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Short Communication

Chromatic-stable white organic light-emitting devices incorporating red color conversion layers

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ABSTRACT

Chromatic-stable white organic light-emitting devices (WOLEDs) are reported by combining simple blue fluorescent devices based on a new kind of blue emitter TC-1759 (derivation of N^6,N^6,N^{12},N^{12}-tetrap-tolylchrysene-6,12-diamine) with red color conversion layer (DCJTB). By adjusting the thickness of color conversion layers (CCLs), a very pure white light emission with CIE coordinates of (0.34, 0.33) is obtained at the fixed bias of 8 V, and its color temperature is 5036 K. The chromaticity of the device shows a good stability with a slight offset of (0.03, 0.02) at the driving voltage varied from 6 V to 10 V. The maximum luminance and maximum current efficiency achieved 1348 cd/m^2 (12 V), and 1.37 cd/A at 3.52 mA/cm^2.

1. Introduction

White organic light-emitting devices (WOLEDs) are currently attracting considerable attention for applications in flat panel displays and as solid state lighting sources [1,2]. Generally there are two approaches to realize white light emission, including a mixture of three primary colors (red, green, and blue, RGB) or two complementary colors. And the two ways above mainly employ multiple emissive layers in which each layer emits different colors, or a single emissive layer with a mixture of different color light emitting materials [3,4]. But these devices generally exhibit color shift with the varying of the driving voltage, which probably due to the uneven exciton distribution in different emitting layers and different life time of various emitting materials. Thus, in order to avoid chromatic instability from the emissive layers, a simple method for designing WOLEDs has been employed by combining blue-emitting devices with color conversion layers (CCLs) which are filmed over the other side of glass substrate, and since this method was reported in 1997 for the first time, much effort has been made on developing this technology [5–10]. The DCJTB was first synthesized and reported by Chen et al. as a red fluorescent electroluminescence (EL) dye in 1997 [11], and since then it has been widely used in red and white OLEDs. However, there have been not any reports on down-conversion method based on the photo-luminescence (PL) character of DCJTB as color conversion material combined with blue light-emitting device to realize WOLED.

In this work, we successfully fabricated the WOLEDs with a simple architecture based on the novel color conversion method, which was realized by combining a blue fluorescent OLED with a vacuum deposited DCJTB color conversion layer (CCL). The pure white light emission and the excellent chromatic-stability of the WOLEDs could be achieved by adjusting the thickness of CCL.

2. Experimental details

The blue fluorescent dye TC-1759 (derivation of N^6,N^6,N^{12},N^{12}-tetrap-tolylchrysene-6,12-diamine) and the color conversion material DCJTB (4-(dicyanomethylene)-2-tert-butyl-6-(1,1,7,7-tetramethyljulolidyl-9-enyl)-4H-pyran) used in this work were shown in Fig. 1.

The WOLEDs were fabricated with the structures: DCJTB (x nm)/ITO/(N,N′-bis(naphthalene-1-yl)-N,N′-bis(phenyl)-benzidine)NPB (40 nm)/TC-1759 (50 nm)/(4,7-diph-nenyl-1,10-phenan throline) Bphen (30 nm)/LiF (0.8 nm)/Al (120 nm) (x = 0 nm, 130 nm, 150 nm and 170 nm), in which DCJTB, NPB, TC-1759 and Bphen was used as color conversion layer, hole transport layer, blue emission layer and electron transport layer, respectively (Fig. 2a). All the organic layers as well as LiF and Al cathode were

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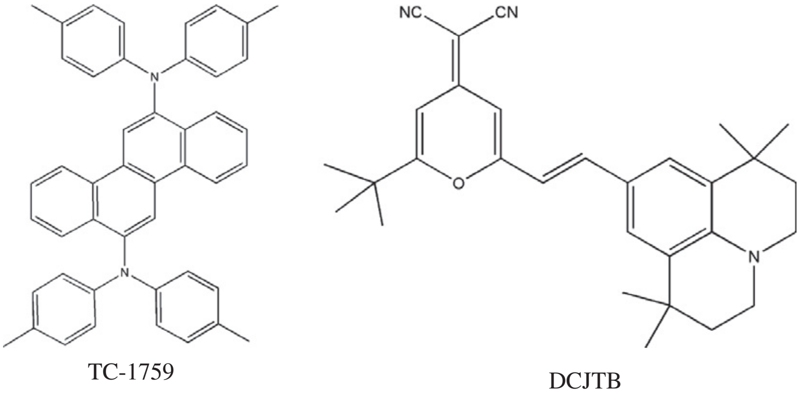

Fig. 1. The chemical structures of the blue fluorescent dye and the color conversion material.

