P-165: Efficient RGBW OLEDs Based on 4, 4'-Bis (1, 2, 2-triphenylvinyl) biphenyl

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Abstract
We report a newly synthesized wide band-gap material 4, 4'-bis (1, 2, 2-triphenylvinyl) biphenyl (BTPE), which can serve as blue emitter directly or as host for fluorescent green and red dyes. By employing BTPE as host and/or emitter, efficient red, green, blue and white OLEDs show a maximum current efficiency of 5 cd/A, 18 cd/A, 7.1 cd/A and 7 cd/A, respectively.

1. Introduction
Organic light-emitting diodes (OLEDs) have been the subject of intense research in recent years due to their potential applications in display and lighting [1, 3, 4]. During the past several decades, green (G) OLEDs and red (R) OLEDs with high efficiency, high luminance and long lifetime have been achieved by molecular engineering and architecture designing; however, high performance blue (B) OLEDs still remain a challenge due to the difficulties of tailoring organic molecules with wide band-gap and high efficiency. Hence, it is extremely urgent to develop high efficiency wide band-gap blue light-emitting materials in order to realize full color OLEDs and white (W) OLEDs for display and lighting.

In this paper, we report a newly synthesized wide band-gap material 4, 4'-bis (1, 2, 2-triphenylvinyl) biphenyl (BTPE), which, in contrast to conventional fluorescent dyes suffering from aggregation-caused quenching effect, emits intense blue light in its aggregation state, a novel phenomenon called aggregation-induced emission (AIE) [1]. Due to the AIE property of this novel fluorophor, the BTPE can be employed as blue emitter directly to construct non-doped BOLEDs. In addition, the BTPE can also serve as good host for the R and G fluorescent dyes owing to their good spectrum overlap and high fluorescent quantum yield of BTPE. Furthermore, simplified white light-emission layer with only two kinds of materials (BTPE/BTPE:DCJTB) can be achieved. By employing BTPE as host and/or emitter, efficient R, G, B and WOLEDs show a maximum current efficiency of 5 cd/A, 18 cd/A, 7.1 cd/A and 7 cd/A, respectively.

2. Experiments
The synthesis method of BTPE was presented in a separated paper [1]. Other organic materials were purchased from Lumtec without further purification. Four kinds of device were prepared on 80-nm-thick ITO coated glass. The structures of the fabricated devices as well as the energy level and molecular structure of BTPE are shown in Figure 1.

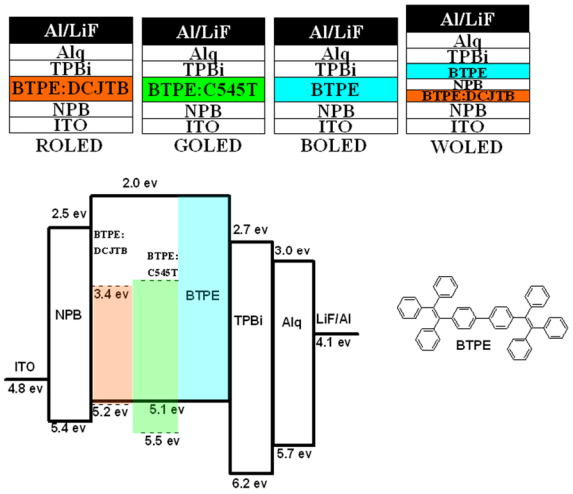

Figure 1. Schematic illustration of the device structures as well as the energy level and molecular structure.

In these devices, a 20-nm-thick BTPE doped with 1% wt. DCJTB, a 20-nm-thick BTPE doped with 1% wt. C545T, a 20-nm-thick BTPE, and a 20-nm-thick BTPE combined with 1-nm-thick BTPE doped with 1% wt. DCJTB were employed as the light-emitting layer for the R, G, B and WOLEDs, respectively. For the WOLEDs, a 2-nm-thick NPB layer was inserted between the BTPE and BTPE:DCJTB serving as the electron-blocking layer. A 60-nm-thick NPB, a 10-nm-thick TPBi, and a 30-nm-thick Alq_3, were used as hole-transporting, hole-blocking, and electron-transporting layers, respectively. All organic layers in the devices were thermally evaporated in sequence in a multi-source vacuum chamber at a base pressure of around 5×10^{-7} Torr. The samples were then transferred to the metal chamber without breaking vacuum for cathode deposition which composed of 1-nm-thick LiF capped with 100-nm-thick Al. The current density-voltage characteristics of the devices were measured by the HP4145B semiconductor parameter analyzer. The forward direction photons emitted from the devices were detected by placing a calibrated UDT PIN-25D silicon photodiode very close onto the top of the devices. The electroluminescent (EL) spectra were obtained with the PR650 spectrophotometer.

