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White organic light-emitting devices with a new DCM derivative as an efficient red-emitting material

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Abstract

We report the fabrication and the characterization of white organic light-emitting devices consisting of a red-emitting layer of a new DCM derivative doped into 4,4'bis[N-(1-napthyl)-N-phenyl-amino]-biphenyl (α-NPD) and a blue-emitting layer of 1,4-bis(2,2-diphenyl vinyl)benzene (DPVBi). The device structure is ITO/PEDOT:PSS/α-NPD (50 nm)/α-NPD:DCM (5 nm, 0.2 %)/DPVBi (x)/Alq3 (40 nm)/LiF (0.5 nm)/Al. The electroluminescence (EL) spectra consist of two broad peaks around 470 nm and 580 nm with the spectral emission depending on the thickness of DPVBi. The device with the DPVBi thickness of about 20 nm show a white light-emission with the Commission Internationale d'Eclairage(CIE) chromaticity coordinates of (0.33, 0.36). The external quantum efficiency is 2.6% and luminous efficiency is 2.0 lm/W at a luminance of 100 cd/m^2. The maximum luminance is about 30,270 cd/m^2 at 13.9 V.

1. Introduction

Organic light-emitting displays (OLEDs) have attracted significant interests due to their excellent display characteristics such as ease of fabrication, high brightness, low power consumption, fast response speed and wide viewing angle [1]. Recently, efficient white OLEDs have become an active research focus since the combination of a white electroluminescence (EL) emission and a RGB-patterned color filter leads to the full-color display that does not require so much accurate alignment of shadow masks as the R, G, B-pixellated OLED displays.

White light emission from an OLED requires mixing of two complementary colors or three primary colors. Various device structures for white OLED are proposed such as a multilayer structure with several emitting layers or doping several different color emitting molecules in layers that are displaced at varying distances from the exciton formation zone [2-8]. In this paper, we report the fabrication and characterization of white OLEDs that show very stable color coordinates with varying current densities. The devices consist of two light-emitting layers of complementary colors: A red-emitting layer was made by doping a new DCM derivative into a hole-transporting 4,4'bis[N-(1-napthyl)-N-phenyl-amino]-biphenyl (α-NPD) and a blue-emitting layer was 1,4-bis(2,2-diphenyl vinyl)benzene (DPVBi). Fig. 1 shows the device structure and the chemical structure of a DCM derivative and DPVBi.

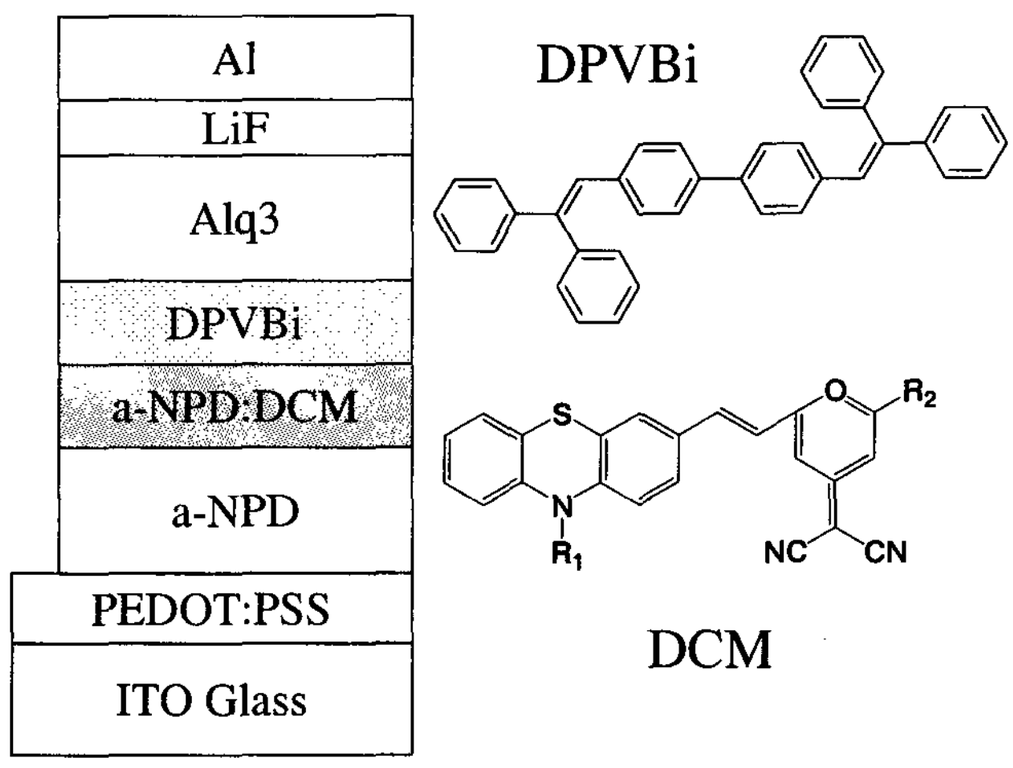

Fig. 1. The device structure of an organic white light-emittng device and the molecular structure of

