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High efficiency all phosphorescent white light-emitting diodes based on conjugated polymer host

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ABSTRACT

High efficiency all phosphorescent white electroluminescence was realized by double doping of blue-light-emitting bis(2-(4,6-difluorophenyl)-pyridinato-N,C2′) picolinate (FIrpic) and red iridium complex $Ir(DMFPQ)_2pbm$ into conjugated polymer host poly(9,9-dioctylfluorene) (PFO). Effects of hole-transport layer (HTL) on the performances of white polymer light-emitting diodes (WPLEDs) were investigated. First of all, PVK as the HTL was essential, because the back energy transfer from FIrpic to PFO caused by the low-lying triplet energy level of PFO was suppressed by PVK. Furthermore, performances of the WPLEDs were enhanced by introducing CBP into PVK owing to improved balance of electron and hole current. The resulting all phosphorescent WPLEDs have a peak luminous efficiency of 15.5 cd/A and a peak power efficiency of 6 lm/W. Commisssion Internationale de L'Eclairage (CIE) coordinates of (0.41, 0.38) were realized at a current density of 18 mA/cm^2. The obtaining of the efficient all phosphorescent white electroluminescence with PFO as host polymer will broaden the approaches of white light generation and be a big promote for the application of phosphorescent WPLEDs.

1. Introduction

White organic/polymer light-emitting diodes (WOLEDs/WPLEDs) based on phosphorescent dyes have gained increasing research interest in both scientific and industrial communities due to their potential applications in full-color flat-panel displays, back-lighting sources for liquid-crystal displays, and especially in next generation solid-state lighting sources [1–5]. Compared with WOLEDs, WPLEDs are more promising for large size or flexible products due to their solvent processing manufacture technology [6,7]. Non-conjugated polymer PVK has been a commonly used polymer host for phosphorescent dyes [8,9]. Indeed, PVK is an excellent material as hole-transport layer (HTL) of polymer light-emitting diodes (PLEDs) [10,11]. As a host polymer, PVK has however an inherent defect in that its electron and hole mobility difference is too large. Electron-transport materials must be used together with PVK to enhance the electron current [12,13]. However, in fabricating functional layers on top of the emissive layer (EML), electron-transport materials may be selectively removed resulting in poor PLEDs efficiency [14–16]. Therefore, it is necessary to find other host polymers for phosphorescent dyes. Poly(9,9-dioctylfluorene) (PFO) is a commonly used blue material, as well as a well-known host polymer for red phosphorescent dyes [17,18]. However, because of the low-lying triplet energy level of PFO, it was thought to be a bad choice as a host for green or blue phosphorescent dyes. But efficient green phosphorescent PLEDs were realized based on PFO host recently by inserting HTL PVK [19,20]. If efficient all phosphorescent white electroluminescence (EL) can be achieved with PFO as host polymer, it will broaden the approaches of white light generation and will be a big promote for the application of phosphorescent WPLEDs.

In this letter, we report a high efficiency all phosphorescent white EL with conjugated polymer PFO as the matrix of two iridium complexes, blue-light-emitting bis(2-(4,6-difluorophenyl)-pyridinato-N,C2′) picolinate (FIrpic) and red dye $Ir(DMFPQ)_2pbm$. EL spectra of PLEDs were tuned by varying the weight ratio of FIrpic and $Ir(DMFPQ)_2pbm$ in PFO, and white EL was obtained at 10:1. Moreover, effects of HTL on the performances of WPLEDs were investigated. First of all, PVK as the HTL was essential, because the back energy transfer from FIrpic to PFO caused by the low-lying triplet energy level of PFO was suppressed by PVK. Furthermore, performances of the WPLEDs were enhanced by introducing CBP into PVK. The resulting all phosphorescent WPLEDs have a peak luminous efficiency of 15.5 cd/A and a peak power efficiency of 6 lm/W. Commisssion Internationale de L'Eclairage (CIE) coordinates of (0.41, 0.38) were realized at a current density of