3. Results and discussion
Figure 2 shows the photoluminescent (PL) spectrum of amorphous thin film BTPE as well as the absorption spectrum of DCJTB and C545T. The PL emission of BTPE peaks at 492 nm, exhibiting a greenish-blue color. The fluorescent quantum yield

(Φ_F) of amorphous thin film BTPE is 92% [1], implying that efficient BOLEDs may be obtained by using BTPE as emitter. A bluer emission at 445 nm and higher Φ_F of 100% can be obtained by crystallizing BTPE; in other words, instead of quenching like conventional fluorescent dyes, crystallization blue-shifts the emission spectrum and enhances the emission of BTPE, which is one of the properties of the novel AIE materials [1]. The band-gap of BTPE is 3.1 eV as measured by cyclic voltammetry; such wide band-gap and high Φ_F may render BTPE as a good host for fluorescent green and red dyes. In general, the Förster energy-transfer rate via induced dipole-dipole coupling between host/donor molecules and guest/acceptor molecules is governed by [2]:

$$K_{ET} = \frac{1}{\tau_D}\left(\frac{R_0}{R}\right)^6$$

$$(R_0)^6 = \frac{0.5291K^2\Phi_F}{N_A n^4}\int_0^\infty F_D(\bar{\gamma})\varepsilon_A(\bar{\gamma})\frac{d\bar{\gamma}}{\bar{\gamma}^4}$$

where Φ_F, F_D and ε_A is the fluorescent quantum yield of the donor, normalized PL spectrum of the donor and normalized absorption spectrum of acceptor, respectively. Clearly, to realize effective energy-transfer from host molecules to guest molecules, the host materials should have high Φ_F. In addition, the overlap between PL spectra of host materials and absorption spectra of guest materials should be large. Obviously, as shown in Figure 2, the PL spectrum of BTPE overlaps very well with the absorption spectrum of DCJTB and C545T, indicating that effective Förster energy-transfer from BTPE to DCJTB or C545T may happen.

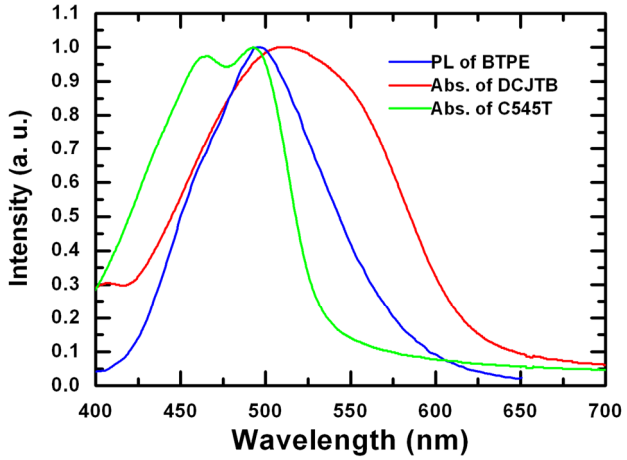

Figure 2. PL spectrum of BTPE as well as absorption spectrum of DCJTB and C545T.

To test this assumption, R, G, B and WOLEDs employing BTPE as host and/or emitter were fabricated. Figure 3 shows the typical current density-luminance-voltage, current efficiency-current density characteristics and EL spectra of the devices. The non-doped BOLEDs employing BTPE as emitter directly show a turn on voltage at 1 cd/m2 of 5 V. The luminance increases quickly with increased of voltage, reaching 20036 cd/m^2 at 15 V. The maximum current efficiency is 7.1 cd/A. By doping BTPE with red dye DCJTB and green dye C545T, the resulting ROLEDs and GOLEDs exhibit a substantially smaller current density and lower turn on voltage compared to the BOLEDs; for example, at a driving voltage of 15 V, the current density is 195 mA/cm^2 and 356 mA/cm^2 for the ROLEDs and GOLEDs respectively, significantly lower than 456 mA/cm^2 for the BOLEDs. Such reduced current

