

## Short communication

## High-luminance and high-efficiency organic electroluminescent devices with a doped co-host emitter system

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## Abstract

TDCJTB, BMDIN and TDIN have been synthesized for using as red fluorescent dye molecules in organic light-emitting diodes (OLEDs). The Commission International d'Eclairage (CIE) coordinates and PL peaks of the devices are [0.61, 0.39], [0.65, 0.35], [0.62, 0.38] and 579 nm, 619 nm, 597 nm, respectively. Compared with traditional DCM ([0.58, 0.41], 575 nm) the three devices have better brightness and CIE coordinates. When TBQ is doped in the three materials the EL efficiency can all be improved at different levels. BMDIN as a high efficient red organic light-emitting material based on this series of fluorescent dyes doped in co-host emitter (CHE) systems of TBQ/poly(*N*-vinylcarbazole) (PVK) can achieve a higher luminescent efficiency and brightness than the other materials. Present research work shows that when TBQ's concentration is 30%, the maximum EL efficiency is 6.1 cd/A at 40 mA/cm<sup>2</sup>.

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**Keywords:** Red light; TBQ; Co-host; Efficient

## 1. Introduction

Organic light-emitting devices (OLEDs) have attracted much attention owing to their advantages of low-power consumption, high brightness, high contrast and potential applications to full color flat panel displays [1]. But the red color OLED due to its low efficiency, poor color purity, remains to be the weakest part in realizing the full potential of full color OLED. One of the key enablers in the development of organic light-emitting device (OLED) technology can be attributed to the discovery of the guest–host doped emitter system [2]. By dispersing 5% of rubrene as a red emitting assist dopant with 2% 4-(dicyanomethylene)-2-*tert*-butyl-6-(1,1,7,7-tetramethyljulolidyl-9-enyl)-4*H*-pyran (DCJTB) in

tris-(8-hydroxyquinoline) aluminum (Alq<sub>3</sub>), Hamada and coworkers at Sanyo [3] were able to achieve a luminance efficiency of 2.1 cd/A with CIE<sub>x,y</sub> = [0.64, 0.35]. Subsequently, the Sanyo/Kodak team discovered [4] that by adding 6% of *N,N'*-bis-(1-naphthyl)-*N,N'*-diphenyl-1,1'-biphenyl-4,4'-diamine (NPB) as hole-trapping dopant to the above emitting system, its efficiency could be further improved to 2.8 cd/A at 20 mA/cm<sup>2</sup> and a red chromaticity coordinate of CIE<sub>x,y</sub> = [0.65, 0.34] was also obtained.

In this work, we doped a series of fluorescent dyes in co-host emitter (CHE) [5] systems of TBQ/poly(*N*-vinylcarbazole) (PVK). It showed that by adjusting the ratio of these two host emitters, the EL efficiency, luminance as well as color can be dramatically improved.

## 2. Experiments

A new DCM derivative (TDCJTB, BMDIN and TDIN) has been synthesized for use as red fluorescent dye molecules in

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OLED. They were designed and synthesized via piperidine-catalyzed condensation of aldehyde with 4-(dicyanomethylene)-2-(*t*-butyl)-6-methyl-4*H*-pyran or 4-(1',3'-indandione)-2-(*t*-butyl)-6-methyl-4*H*-pyran in good yields. The molecule structures of this series of red fluorescent dyes are shown in Fig. 1.