DPVBi and a new DCM derivative.

2. Experimental

The devices were fabricated on precleaned ITO glass substrates with a sheet resistance of about 10 Ω/€. The hole injection layer of poly(3,4-ethylene dioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) was deposited by spin coating from a solution at 4000 rpm for 30 s, followed by drying at 100 °C for 1 hour in vacuum. Multiple organic layers were deposited on top of the PEDOT:PSS layer by successive vacuum-deposition of α-NPD (500 Å), the red-emitting layer (50 Å), DPVBi with various thicknesses, and Alq_3 (400 Å). Then LiF (5 Å) and Al cathodes were deposited without breaking vacuum. The overlap area of the Al and ITO electrodes is about 2.5 mm^2.

The red-emitting layer was deposited by simultaneously evaporating DCM and α-NPD. The synthesis and characterization of the new DCM derivative will be reported elsewhere [9]. The DCM doping concentration and the thickness of DPVBi was controlled to obtain a balanced white light emission of the CIE coordinate of (0.33, 0.33). For each different DCM concentration, we fabricated devices with the DPVBi thickness of 50, 100, 150 and 200 Å. Efficient white light emission was obtained for the device with a DCM concentration of ~0.2 % and the DPVBi thickness of about 100~200 Å. The device performances such as the current-voltage-luminance (I-V-L) characteristics, and the EL quantum efficiency (QE) were measured with a Keithley 236 source-measure unit and a Keithley 2000 multimeter equipped with a PMT or calibrated Si photodiode. The EL spectra were measured by dispersing the EL emission through an ARC 275 monochromator.

3. Results and discussion

Fig. 2 shows the EL spectra for the devices with four different thicknesses of DPVBi measured under a current density of 20 mA/cm^2 at room temperature. The DCM concentration in α-NPD is 0.2 % for all devices. Devices with the DPVBi thickness of about 100~200 Å show two broad EL peaks with around 470 nm (DPVBi) and 580 nm (DCM), resulting in a white light emission. The red EL peak from this new DCM derivative shows a red-shift of more than 10 nm compared with DCM2 doped with the same concentration in α-NPD [4]. Therefore, the EL spectra of the devices using a new DCM derivative cover broader spectral range in the visible wavelength of 400–700 nm. Fig. 3 shows the CIE chromaticity coordinates for the devices shown in Fig. 2. The device with the DPVBi thickness of 200 Å shows the CIE coordinates of about (0.33, 0.36), very close to the balanced white point of (0.33, 0.33).

