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# White OLED Using Highly Efficient Green Dopant via Solution Process

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*A new green dopant of TCBzC-substituted carbazole units was investigated in a solution processed white organic light-emitting diode (WOLED) device. 4-(10-(3',5'-diphenyl-biphenyl-4-yl)anthracen-9-yl)-N,N-diphenyl-aniline (TATa) and 4-(dicyanomethylene-4)-2-t-butyl-6(1,1,7,7-tetramethyljulolidyl-9-enyl)-4H-pyran (DCJTb) were used for the blue host and red dopant. Structure of the device was fabricated as ITO / PEDOT: PSS (40 nm) / PVK (14 nm) / EML: TATa + TCBzC: 3.0wt% + DCJTb: 0.08wt% (50 nm) / TPBi (20 nm) / LiF (1 nm) / Al. As a result, a TCBzC device of 1.44 cd/A was obtained. Commission Internationale de l'Eclairage (CIE) value of the TCBzC device was (0.26, 0.41).*

**Keywords** Organic light-emitting diode; green dopant material; solution process; white OLED.

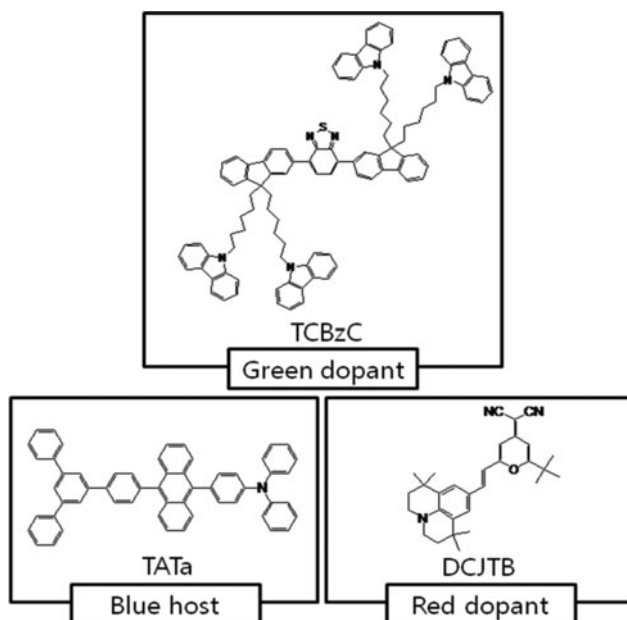
## Introduction

Many researchers have investigated to make highly efficient organic light-emitting diode (OLED) in the field of OLED materials. [1–4] Especially, The interest in OLED based on white OLED (WOLED) has been rapidly growing in the fields of OLED TV and lighting application. [5] Until now, WOLED has been produced using vacuum evaporation method, but this method involves disadvantages such as high cost, difficulty of large scaling, and difficulty of adjusting doping concentration. [6] Therefore, many studies are conducted on methods of producing solution processed WOLED such as spin-coating, screen-printing, and ink-jet printing methods with advantages like large scaling and relatively inexpensive cost. [7, 8]

Many approaches to WOLED have been reported since the first report of Kido group. [9] Many researchers are also involved in ongoing efforts to make two or three emissive layers in OLED. Host-dopant system was often used in WOLED because it can significantly improve efficiency and show stable color purity. Especially, many molecules were designed and synthesized in order to develop dopants for high performance.

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**Figure 1.** Chemical structures of materials.

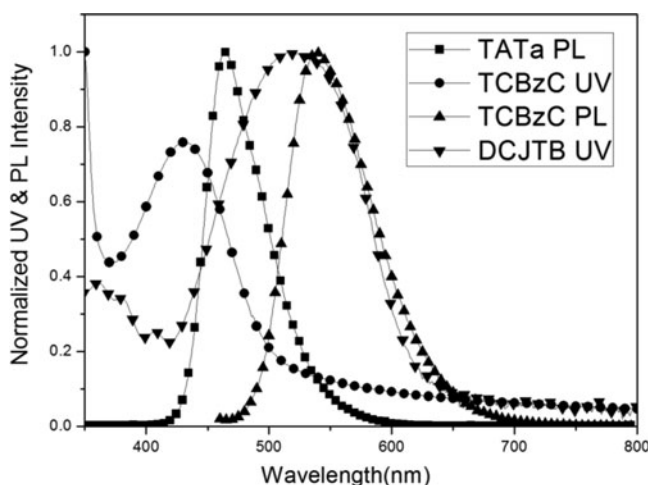
In this paper, a solution processed WOLED device is reported by using high performance TCBzC in solution process as a green dopant, 4-(10-(3',5'-diphenylbiphenyl-4-yl)anthracen-9-yl)-N,N-diphenylaniline (TATa), high efficiency blue fluorescent material, as a host material, and 4-(dicyanomethylene)-2-t-butyl-6(1,1,7,7-tetramethyljulolidyl-9-enyl)-4H-pyran (DCJTb) as a red dopant.