In this study three devices were fabricated: (1) Glass/ITO/PVK: dopant/LiF/Al; (2) Glass/ITO/PVK: dopant/BCP/Alq<sub>3</sub>/LiF/Al; (3) Glass/ITO/CHE/BCP/Alq<sub>3</sub>/LiF/Al. The thickness of the PVK: dopant is 70 nm, that of the BCP is 20 nm, the CHE is 70 nm, the Alq<sub>3</sub> is 15 nm, the LiF is 0.3 nm and the Al is 150 nm. The CHE consists of a mixture of TBQ/PVK doped with a series of red fluorescent dyes (10%). The light-emitting film of CHE was prepared by spin coating their chloroform solution onto ITO glass substrate (with a sheet resistance of 20 Ω/□). And then hole blocking material (2,9-dimethyl-4,7 diphenyl-1,10-phenanthroline (BCP)), electron transporting material (Alq<sub>3</sub>), LiF, and Al were deposited onto the emitting layer by a conventional thermal evaporation method at a chamber pressure of about  $3 \times 10^{-3}$  Pa. Prior to organic deposition, the ITO coated glass plate was thoroughly cleaned by scrubbing, sonication, vapor degreasing, and oxygen plasma treatment. The deposition rates were maintained to be 0.05 nm s<sup>-1</sup>, 0.05 nm s<sup>-1</sup> and 0.02 nm s<sup>-1</sup> for BCP, Alq<sub>3</sub> and LiF, respectively. The thickness of each layer was monitored by a quartz oscillating thickness monitor (IL-400). LiF was deposited onto an electron transport layer (ETL) as an electron injection material [6]. We used PVK as host material in order to get the film-forming possibility and conductivity of their mixture. The emitting layer was made by spin coating, which can avoid the thermal decomposition caused by the thermal evaporation. The PL and EL spectra were measured by the Fluolog-3 fluorescent spectrometer, and the brightness was measured by PR-650. All the measurements were carried out in ambient atmosphere at room temperature.

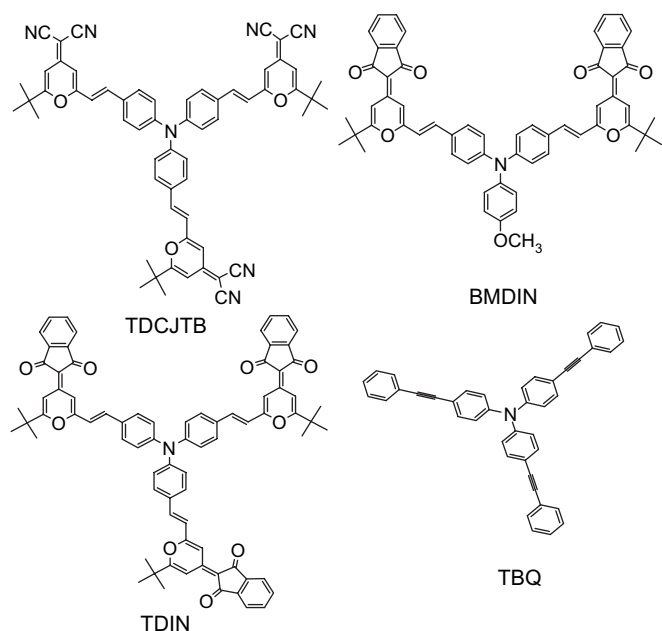


Fig. 1. Molecular structures of TDCJTB, BMDIN, TDIN, TBQ.

### 3. Results and discussion

Fig. 2 shows that the PL peaks of TDCJTB, BMDIN, TDIN and DCM were 579 nm, 619 nm, 597 nm, 575 nm, respectively. The emitting layer was made by spin coating (1000 rpm; 70 nm), which can avoid the thermal decomposition caused by the thermal evaporation. The weight ratio of 1:10 (dopant: PVK) was the best. Only bright red emission from this device was observed. This may indicate that emission of the red dopants originate from the excitation of PVK. The EL peaks of TDCJTB, BMDIN, TDIN and DCM are 603 nm, 621 nm, 607 nm, 598 nm, respectively.

Bright red emission could be obtained from the optimized double-layer device ((2) Glass/ITO/PVK: dopant/BCP/Alq<sub>3</sub>/LiF/Al). The devices with 20 nm-thick blocking layer (BCP) showed only the light emission from the red dopants. This indicate that the BCP layer with 20 nm thickness could completely block the holes flowing to the Alq<sub>3</sub> layer, and the Alq<sub>3</sub> layer in this device only functions as electron transporting layer. The CIE coordinates were [0.61, 0.39], [0.65, 0.35], [0.62, 0.38]. The highest EL brightness of TDCJTB, BMDIN and TDIN reached 1311 cd/m<sup>2</sup> (18 V), 2934 cd/m<sup>2</sup> (15 V) and 2497 cd/m<sup>2</sup> (16 V) respectively. Compared with traditional DCM ([0.58, 0.41], 1032 cd/m<sup>2</sup> (18 V)) the three devices have better CIE coordinates and brightness.