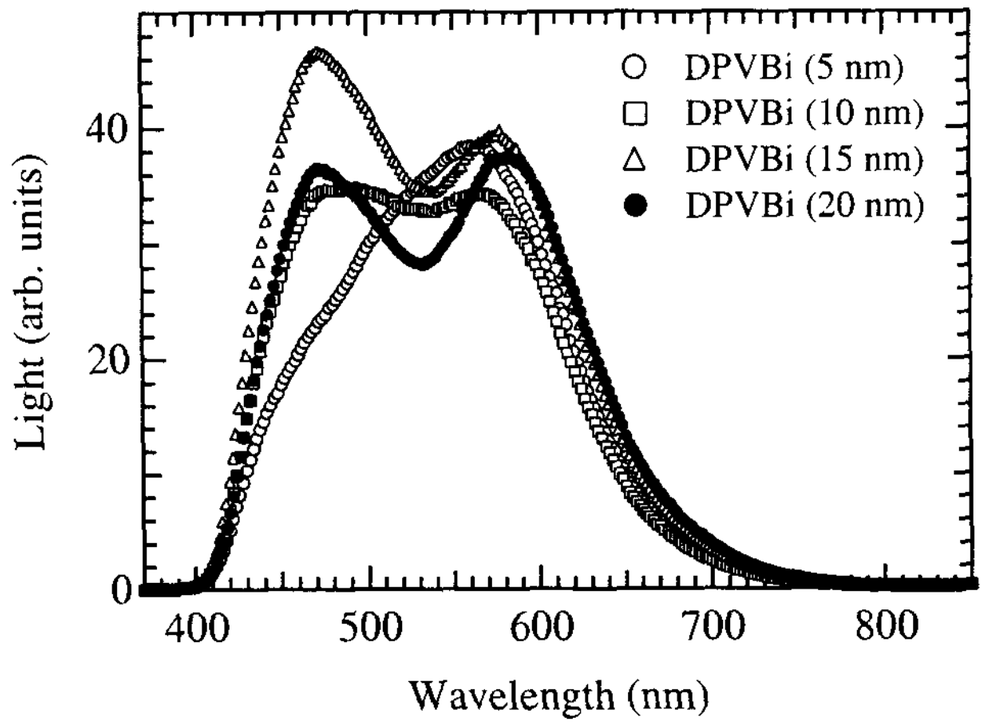

Figure 2. Comparison of the EL spectra for the devices with four different DPVBi thicknesses, ITO/PEDOT:PSS/α-NPD (50 nm)/α-NPD:DCM (5 nm)/DPVBi (*x*)/Alq_3 (40 nm)/LiF (0.5 nm)/Al under a current density of 20 mA/cm^2 at room temperature. The DCM concentration is 0.2 %.

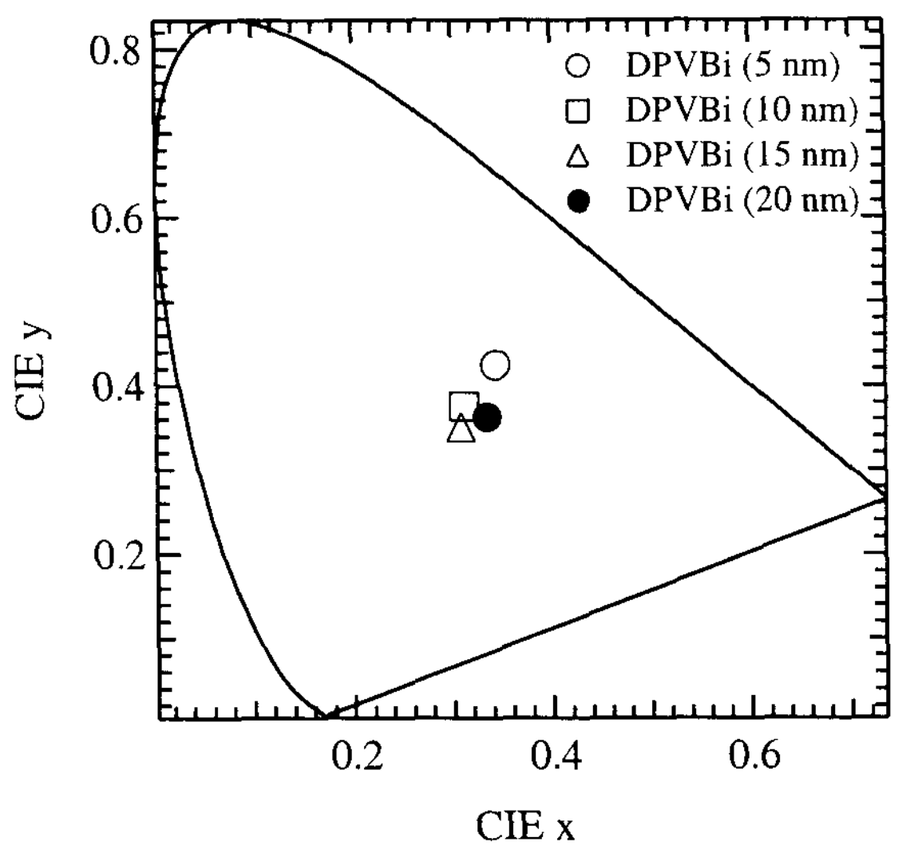

Figure 3. The CIE chromaticity coordinates for the four devices shown in Fig. 2.

