Organic Electronics 14 (2013) 3024–3029

Contents lists available at ScienceDirect

Organic Electronics

journal homepage: www.elsevier.com/locate/orgel

High quantum efficiency and color stability in white phosphorescent organic light-emitting diodes using carboline derivative as a host material

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ARTICLE INFO

Article history:
Received 8 July 2013
Received in revised form 31 August 2013
Accepted 3 September 2013
Available online 19 September 2013

Keywords:
Phosphorescent white organic light emitting diodes
High efficiency
Carboline host
Two color device
Color stability

ABSTRACT

Highly efficient and color stable phosphorescent white organic light-emitting diodes were developed using a high triplet energy host material, 3,3′-bis(9H-pyrido[2,3-b]indol-9-yl)-1,1′-biphenyl (CbBPCb), derived from carboline. Two color phosphorescent white organic light-emitting diodes were fabricated by co-doping of blue and orange triplet emitters or double emitting layer structure of blue and orange emitting layers. High quantum efficiency above 20% and color stability were achieved in the white device by optimizing the doping concentration and emitting layer thickness.

1. Introduction

Phosphorescent white organic light-emitting diodes (PHWOLEDs) have been developed to improve the low quantum efficiency of fluorescent white organic light-emitting diodes [1–3]. Although hybrid white organic light-emitting diodes with both fluorescent and phosphorescent emitters were also reported, the quantum efficiency of the hybrid white organic light-emitting diodes was lower than that of PHWOLEDs [4,5].

The quantum efficiency of PHWOLEDs can be improved by developing high efficiency blue phosphorescent organic light-emitting diodes because one dominant white light emission mechanism of PHWOLEDs is energy transfer from blue emitting material to orange emitting material [5–9]. Blue emission of blue triplet emitter is partially absorbed by the orange emitter and balanced white emission is obtained. Therefore, it is important to apply highly efficient blue emitting layer to increase the quantum efficiency of PHWOLEDs.

In this work, high efficiency PHWOLEDs were developed using a high triplet energy host material, 3,3′-bis(9H-pyrido[2,3-b]indol-9-yl)-1,1′-biphenyl (CbBPCb), derived from carboline. It was demonstrated that high quantum efficiency above 20% was achieved in the two color PHWOLEDs with single emitting layer co-doped with blue and orange emitters, or double emitting layer of blue and orange emitters.

2. Experimental

The stack structure of the single emitting layer PHWOLEDs was indium tin oxide (ITO, 50 nm)/poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS, 60 nm)/4,4′-cyclohexylidenebis[N,N-bis(4-methylphenyl)aniline] (TAPC, 20 nm)/1,3-bis(N-carbazolyl)benzene (mCP, 10 nm)/CbBPCb:iridium(III) bis[(4,6-difluorophenyl)-pyridinato-N,C^2]picolinate (FIrpic): iridium(III) bis(2-phenylquinoline) acetylacetonate($Ir(pq)_2acac$) (30 nm, 10%:*x*% doping)/

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http://dx.doi.org/10.1016/j.orgel.2013.09.005

diphenylphosphine oxide-4-(triphenylsilyl)phenyl (TSPO1, 35 nm)/LiF(1 nm)/Al (200 nm). Doping concentrations of FIrpic (x) were 0.5 and 1.0%. Double emitting layer PHWOLEDs had the device structure of ITO (50 nm)/PEDOT:PSS (60 nm)/TAPC (20 nm)/mCP (10 nm)/CbBPCb:FIrpic (30-y nm, 10%)/CbBPCb:Ir(pq)$_2$acac (y nm, 5%)/TSPO1 (35 nm)/LiF (1 nm)/Al (200 nm). The thicknesses of the blue emitting layer (y) were 5 (device I), 15 (device II) and 25 nm (device III). Chemical structures of CbBPCb, FIrpic and Ir(pq)$_2$acac are shown in Fig. 1 in addition to the device structure of PHWOLEDs. CbBPCb was synthesized according to the method reported earlier [10]. All devices were fabricated by vacuum thermal evaporation process.