## Experimental

The synthesis method for TCBzC in Figure 1 is published in Chem. Commun. [10] TATa is introduced in Organic Electronics. [11] These new compounds were first synthesized by our groups. Optical absorption spectra were obtained by HP 8453 UV-VIS-NIR spectrometer. Perkin Elmer luminescence spectrometer LS50 (Xenon flash tube) was used for photoluminescence (PL) spectroscopy. Current-voltage-luminance (I-V-L) characteristics of the fabricated electroluminescence (EL) devices were obtained by Keithley 2400 electrometer and light intensity was obtained by Minolta CS-1000 A, respectively.

## Preparation of OLED

TATa was used as the blue host substance in the emitting layer. TCBzC was used as the green dopant and DCJTb was used as the red dopant. TCBzC with ratio of 3.0% each and DCJTb with ratio of 0.08% were mixed for optimized dopant compounds based on the mass of the blue host. Solvent was used with toluene. A water-dispersed poly(3,4-ethylenedioxythiophene): poly(4-styrenesulfonate) (PEDOT: PSS) mixture (Baytron PVP CH8000, H. C. Starck GmbH) was spin-coated on top of indium tin oxide (ITO) in air to achieve a thin film of 40 nm. The spin-coated film was baked on a hot plate at 110°C for 5 minutes in air and 200°C for 5 minutes in N<sub>2</sub> glove box. Polyvinylcarbazole (PVK)



**Figure 2.** UV-Visible absorption of TCBzC and DCJTb and PL spectra of TATa and TCBzC in film state.

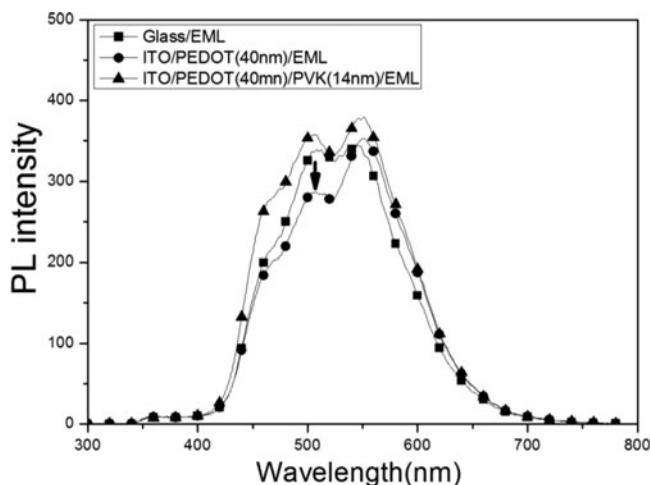
( $M_n = 1,100,000$ ) was spin-coated as an interlayer and the film was baked on a hot plate ( $110^\circ\text{C}$ , 1h) in  $\text{N}_2$  glove box. The emitting layer was formed by spin-coating to obtain thickness of 50 nm. The solution-processed films were baked on a hot plate ( $110^\circ\text{C}$ , 30 min) in  $\text{N}_2$  glove box. 2,2',2''-(1,3,5-Benzinetriyl)-tris(1-phenyl-1-H-benzimidazole (TPBi), an electron-transporting layer with thickness of 20 nm, was deposited by vacuum evaporation (at a pressure about  $10^{-6}$  torr). LiF (1 nm) and Al films were sequentially deposited on the electron-transporting layer under vacuum (at a pressure of about  $10^{-6}$  torr).

## Results and Discussion

TCBzC is a new bipolar solution processed green material designed by considering solubility, morphology, fluorescence efficiency and carrier balance. Especially, the green TCBzC-based device shows maximum luminous efficiency of 31.6 cd/A. A WOLED device was fabricated by using TCBzC as the green dopant. [10] TATa is a blue host material with high performance in evaporation devices and was applied as the blue host. Figure 1 shows the materials used in WOLED.

In order to show the transfer of Förster energy, PL spectra of the host material used in the emitting layer and PL and UV-visible spectra of dopants were compared in Figure 2. PL peak of TATa was shown at 464 nm and TCBzC showed an absorption peak at 429 nm. Also, PL peak of DCJTb was 540 nm. DCJTb had absorption maximum at 515 nm, and the absorption and PL spectrum were well overlapped.