Since the electron-hole recombination takes place

in DPVBi near the α-NPD/DPVBi interface, the red EL emission from DCM doped in α-NPD is due to the energy transfer from DPVBi to DCM. For a given DCM concentration, the blue EL peak is observed to increase with increasing DPVBi thickness and then decreases after reaching a maximum around 150 Å. At the DPVBi thickness of less than 150 Å, there is some contribution of the EL emission (around 510 nm) from Alq_3 used as an electron-transporting layer. Therefore, the energy transfer from DPVBi to nearby Alq_3 occurs but it decreases with larger DPVBi thickness due to the limited exciton diffusion length.

Figure 4 shows the variation of the EL spectra with the current density for the device with the DCM2 concentration of 0.2 %, ITO/PEDOT:PSS/α-NPD (50 nm)/α-NPD:DCM2 (5 nm, 0.2 %)/DPVB (20 nm)/Alq_3 (40 nm)/LiF (0.5 nm)/Al. Although the red/blue ratio changes slightly with the variation of the current density, the overall EL spectra are quite stable. The change in the CIE coordinates is from (0.33, 0.36) at 4 mA/cm^2 to (0.34, 0.35) at 80 mA/cm^2. As the current density increases, the relative ratio of the red/blue emission decreases. It is understood as the increased hole transport across the α-NPD/DPVBi interface at the high electric field. Therefore the electron-hole recombination in DPVBi enhances at the high electric field, resulting in a larger blue emission from DPVBi.

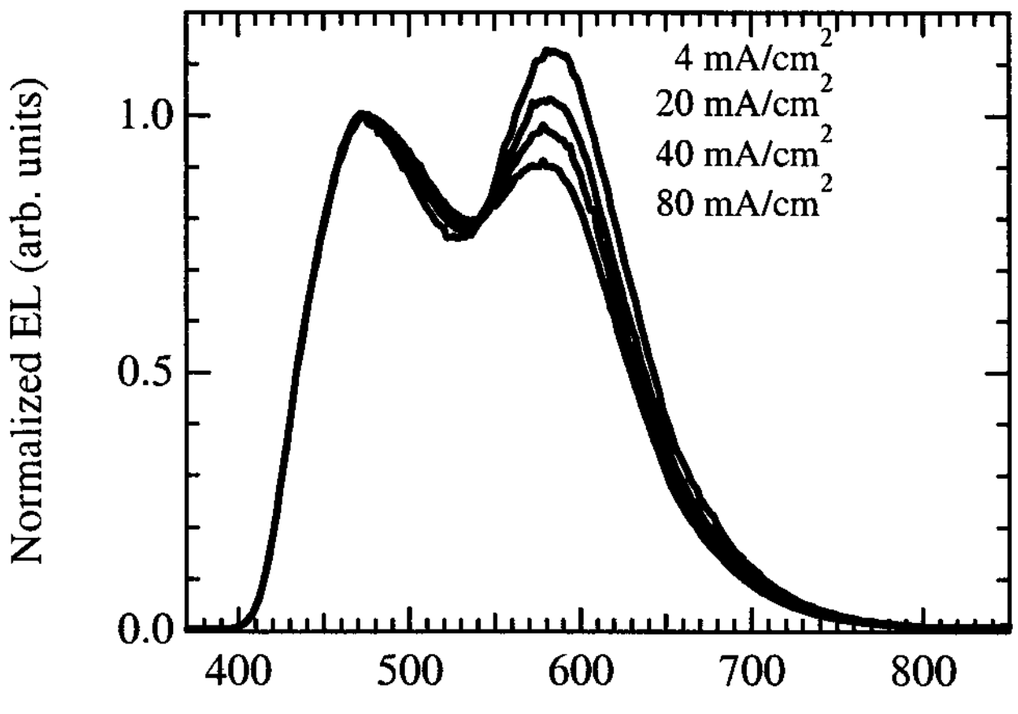

Figure 4. The EL spectra normalized at the blue emission peak for ITO/PEDOT:PSS/α-NPD(50 nm)/α-NPD:DCM (0.2%, 5 nm)/DPVBi (20 nm)/Alq_3 (40 nm)/LiF (0.5 nm)/Al under various current densities between 4 and 80 mA/cm^2.

Figure 5 compares the current-voltage and luminance-voltage characteristics for the device of ITO/PEDOT:PSS/α-NPD (50 nm)/α-NPD:DCM2 (5 nm, 0.2 %)/DPVB (20 nm)/Alq_3 (40 nm)/LiF (0.5 nm)/Al. The inset shows the external quantum efficiency (QE) and the luminous efficiency as the function of the current density for the same device. The onset voltage of the light emission is about 3.1 V. At a luminance of 100 cd/m^2 (current density of 1.84 mA/cm^2 and bias voltage of 8.3 V), the external quantum efficiency is 2.6 % and the luminous efficiency is 2.0 lm/W. The device shows a maximum luminance of 30,270 cd/m^2 at 13.9 V and 1160 mA/cm^2.

