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Highly efficient blue and all-phosphorescent white polymer light-emitting devices based on polyfluorene host

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ABSTRACT

We report efficient blue electrophosphorescent polymer light emitting devices with polyfluorene (PFO) as the host and iridium bis[2-(4,6-difluorophenyl)-pyridinato-N,C^2] picolinate (FIrpic) as the dopant. Despite the low-lying triplet energy level of the polyfluorene polymer host, phosphorescent quenching can be suppressed by using poly(*N*-vinylcarbazole) (PVK) as anode buffer layer, resulting in a high luminous efficiency of 26.4 cd A^{-1}, which is one of the best results in the literature based on conjugated polymer reported to date. The reduced phosphorescent quenching is found to be associated with the exciton formation and charge carrier recombination within the PVK layer and the PVK/PFO interface due to the accumulation of holes. As compared with the devices based on non-conjugated host polymer PVK, the devices based on PFO showed a lower turn-on voltage (3.6 V vs. 4.4 V) and higher power efficiency (17 lm W^{-1} vs. 8.3 lm W^{-1}) due to the higher mobility of PFO. When doubly doped with a newly synthesized yellow-emitting metallophosphor, white polymer light-emitting devices with superior device performance (a peak device efficiency of 40.9 cd A^{-1}, a CIE coordinates of (0.32, 0.48), and a power efficiency of 31.4 lm W^{-1}) was achieved. These findings can broaden our selection in polymer hosts for highly efficient phosphorescent blue emitting devices and can find potential applications in full color displays and solid-state lighting applications in the future.

1. Introduction

White polymer light-emitting devices (WPLEDs) have attracted broad research interest due to their potential applications in full-color display panels, flexible displays and solid-state lighting sources [1,2]. In the past decade, the performance of WPLEDs has been improved significantly, in terms of efficiency and stability, due to the advance of novel materials and device configuration. Among all kinds of WPLEDs, the polymer host-all phosphorescent dopants system is of particular interest, since it can allow for a conversion of up to 100% of injected charges (both singlet and triplet excitons can be harvested) into emitted photons [3–6], while it can be fabricated via solution-processed technology.

However, high-efficiency blue-emitting electrophosphorescent PLEDs represents a big challenge all along because high-energy triplet excitons tend to flow back to low-energy sites [7–9], and the species of stable deep blue phosphorescence emitter are very rare. Alternatively, sky-blue-emitting triplet emitters, in combination with non-conjugated polymer, such as poly(*N*-vinylcarbazole) (PVK), which has relatively high triplet level (3.0 eV) [10,11], were commonly used to achieve blue-emitting electrophosphorescent