Device performances of PHWOLEDs were measured using Keithley 2400 source measurement unit and CS1000 spectroradiometer after encapsulating the devices with a glass lid in glove box with CaO getter inside.

3. Results and discussion

The CbBPCb host was reported as a high triplet energy host with balanced hole and electron density in the emitting layer [10]. A high quantum efficiency of 30.1% was achieved in the blue device doped with FIrpic due to efficient energy transfer and charge balance in the emitting layer. Therefore, the CbBPCb host can be effectively used as the host material to develop high efficiency PHWOLEDs.

In this work, two device structures of single emitting layer PHWOLED and double emitting layer PHWOLED were fabricated. Single emitting layer structure is better than the double emitting layer structure in that color stability can be easily achieved because of constant energy transfer from blue emitter to orange emitter irrespective of the luminance of the device. Additionally, simple management of the orange doping concentration can control the color of the PHWOLEDs. However, as the device performances of the PHWOLEDs are dominated by the blue emitter, highly efficient and stable blue emitters are required to obtain good device performances from the single emitting layer PHWOLEDs. In addition, careful control of the orange doping concentration is necessary because the emission color of the PHWOLEDs is sensitive to the doping concentration of the orange emitter.

Double emitting layer structure is advantageous in that orange doping concentration is not critical to the device performances of PHWOLEDs, which provides easy fabrication process of the device. Better stability of the PHWOLEDs is another merit of the double emitting layer structure. However, the double emitting layer device suffers from poor color stability and complicated parameter management because both doping concentration and emitting layer thickness should be optimized to obtain balanced white emission.

Single emitting layer PHWOLEDs were fabricated by co-doping of blue and orange triplet emitters. Doping concentration of blue triplet emitter was fixed at 10% and the doping concentrations of orange triplet emitter were 0.5%–1.0% to manage the relative intensity of blue and orange emission. Fig. 2 shows current density–voltage–luminance curves of blue PHWOLEDs. The current density of the PHWOLEDs was not greatly affected by the doping concentration of Ir(pq)$_2$acac although slight increase of current density at 1.0% doping concentration of Ir(pq)$_2$acac. The luminance was also similar in the two PHWOLEDs with different Ir(pq)$_2$acac doping concentration. Turn-on voltage which is defined as the voltage at 1 cd/m^2 was 3.5 V.

Quantum efficiency–luminance and power efficiency–luminance curves of the PHWOLEDs are shown in Fig. 3. The quantum efficiency of PHWOLEDs was high at 0.5%

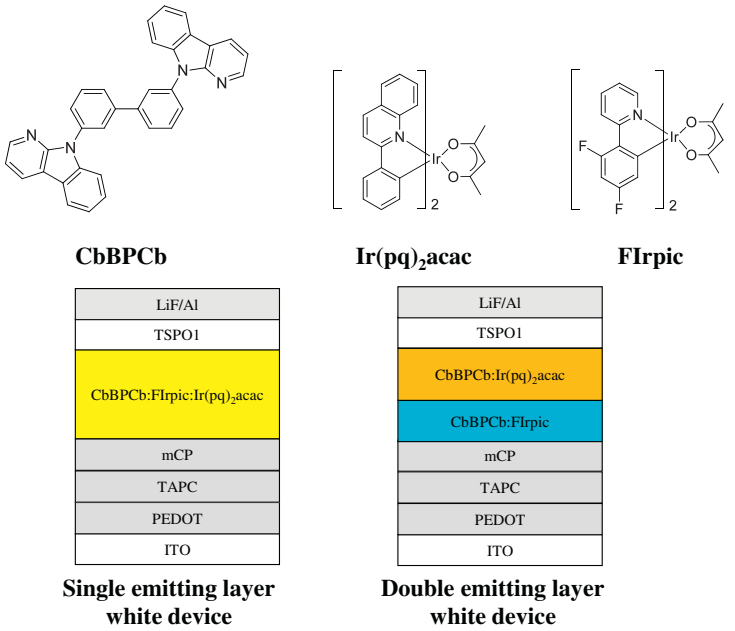

Fig. 1. Chemical structure of CbBPCb, FIrpic and Ir(pq)$_2$acac and the device structure of PHWOLEDs.