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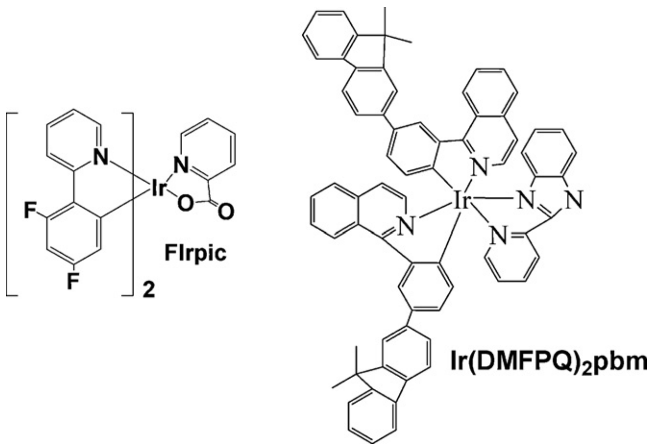

Fig. 1. The molecular structures of FIrpic and Ir(DMFPQ)$_2$pbm.

$18\,mA/cm^2$. This efficiency was comparable with that of the phosphorescent WPLED based PVK host, which was about 20 cd/A [9]. To the best of our knowledge, this is the first report of high efficiency all phosphorescent WPLEDs based on conjugated polymer host. The obtaining of the efficient all phosphorescent white EL with PFO as host polymer will broaden the approaches of white light generation and be a big promote for the application of phosphorescent WPLEDs.

2. Materials and methods

Chemical structures of FIrpic and Ir(DMFPQ)$_2$pbm [21] are shown in Fig. 1.

Devices configurations consist of ITO/PEDOT:PSS (40 nm)/PVK (40 nm)/EML (70 nm)/CsF (1 nm)/Al (100 nm), where PEDOT (Baytron P4083, purchased from Bayer AG) and PVK (purchased from Aldrich) were served as hole injecting and transporting layer, respectively. The EML consists of two phosphorescent iridium complexes simultaneously dispersed in a PFO host matrix: blue-light-emitting FIrpic and red iridium complexes Ir(DMFPQ)$_2$pbm. To prepare the device, an ITO-coated glass substrate was thoroughly cleaned in an ultrasonic bath. Acetone, detergent, deionized water, and isopropanol were sequentially used. Subsequently, the substrate was baked in a vacuum oven at 80 °C for 2 h. Before PEDOT coating, the substrate was treated with oxygen plasma for 4 min. 40 nm of PEDOT was then spin-coated onto the ITO surface, and the resulting film was baked in a vacuum oven at 90 °C for 12 h to remove residual water. In the next step, PVK and the EML were spin-coated onto the substrate sequentially. The thickness of PVK and EML were determined by profilometry (Tencor Alfa-Step 500). Sequential depositions of CsF (1 nm) and Al (100 nm) were carried out at a base pressure of 3×10^{-4} Pa by thermal evaporation. An active emission area of $0.15\,cm^2$ was defined by a shadow mask. Apart from the spin-coating of PEDOT layer, all other processes were carried out in a drybox (Vacuum Atmospheres) under N_2 atmosphere. The luminous efficiency (*LE*)–current density (*J*)–voltage (*V*) data was collected by using a Keithley 236 source measurement unit and a calibrated silicon photodiode. The emission spectra and CIE coordinates were measured using a PR-705 SpectraScan Spectrophotometer (Photo Research). And the absorption spectra were measured by using a UV–Visible spectrophotometer (Agilent 8453).

3. Results and discussion

Monochromatic, blue- and red-light-emitting PLEDs with devices structures of ITO/PEDOT:PSS (40 nm)/PVK (40 nm)/