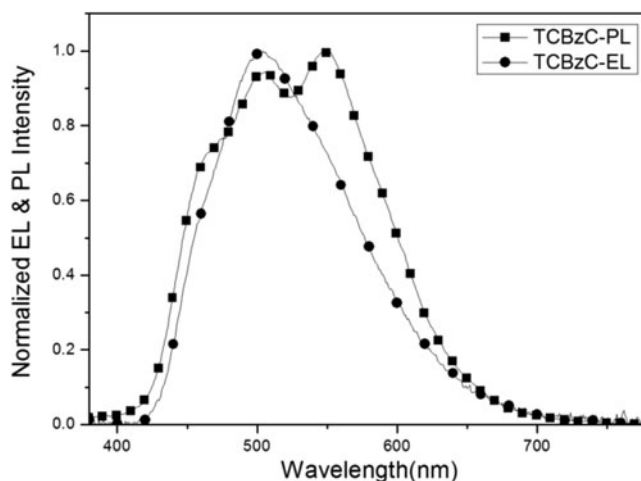
PEDOT: PSS is a material most widely used as the hole injection layer in solution processed OLED. However, PEDOT: PSS is acidic in OLED and accompanies disadvantages of reduced lifetime and efficiency due to exciton quenching and degradation effect. [12] In order to reduce such disadvantages and increase OLED performance, an interlayer is inserted between PEDOT: PSS and EML layer. [13] PVK is widely used as an interlayer because it efficiently increases hole-electron balance and improves device performance. Figure 3 shows the effect of PVK as an interlayer between PEDOT: PSS and EML layer. The film with EML: TATa + TCBzC (3.0wt%) + DCJTb (0.08wt%) spin-coated on top of glass is a square curve as shown in Figure 3. However, when an EML layer was coated



**Figure 3.** Effect of poly(N-vinylcarbazole) (PVK) as an interlayer between PEDOT: PSS and EML (EML: TATa + TCBzC (3.0wt%) + DCJTb (0.08wt%)).

with same thickness on top of PEDOT: PSS layer, intensity of blue and green regions was reduced as shown in circle line of Figure 3. On the contrary, PL pattern of PEDOT: PSS / PVK / EML that used PVK as the interlayer was recovered. Based on the use of PVK between PEDOT: PSS with a hydrophilic surface and EML layer, the degradation effect of PL was alleviated.

An OLED was fabricated with a structure of ITO / PEDOT: PSS (40 nm) / PVK (14 nm) / EML: TATa + TCBzC (3.0wt%) + DCJTb (0.08wt%) (50 nm) / TPBi (20 nm) / LiF (1 nm) / Al. Figure 4 shows PL and EL spectrum peaks of EML using mixed host and dopants. In Figure 4, EL maximum values of the TCBzC device are 504 nm and 551 nm. Device performance of TCBzC as the green dopant is summarized in Table 1. Operating voltage of the device using TCBzC was obtained in the range of about 9.4 V at 100 mA/cm<sup>2</sup>,



**Figure 4.** Photoluminescence of EML film and electroluminescence spectra of the WOLED device.

**Table 1.** EL device performance of ITO / PEDOT: PSS (40 nm) / PVK(14 nm) / EML: TATa + TCBzC (3.0wt%) + DCJTB (0.08wt%) (50 nm) / TPBi (20 nm) / LiF / Al at 100 mA/cm<sup>2</sup>

	Voltage (V)	Turn on Voltage <sup>a)</sup>	L. E. <sup>b)</sup> (Cd/A)	P. E. <sup>c)</sup> (lm/W)	CIE (x,y) <sup>d)</sup>
TCBzC	9.4	3.0	1.44	0.52	(0.26, 0.41)

[a] Turn-on voltage measured at 1 cd/m<sup>2</sup> [b] L. E.: luminance efficiency, [c] P. E.: power efficiency, [d] CIE: Commission Internationale de l'Eclairage

as shown in Table 1. Luminance efficiency (L. E.) of the device used TCBzC as the green dopant is 1.44 cd/A. Power efficiency (P. E.) and CIE value of the TCBzC device are 0.52 lm/W and (0.26, 0.41), respectively.

## Conclusions

TCBzC OLED device using a green dopant substituted carbazole group was fabricated by WOLED configuration used 4-(10-(3',5'-diphenyl-biphenyl-4-yl)anthracen-9-yl)-N,N-diphenyl-aniline (TATa) and 4-(dicyanomethylene)-2-t-butyl-6(1,1,7,7-tetramethyljulolidyl-9-enyl)-4H-pyran (DCJTB) as blue host and red dopant. Also, PVK was used as an interlayer to reduce the degradation effect by PEDOT: PSS. As a result, a TCBzC device of 1.44 cd/A was obtained. CIE value of the TCBzC device was (0.26, 0.41).

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