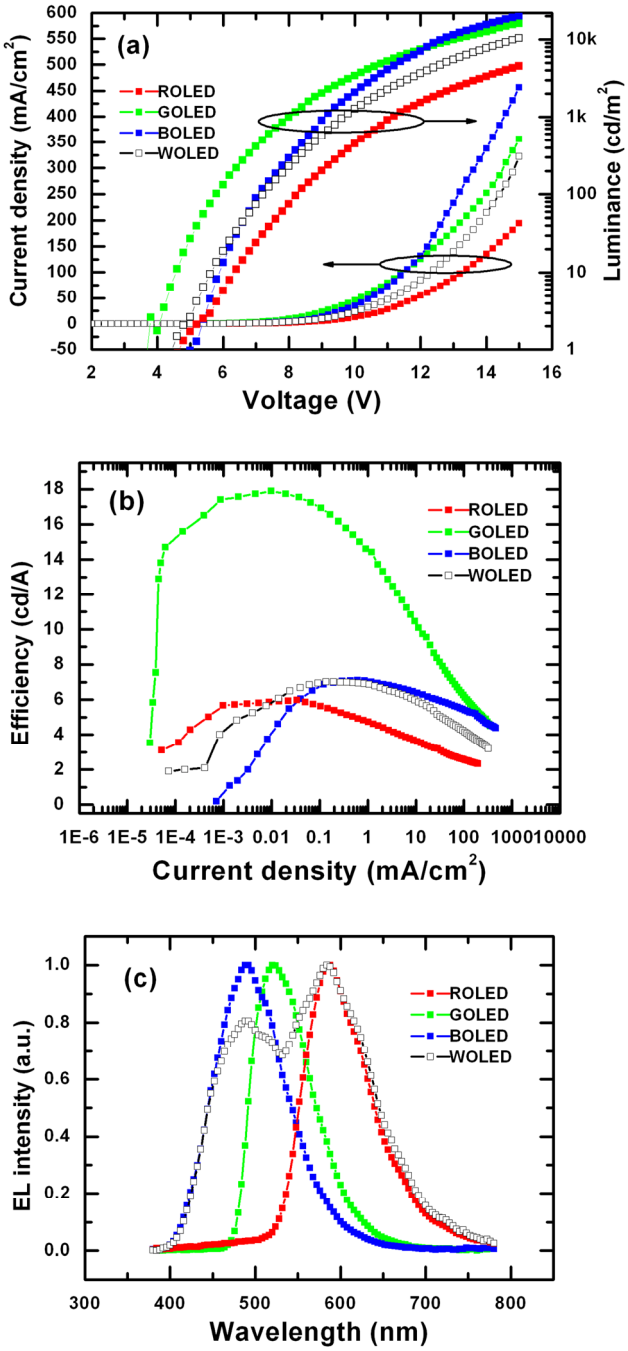

Figure 3. (a) Current density-luminance-voltage, (b) current efficiency-current density characteristics and (c) EL spectra of the fabricated devices.

density and turn on voltage of the R and GOLEDs, implies that besides effective energy transfers from BTPE, the excitons may form by directly trapping electrons and holes due to their narrower band-gap compared with BTPE (Figure 1). This effective dual channels energy capturing of the dyes results in a maximum current efficiency of 5 cd/A and 18 cd/A for the ROLEDs and GOLEDs, respectively. The EL spectra shown in Figure 3 (c) further confirm our assumption. The non-doped BOLEDs exhibit a greenish-blue EL color with its peak at 488 nm; however, by doping BTPE with 1% wt. C545T or DCJTB, the blue emission is completely vanished and replaced by a 520 nm green or 588 nm red emission, clearly demonstrating that the energy is completely transferring from BTPE to C545T or DCJTB.