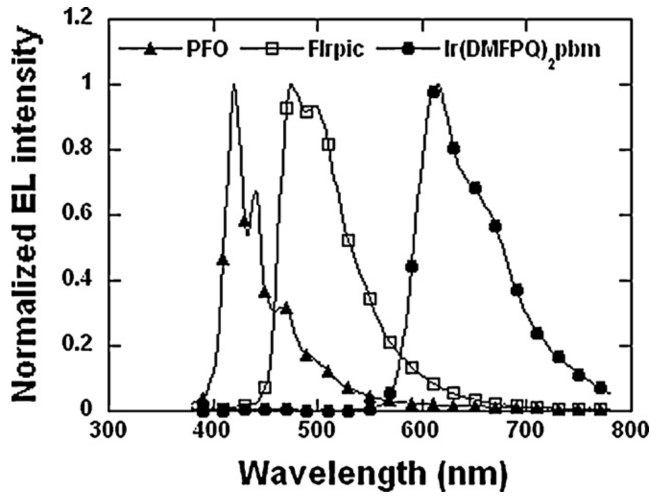

Fig. 2. EL spectra of PFO, FIrpic and Ir(DMFPQ)$_2$pbm.

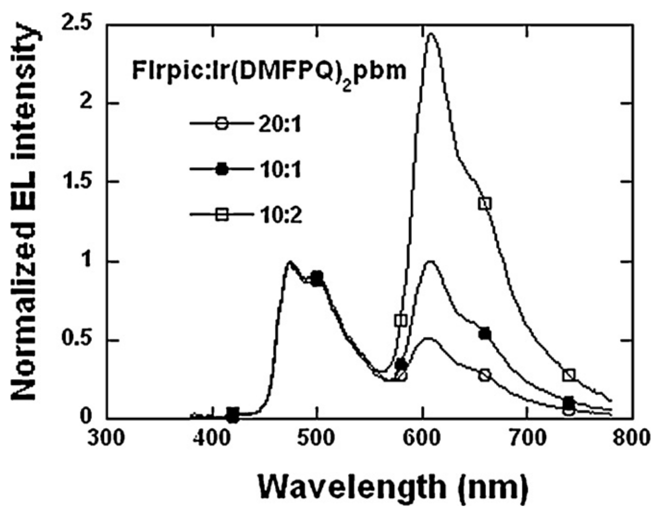

Fig. 3. EL spectra of PLEDs, ITO/PEDOT:PSS/PVK/PFO:FIrpic (10 wt%):Ir(DMFPQ)$_2$pbm/CsF/Al, with ratio of FIrpic to Ir(DMFPQ)$_2$pbm increased from 20:1, 10:1 to 10:2.

PFO:FIrpic (10 wt%) or PFO: Ir(DMFPQ)$_2$pbm (2 wt%) (70 nm)/CsF (1 nm)/Al (100 nm) were characterized, respectively. Fig. 2 shows the EL spectra of PFO, FIrpic and Ir(DMFPQ)$_2$pbm. Their 1931 CIE coordinates are (0.17, 0.10), (0.20, 0.41) and (0.65, 0.34), respectively. In 1931 CIE chromaticity diagram, the connection of FIrpic and Ir(DMFPQ)$_2$pbm across the white region, suggesting that white light can be obtained by blending them with an appropriate ratio.

First, doping concentration of FIrpic in PFO was considered. High efficiency blue emission from FIrpic was the precondition for efficient white light in this all phosphorescent PFO-phosphorescent dopant system. As we know, efficiencies of phosphorescent PLEDs were strongly depended on the doping concentration of phosphorescent dyes [17,18]. According to a previous report, 10 wt% was the optimum doping concentration of FIrpic in polymer matrix [22]. Hence, we fixed PFO (90 wt%):FIrpic (10 wt%) as the basis for the matrix, and tuned the emission color by changing the ratio of Ir(DMFPQ)$_2$pbm to PFO from 0.5, 1 to 2 wt%. Fig. 3 shows the EL spectra of the PLEDs, ITO/PEDOT:PSS/PVK/PFO:FIrpic (10 wt%):Ir(DMFPQ)$_2$pbm/CsF/Al, with ratio of FIrpic to Ir(DMFPQ)$_2$pbm increased from 20:1, 10:1 to 10:2. All of the spectra show two intense peaks, 471 and 610 nm, assigned to the emissions of FIrpic and Ir(DMFPQ)$_2$pbm, respectively. The EL spectra showed strong concentration dependence.