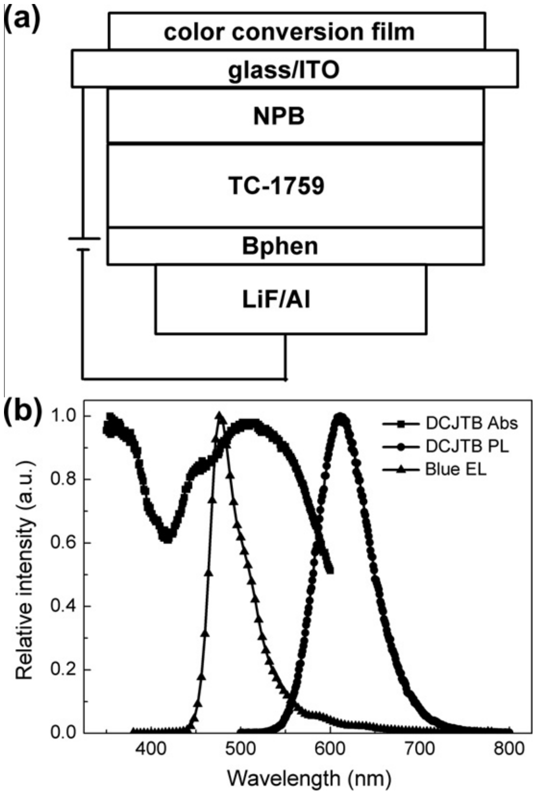

Fig. 2. (a) The schematic device structure of the WOLEDs. (b) EL spectrum of TC-1759, absorption and PL spectrum of DCJTB.

deposited onto a pre-cleaned ITO anode glass substrate with a sheet resistance of 20 Ω/sq, by thermal evaporation coating system at a pressure of about 2×10^{-4} Pa. The deposition rates and thickness of the various layers were monitored using a quartz crystal oscillator. The evaporation rates were 0.1–0.3 nm/s, 0.05 nm/s, 1 nm/s for each organic layer, LiF layer and Al cathode, respectively. The fluorescent emission spectra and the absorption (Abs) spectra of DCJTB were measured using the Hitachi F-4500 fluorescence spectrophotometer and the Hitachi U-4100 UV absorption spectrophotometer, respectively. And the luminance–voltage–current density (*L–V–J*) and EL characteristics of the devices were measured by the Keithley model 2400 programmable voltage–current source and the PR650 spectra scan spectrometer. And all of the records were carried out at room temperature in air without encapsulation.

3. Results and discussions

Fig. 2b shows the absorption and photoluminescence (PL) spectrum of CCL (DCJTB) and the Electroluminescence (EL) spectrum of TC-1759. The CCL exhibits a strong absorption band from 400 nm to 550 nm, which has an appropriate overlap with the EL emission of TC-1759 (476 nm and 500 nm). Meanwhile the PL spectrum peak of the pure DCJTB locates at 611 nm is also shown in this figure. These results indicate that DCJTB could be excited by the blue light from TC-1759, then the white light emission could be achieved by the mixture of the PL red light from color-conversion of DCJTB and the remanent EL blue light from TC-1759.

Fig. 3a shows the normalized EL spectrum of the devices with different thickness of CCL (DCJTB) at the driving voltage of 8 V, together with that of the blue OLED. And their CIE coordinates at different driving voltages for different thickness of CCL (130 nm, 150 nm and 170 nm) were shown in Fig. 3b, respectively. Clearly, the blue OLED exhibits a main peak at 476 nm with a shoulder peak at 500 nm. But when it combines with the CCL, the main blue peak shifts to 472 nm and its shoulder peak disappears with the emergence of the 611 nm red peak. That is because some of the blue EL emission is absorbed by the DCJTB CCL, and other remanent blue light will transmit through the CCL directly. Then the white light emission will be mixed by combining the EL emission (472 nm) of blue device with the PL emission (611 nm) of DCJTB CCL. Hence different CIE coordinates of the devices could be reached by adjusting the thickness of the CCL for the same excited condition. The CIE coordinates migration of all the WOLEDs are about $x = \pm 0.03$, $y = \pm 0.03$ with the driving voltage varied from 6 V to 11 V, and when the thickness of DCJTB CCL is optimized to 170 nm, a very pure white color of (0.34, 0.33) is reached at the fixed bias of 8 V, which is rather close to the equal energy point (0.33, 0.33), and its color temperature is 5036 K. Accordingly, the thickness of CCL is optimized to 170 nm to obtain a pure white light emission. Meanwhile, the photograph of the white device with 170 nm CCL on operation at 8 V is shown in the inset of Fig. 3a.

Furthermore, the normalized EL spectrum and CIE coordinates of the white devices with 170 nm CCL at different voltages are shown in Fig. 4. It can be clearly seen that there is not too much EL spectrum change for the WOLED with the voltage (varied from 6 V to 10 V), and the CIE coordinates of the white emission only shift from (0.36, 0.34) to (0.33, 0.32), finally an excellent color stability of white light is obtained.

However, the attenuation of the light emission is not slight. Fig. 5a is the *L–V–J* characteristics of the devices, in which the maximum luminance are 12420 cd/m^2, 3234 cd/m^2, 2031 cd/m^2 and 1348 cd/m^2 for the devices with 0 nm, 130 nm, 150 nm and