from the light sources [10]. The white-light sources are required to have similar color coordinates to that of a blackbody radiator with a color correlated temperature from 2500 K to 6500 K, and a CRI more than 80 to gain high-quality white-light illumination [11–15].

There have been several methods to realize white emission in the WOLEDs. Firstly, a stacked WOLED based on multiple emissive layers with red, green and blue emitters in each emitting layer is the most well-known method to obtain white emission. For example, D'Andrade et al. demonstrated a tri-layer WOLED in which the red, green and blue phosphorescent dopants were doped in the separate layers [16]. Other than that, many WOLEDs having at least two stacked emitting layers were reported. Secondly, co-doping of two or more emitters in a single emitting layer is also a widely used method to realize white color in the WOLEDs. For instance, D'Andrade et al. demonstrated WOLEDs using a single emissive layer containing three electrophosphorescent dopants [17]. However, this method is rather difficult to apply in the vacuum deposited WOLEDs because co-deposition of several organic materials is very complicated due to the low doping concentration of red emitters, which cannot be handled in deposition process. Thirdly, white color in the WOLEDs can be demonstrated by excimer based white emission. It was reported that Pt type phosphorescent emitters can show excimer emission by stacking planar geometry based Pt type triplet emitters. The Pt based blue triplet emitters showed white emission in the devices by combination of blue emission from the Pt emitter and red emission from the excimer. In 2002, Adamovich et al. demonstrated a single-dopant excimer WOLED using a Pt emitter [18]. The use of the excimer emission is a good way in order to avoid the increasing dopant concentration and heterogeneous structure of the multiple layer [19]. Other than these main approaches, there have been other methods such as tandem structure, blue color conversion, single white emitter and so on. However, there has been no work reporting white emission using exciplex in spite of broad light emission spectrum which is favorable for high CRI. In 2014, Hung et al. demonstrated all-exciplex-based WOLED using a tandem structure, but they used two different exciplexes for blue and red emission color in separated emission layer [20].

In this work, a new method to fabricate high CRI WOLED is suggested by doping two blue emitters which partially form a red exciplex in a single emitting layer. In the emitting layer, blue light was generated by the blue emitter and red light was illuminated by the exciplex at the same time. 2,3,4,5,6-Penta(9H-carbazol-9-yl)

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benzonitrile (5CzCN) and tris(2-(1-(2,4-diisopropyldibenzo[b,d]furan-3-yl)-1H-imidazol-2-yl)phenyl)iridium ($Ir(dbi)_3$) were used as the blue dopant materials and were doped in the (oxybis(2,1-phenylene))bis(diphenylphosphine oxide) (DPEPO) host material. 5CzCN was a blue thermally activated delayed fluorescence (TADF) material and $Ir(dbi)_3$ was a blue phosphorescent material. The WOLEDs developed using the blue TADF emitter and blue triplet emitter co-doped emitting layer showed high CRI of 90.8.

Experimental

The device was designed as follows.

ITO (120 nm)/PEDOT:PSS (60 nm)/TAPC (20 nm)/mCP (10 nm)/DPEPO:$Ir(dbi)_3$:5CzCN (25 nm:10%:x%)/TSPO1 (5 nm)/TPBi (40 nm)/LiF (1.5 nm)/Al (200 nm). ITO was indium tin oxide, PEDOT:PSS was poly(3,4-ethylenedioxythiophene) polystyrene sulfonate, TAPC was 4,4′-cyclohexylidenebis[*N*,*N*-bis(4-methylphenyl)benzenamine], mCP was 1,3-bis(*N*-carbazolyl)benzene, TSPO1 was diphenyl-4-triphenylsilylphenyl-phosphine oxide and TPBi was 2,2′,2″-(1,3,5-benzinetriyl)-tris(1-phenyl-1-H-benzimidazole). 5CzCN was reported as a blue TADF emitter possessing five carbazole groups in the benzonitrile core [21]. The strong electron deficiency of the benzonitrile core stabilized the highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) of 5CzCN, which resulted in the HOMO/LUMO level of −6.29/−3.44 eV. On the other hand, $Ir(dbi)_3$ was known as a blue phosphorescent emitter having an isopropyl modified dibenzofuran substituted phenylimidazole ligand [22]. The doping concentrations of 5CzCN were 20%, 30%, 40% and 50%. Device structure and molecular structures of organic materials used in this work are shown in Fig. 1(a) and (b).