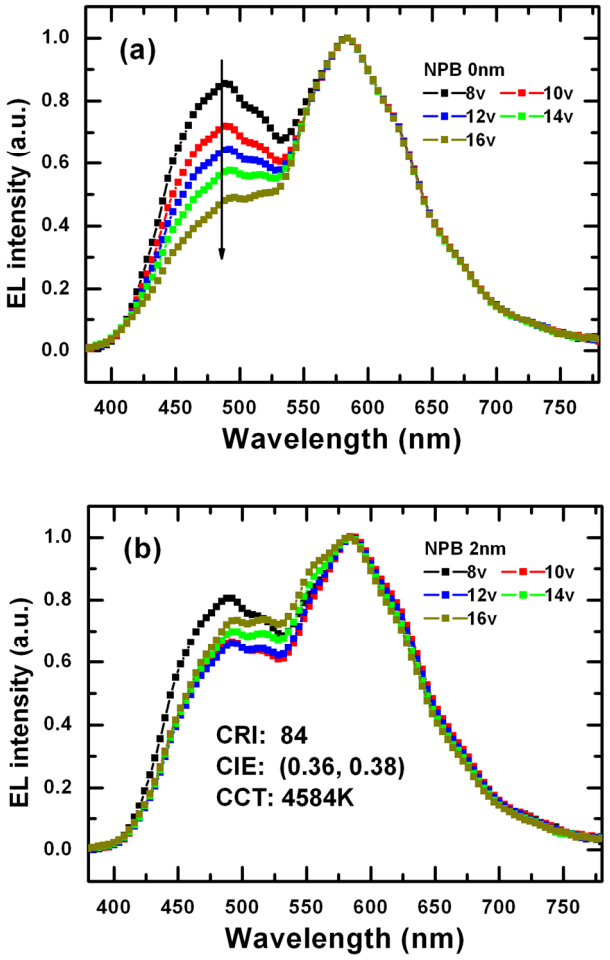

Fig. 4. The EL spectra of the WOLEDs without (a), and with 2-nm-thick NPB electron-blocking layer (b).

Without doubts, the BTPE not only is a good blue emitter, but also is a good host for the red and green dyes. Hence, we employ BTPE as a blue emitter and host for DCJTB to construct WOLEDs. Compared to conventional WOLEDs, which in general require R, G, B three dopants and at least two hosts to generate the white color [3], the WOLEDs studied here only employ two kinds of materials as the white light-emission layer, and thus can significantly cut down the cost and simplify the fabrication process. The simplified WOLEDs exhibit a turn on voltage of 4.5 V, a luminance of 10319 cd/m^2 at 15 V, and a maximum current efficiency of 7 cd/A. Two emission peaks at 488 nm and 588 nm, originating from BTPE and BTPE:DCJTB can be clearly observed. Figure 4 shows the EL spectra of the WOLEDs at different driving voltages. Without the NPB electron-blocking layer, the blue emission decreases as increasing of voltages, mainly due to more excitons recombine in the BTPE:DCJTB layer with increased of voltages, resulting in 1931 Commision International de L'Eclairage (CIE) coordinates and color correlate temperature (CCT) changing from (0.35, 0.37), 4832K at 8 V to (0.40, 0.41), 3688K at 16 V. With the help of NPB electron-blocking layer [4], the WOLEDs exhibit moderate color stability with CIE coordinates changing from (0.36, 0.38) to (0.38, 0.40) over a wide range of driving voltages. Moreover, a high color rendering index (CRI) of 84 is achieved by employing this simplified white light-emission layer containing only two kinds of materials. The key characteristics of the devices are listed in Table 1.

Table 1. Performance of the devices

	ROLED	GOLED	BOLED	WOLED
Turn on voltage (V) at 1cd/m^2	4.8	4	5.2	4.6
Driving voltage (V) at 100 mA/cm^2	13.3	11.5	11.4	12.4
Luminance (cd/m^2) at 15V	4528	15991	20036	10319
Power efficiency (lm/w) at 100 cd/m^2	1.6	8.1	3	2.9
Current efficiency (cd/A) at 100 cd/m^2	4.4	15	7	6.7
Peak EL emission wavelength (nm)	588	520	488	488&588
CIE & CRI	(0.53,0.45)	(0.3,0.6)	(0.19,0.33)	(0.36,0.38) & 84

4. Conclusions

In conclusion, efficient R, G, B and WOLEDs have been demonstrated by employing newly synthesized high Φ_F blue light-emission material BTPE as host and/or emitter. The R, G, B and WOLEDs show a maximum current efficiency of 5 cd/A, 18 cd/A, 7.1 cd/A and 7 cd/A, respectively. Moreover, the WOLEDs with simplified light-emission layer containing only two kinds of materials show a moderate color stability and high CRI of 84. These preliminary results demonstrate that the BTPE may be a good candidate for constructing full color and white OLEDs for display and lighting applications.

5. References

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