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Deep blue light-emitting diode based on high molecular weight poly(9,9-dioctylfluorene) with high efficiency and color stability

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Abstract

A highly efficient deep blue polymer light-emitting diode based on poly(9,9-dioctylfluorene) is demonstrated. The performance is found to increase significantly with the molecular weight. Two different molecular weights are compared, one is 71,000 and the other is 365,000. The electroluminescent efficiency and color stability are improved by slightly doping hole traps into the emission layer and bilayer structure. The maximum efficiency is 3.8 cd/A with the corresponding external quantum efficiency of 3.7% at deep blue with Commission Internationale de L'Eclairage (CIE) coordinate at (0.15, 0.09). Stable blue emission is maintained up to 6600 cd/m^2 without growth of green shoulder in emission spectrum.

Keywords: Polymer light-emitting diodes; Blocking layer; Molecular weight; Deep blue; Stability

Conjugated polymer light-emitting diodes (PLED) have generated a great deal of interest due to their easy solution process, potentially high emission efficiency and many optoelectronic applications. Therefore, they are viewed as the material for light-weight large-area flat panel display of the new generation. One promising way for display application is using the white PLED combined with color filters. For this purpose highly efficient blue PLED is critical to achieve white PLED through energy transfer by using the blue emitters as the host and red/green emitter as the dopants [1,2]. Deep blue PLED is more essential than the sky blue one in making white light. However the deep blue material still remains a challenge due to their large band gap and difficulty in charge balance. Up to now, the highest reported efficiency for deep blue PLED is about 3 cd/A by the Covion company with unavailable chemical structure [3]. The most well-known and commonly used materials for deep blue PLED are polyfluorene (PF) and its derivatives due to their high photoluminescence quantum efficiency [4–7]. However, they

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still suffer from low electroluminescence (EL) efficiency due to the poor charge balance caused by the difficulty in electron injection and transport. In addition, the color is unstable due to the formation of excimer in its liquid crystalline phase and ketone defect in the presence of oxygen [8,9]. Among all the PF derivative poly(9,9-dioctylfluorene) (PFO) is archetypical and the easies to synthesize. It would greatly reduce the barriers to make high-performance blue PLED using simply PFO. The optical and morphological properties of PFO have been shown to depend sensitively on the molecular weight [10]. In general the higher molecular weight implies better stability and purity of the material. The low molecular weight polymers are also known to have poor color stability due to easier chain motions under device operation. Removal of the low molecular weight components is known to improve the performance [11]. So far the efficiency remains far lower than the Covion material even with molecular weight control. In this work we employ a high molecular weight PFO with MW up to 365,000 to demonstrate a deep blue PLED with efficiency as high as 3.8 cd/A with corresponding external quantum efficiency 3.7%, which is even better than the Covion blue PLED. Color stability is also improved relative to the low molecular weight counterpart. High molecular weight is found to enhance the electron current resulting in a better charge balance. Moreover, the efficiency is significantly enhanced by the doping of hole traps [12]. Instead of using a cross-linking polymer [13], a soluble hole-transport layer (HTL) is added by buffer liquid method [14] to increase the efficiency.

In this letter, three types of device are fabricated, including the doped host–guest emission layer (EML) in single layer structure (type I), HTL/EML bilayer device (type II), and HTL/host–guest EML bilayer device (type III). Fig. 1A shows the schematic energy profile for type I devices and Fig. 1B for type II. Low molecular weight PFO (MW = 71,000) and high molecular weight HMW-PFO (MW = 365,000) purchased from American Dye Source (ADS) are chosen as light-emitting polymers without any further purification. Poly[(9,9-dioctylfluorenyl-2,7-diyl)-co-(4,4′-(*N*-(4-*sec*-butylphenyl))diphenylamine)] (TFB, MW = 197,000, purchased from ADS) are chosen as dopant for type I devices and HTL for the bilayer devices (type II and type III). Single layer PLEDs based on PFO and HMW-PFO without any TFB are made as standard devices. All PLED devices

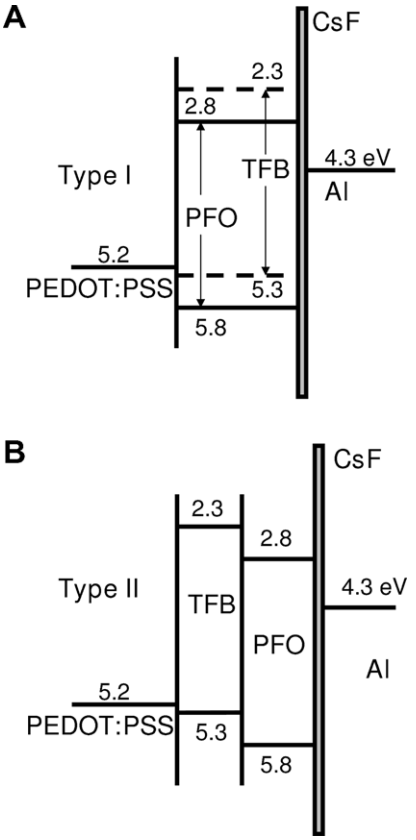

Fig. 1. Schematic electronic energy profile for the (A) type I (PFO: 1 wt% TFB) device structure (B) type II (TFB/ PFO) device structure. The numbers are in eV.

are fabricated on glass substrates with poly-(3,4-ethylenedioxythiophene):poly-(styrenesulfonate) (PEDOT:PSS) layer on a patterned ITO layer. For type I devices 1 wt% of TFB is blended into PFO and HMW-PFO individually as the dopant. The film is formed by spin-coating and baking at 120 °C in vacuum (10^{-3} torr) for 40 min to remove the solvent. For type II and type III devices TFB dissolved in toluene is spin-coated to make a 30 nm thin film then baked at 180 °C in vacuum for 40 min. PFO and HMW-PFO are also dissolved in toluene and spin-coated to make bilayer devices (type II and III) by a liquid buffer layer to prevent the dissolution problem [14]. For the bilayer structure, PFO layer is baked in vacuum at 120 °C for 1 h to remove the residual 1,2-propylene glycol liquid buffer and organic solvent. Except for the PEDOT:PSS layer all the fabrication processes are carried out in the glove box to reduce oxygen adsorption of PFO. CsF (2 nm)/Al (100 nm) are deposited as cathode by thermal evaporation [15].