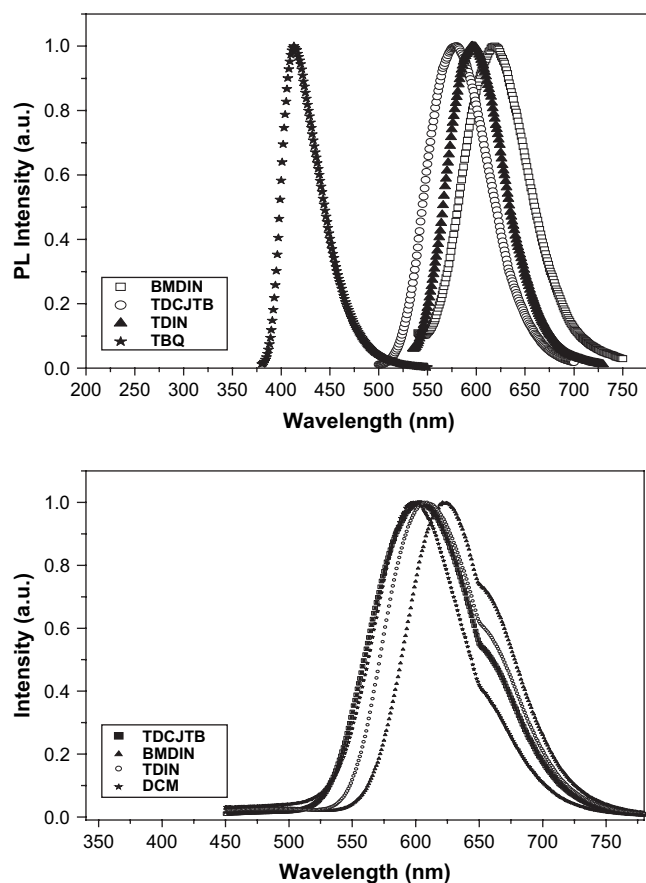


Fig. 2. The PL spectra of TDCJTB, BMDIN, TDIN, TBQ and EL spectra of TDCJTB, BMDIN, TDIN and DCM.

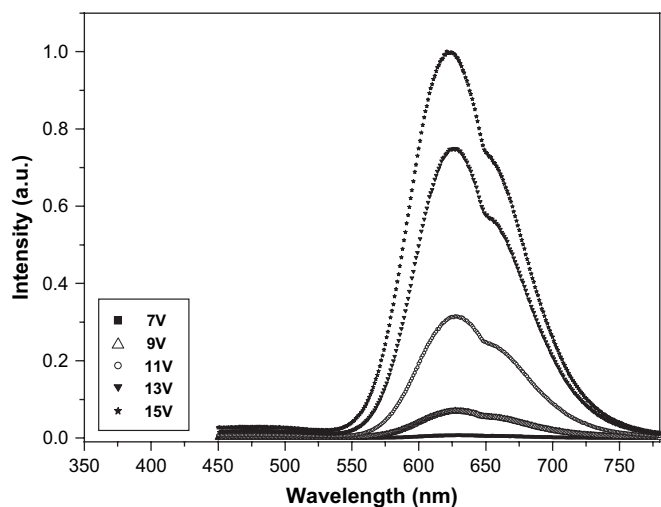


Fig. 3. EL spectra at various voltages for device (2) of BMDIN.

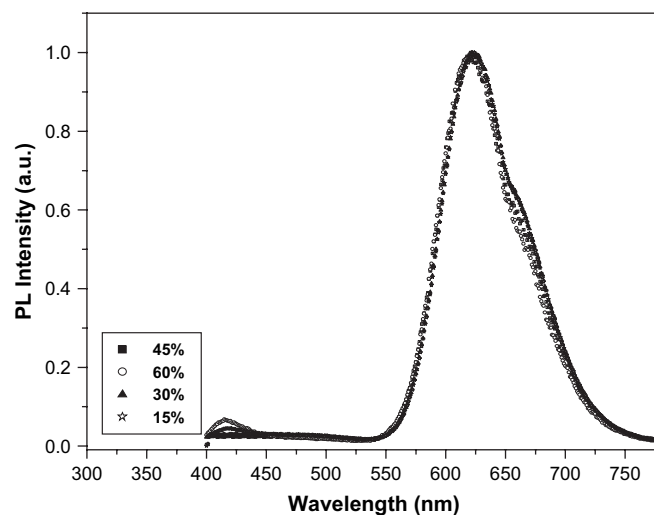


Fig. 4. EL spectra at different concentrations of TBQ in PVK of 10% BMDIN doped CHE devices.

