Organic Electronics 17 (2015) 1–8

Contents lists available at ScienceDirect

Organic Electronics

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

Efficient solution-processed green and white phosphorescence organic light-emitting diodes based on bipolar host materials

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ARTICLE INFO

Article history:
Received 18 August 2014
Received in revised form 31 October 2014
Accepted 1 November 2014
Available online 13 November 2014

Keywords:
Solution-process
Organic light-emitting diode
Bipolar
Carbazole

ABSTRACT

Four carbazole-based bipolar host materials are utilized for solution-processed phosphorescent organic light-emitting diodes (PhOLEDs). These bipolar materials consist of an electron-donor unit (carbazole) linking to a fluorene unit bearing various electron-acceptor units (oxadiazole, cyano, and benzimidazole) via a saturated carbon, giving sufficiently high triplet energies due to the lack of direct electronic coupling between the donor and acceptor(s). The resulting physical properties and bipolar characteristics render the realization of efficient solution-processed green and white OLEDs feasible. The best green light-emitting device based on bipolar host **CzFCBI** incorporating a stepwise hole-injection/transporting system exhibit a low drive voltage, a maximum external quantum efficiency of 14.0%, a current efficiency of 49.0 cd/A, and a power efficacy of 55.0 lm/W. Moreover, the **CzFOXa**-based two-component (blue–orange) white light-emitting device shows a warmish-white emission with a maximum external quantum efficiency of 6.9% and stable chromaticity coordinates at different luminance levels and yield a high color rendering index (CRI) reaching 76 at a luminance of 1000 cd/m^2.

1. Introduction

The excellent brightness and self-emission allow organic light emitting devices (OLEDs) exhibiting low power consumption and fast response required for mainstream and futuristic displays, making them interesting candidates for advanced display and lighting devices. In spite of the complicated and expensive vacuum process, solution-processed phosphorescent OLEDs (PhOLEDs) are of extensive research interest owing to their merits and promising applications in low-cost fabrication and facile manufacturing processes. High-performance solution-processed PhOLEDs are expected to play a central role in ultra-low-cost fabrication processes and large area manufacturing [1–4]. However, the interfacial mixing and/or the erosion of the underlayer during solution processing make multi-layered OLEDS more challenging. To fabricate the high performance solution-processed PhOLEDs with well-developed iridium-based emitters, the host materials play an important role. In general, the host materials with good thin film forming and balance charge-transporting characters are highly desired. Consequently, host materials with bipolar carrier transportation characteristics are good candidates for solution-processed PhOLEDs. Numerous efforts have been recently reported to meet these challenges. In general, bipolar host materials incorporate units with hole- and electron-transporting characteristics in different ways [5–9]. Carbazole and triphenylamine are commonly used as a hole-transporting unit while oxadiazole [10,11], cyano [12,13], and benzimidazole [14,15] act as electron-transporting units. For example, Kakimoto et al. synthesized a new series of

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http://dx.doi.org/10.1016/j.orgel.2014.11.002
1566-1199/

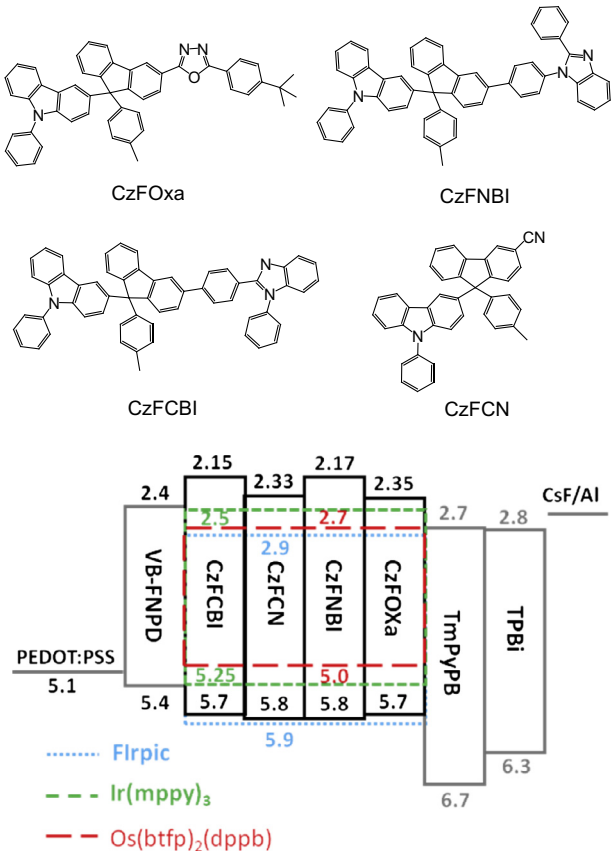

Fig. 1. Chemical structures of carbazole-based bipolar hosts and energy diagram of device components in this study.

star-shaped bipolar host molecules incorporating triphenylamine and benzimidazole groups. The solution-processed green phosphorescent OLEDs employed this star-shaped bipolar host and $Ir(ppy)_3$ as a guest achieved a maximum current efficiency (CE) of 27.3 cd/A [16]. Yang et al. also reported a solution-processable bipolar host material comprising hole-transporting triphenylamine and electron-transporting oxadiazole that produced a green light-emitting device showing a maximum CE of 56.8 cd/A [17]. Karatsu et al. manufactured an $Ir(ppy)_3$-based device displaying a CE of 15.0 cd/A using a bipolar host material consisting of carbazole and m-terphenyl derivatives [18]. In this study, efficient solution-processed green and white OLEDs were fabricated using a series of carbazole-based bipolar host materials in the emission layers. The carbazole electron donor was combined via a sp^3-carbon (C9) center with different fluorene-based electron acceptors including C-linked (**CzFCBI**) or N-linked (**CzFNBI**) benzimidazole group as well as cyano (**CzFCN**), and 1,3,4-oxadiazole group (**CzFOXa**) to the C3 of fluorene. These carbazole-based bipolar host materials have previously shown balance carrier-transporting properties and high triplet energies (E_T) in vacuum-sublimed thin films [19,20]. The carrier transport character and the capability of confining emissive exciton make them potential candidates for the development of efficient solution-processed PhOLEDs. In this work, we selected tris-(2-4(4-toltyl) phenylpyridine)iridium(III) ($Ir(mppy)_3$) as the green dopant to be incorporated into these bipolar hosts. The solution-processed green PhOLEDs based on the carbazole-based bipolar host materials exhibited peak external quantum efficiency (EQE) of 14.0–11.9%, CE of 49.0–41.7 cd/A, and power efficacy (PE) of 55.0–39.9 lm/W. A thermally polymerizable hole-transporting material (VB-FNPD) [21,22] was introduced as an inter-layer between hole-injection (PEDOT:PSS) and emitting layers to give a stepwise hole-injection/transporting system, rendering these devices to show a low drive voltage of <3.0 V (<5.0 V) at a luminance of 1 cd/m^2 (1000 cd/m^2). Using these bipolar host materials, two-color based warmish-white PhOLEDs with limited color variation upon a wide luminance range of 100–5000 cd/m^2 were also obtained.

2. Experiments

2.1. Device fabrication

Chemical structures of compounds and device architecture utilized in this study are shown in Fig. 1. Before the organic thin-film deposition, pre-patterned indium tin oxide (ITO) glass substrates (sheet resistance ~12 Ω/sq) were consecutively cleaned using deionized water, 2-propanone, and methanol for 15 min each in an ultrasonic bath