Before device fabrication, the substrates were cleaned using acetone, distillated water, isopropanol (IPA), and boiling IPA. The substrates were sonicated for 10 min in each cleaning process. After the washing process, the substrates were soaked in the boiling IPA for 2 min and the solvent was evaporated in a vacuum condition. On the cleaned ITO substrates, IPA diluted PEDOT:PSS solution was spin coated for 5 s at 500 rpm and 45 s at 1000 rpm.

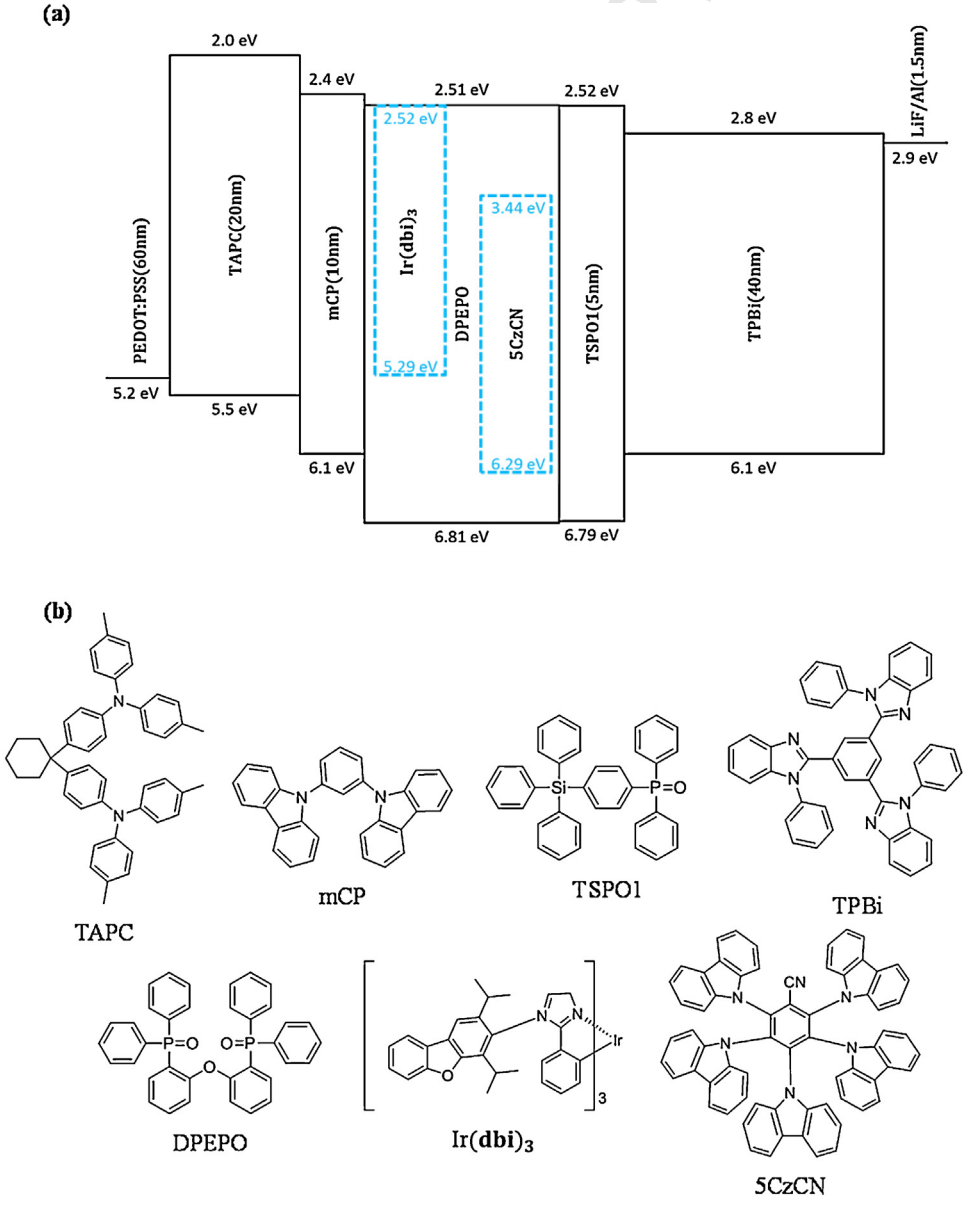

Fig. 1. (a) Device structure of WOLEDs (b) molecular structures of organic materials.

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