Fig. 3 shows the EL spectra at different voltages (7 V, 9 V, 11 V, 13 V, and 15 V) of the double-layer device for BMDIN. With increasing of the driven voltage the emitting that came from BMDIN was intensified, yet the locations of the peaks were not modified.

When TBQ was doped in the three materials the EL efficiency could all be improved at different levels. BMDIN as a high efficient red organic light-emitting material based on this series of fluorescent dyes doped in co-host emitter (CHE) systems of TBQ/PVK could achieve a higher luminescent efficiency and brightness than the other materials. Fig. 4 shows the EL spectra at different concentrations of TBQ in PVK of 10% BMDIN doped CHE devices ((3) ITO/CHE (70 nm)/BCP (20 nm)/Alq<sub>3</sub> (15 nm)/LiF (0.3 nm)/Al (150 nm)). From this figure, a peak at 415 nm of TBQ could be seen when its concentration was 45%. We could also see with the increasing of the concentration of TBQ in PVK (60%), the emission that came from TBQ was intensified. When the concentration of TBQ in PVK less than 45%, we could not see the light of TBQ.

Fig. 5(a) shows the characteristics of brightness versus voltage at different concentrations of TBQ in PVK of 10% BMDIN doped CHE devices. From this figure we could see

that the properties of the device with the 30% concentration of TBQ were best. The highest EL brightness of the device reached 6766 cd/m<sup>2</sup> at the voltage of 16 V and the maximum EL efficiency was 6.1 cd/A at 40 mA/cm<sup>2</sup> with 30% concentration of TBQ.

Fig. 5(b) shows the luminance yield (cd/A) and drive voltage dependency on TBQ concentration (in wt%) in PVK of 10% BMDIN doped CHE devices. From this figure, we could see the luminance efficiency topped out at 30% for TBQ. While the drive voltage decreased steadily with respect to increasing TBQ concentration. The decrease in drive voltage of the device with increasing TBQ concentration in the co-host mixture was apparently due to the enhanced bipolar transport nature of TBQ.

#### 4. Conclusion

In summary, a new DCM derivative (TDCJTB, BMDIN and TDIN) has been synthesized, which was first used as red fluorescent dye molecule in organic light-emitting diodes (OLEDs). The devices of the new DCM derivative have better brightness and CIE coordinates. Present research work shows that when TBQ is doped in the three materials the EL

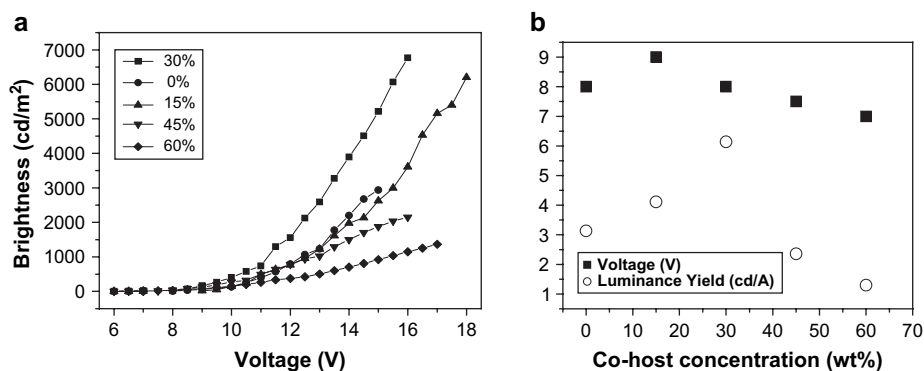


Fig. 5. (a) Characteristics of brightness versus voltage at different concentrations of TBQ in PVK of 10% BMDIN doped CHE devices; (b) efficiency (○) and drive voltage (■) dependency on TBQ concentration in PVK of 10% BMDIN doped CHE devices.

efficiency can all be improved at different levels. BMDIN as a high efficient red organic light-emitting material based on this series of fluorescent dyes doped in co-host emitter (CHE) systems of TBQ/PVK can achieve a higher luminescent efficiency and brightness than the other materials. The highest EL brightness of the device reached 6766 cd/m<sup>2</sup> at the voltage of 16 V and the maximum EL efficiency was 6.1 cd/A at 40 mA/cm<sup>2</sup> with 30% concentration of TBQ.

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