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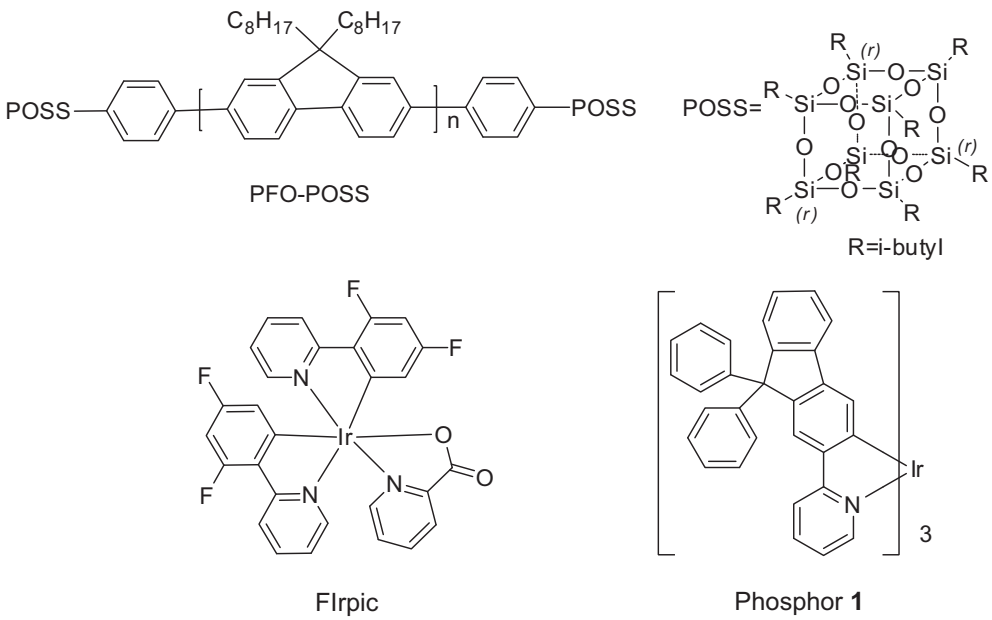
PLEDs. Yang et al. reported efficient blue phosphorescent polymer light-emitting devices with iridium bis[2-(4,6-difluorophenyl)-pyridinato-N,C^2] picolinate (FIrpic) as dopant, while PVK and electron-transporting 1,3-bis[(4-tert-butylphenyl)-1,3,4-oxadiazolyl] phenylene (OXD-7) as the host. The obtained devices showed a maximal luminous efficiency (LE) of 18.2 cd A^{-1} and power efficiency (PE) of 8.8 lm W^{-1}, respectively [12]. Huang et al. reported that by using Li_2CO_3-doped poly[9,9-bis(2-(2-(2-diethanol-amino-ethoxy) ethoxy) ethyl) fluorene-alt-4, 4′-phenylether] (PDFPE) as the electron transporting layer and *p*-doped poly(3,4-ethylenedioxythiophene):poly(styrenesulfonic acid) (PEDOT:PSS) as hole transporting layer, blue-emitting phosphorescent PLEDs based on PVK: FIrpic exhibited a maximal LE of 20.3 cd A^{-1} and PE of 9.2 lm W^{-1} [13]. With similar strategy, the efficiency of the blue-emitting phosphorescent PLEDs from PVK: FIrpic have been improved to 22–28 cd A^{-1}, via doping the active layer with electron transporting molecules or incorporation of small-molecule based electron-transport layer [14–17]. Despite the progress in the LE of these devices, their power efficiency are relatively low (i.e. 9–15 lm W^{-1}), mainly due to the non-conjugated nature of the PVK (low hole transport mobility of $\sim 10^{-5}$ cm^2/V s), and its unmatched energy level (due to the very deep HOMO energy level of ~ -5.8 eV). On the other side, we found recently that despite the presence of the low-lying triplet states [18], conjugated polyfluorenes and their derivatives can be utilized as the host for green phosphorescent complexes, so long as there is a thin layer of PVK layer incorporated as the anode buffer interlayer [19]. More recently, we demonstrated highly efficient hybrid WPLEDs in which PFOs play the roles of a fluorescent blue emitter and a host material for the emitters, with the presence of PVK as the key anode interfacial layer [20,21]. Due to the broad emission covering the entire visible light spectrum from 400 to 780 nm, the resulting devices show a nearly pure white color with Commission Internationale d'Énclairage coordinates of (0.356, 0.334), with a maximal LE reaching 21.4 cd A^{-1} [21].

In this study we demonstrated that the application of polyfluorene as the host for electrophosphorescent PLEDs can be extended to sky-blue emitter FIrpic, despite their lower-lying triplet energy levels ($\sim$2.3 eV) as compared to FIrpic ($\sim$2.64 eV). Due to a suppressed phosphorescent quenching by using PVK as the anode buffer layer, a high LE of 26.4 cd A^{-1}, which is one of the best results based on conjugated polymer reported to date [11–17] was achieved. More importantly, as compared with the devices based on the non-conjugated host polymer PVK, the devices based on polyfluorene host showed a lower turn-on voltage (3.6 V vs. 4.4 V) and higher PE (17 lm W^{-1} vs. 8.3 lm W^{-1}). To the best of our knowledge, this is one of the most efficient solution-processed blue-emitting PLEDs reported so far [15]. On the basis of the blue-emitting PLEDs, we further found that this strategy is applicable to achieve efficient all-phosphorescent WPLEDs [22,23]. In combination with a newly reported yellow-emitting iridium complex [24], the obtained WPLEDs showed a peak PE of 31.4 lm W^{-1}, which is among the best efficiency for WPLEDs based on conjugated polymer [2,25,26]. It is worthy of note that the PE of the device can be retained as high as 28 lm W^{-1} and 23 lm W^{-1} at a luminance of 100 cd m^{-2} and 1000 cd m^{-2}, respectively, mainly due to the low operation voltage and low turn-on voltage ($\sim$3.4–3.6 V).

2. Experimental

2.1. Materials

PVK was purchased from Aldrich while PFO–POSS, OXD-7, FIrpic were purchased from American Dyes Sources. The synthesis of the home-made phosphor **1**



Scheme 1. Molecular structure of the polymer host PFO–POSS, and the phosphorescent dyes FIrpic and **1** [24] used in this study.