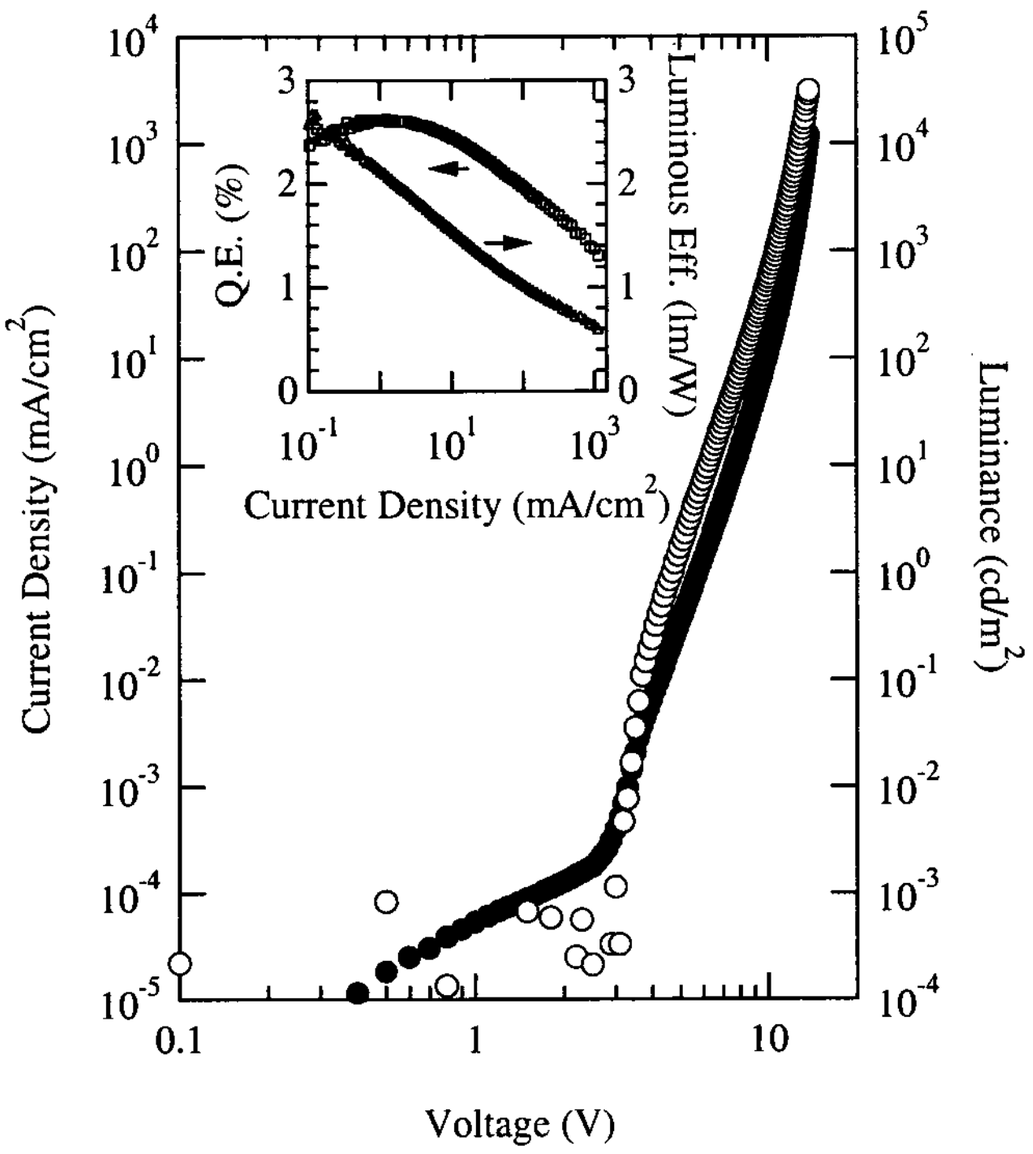

Figure 5. The current-voltage (solid circle) and luminance-voltage (open circle) characteristics for ITO/PEDOT:PSS/α-NPD(50 nm)/α-NPD:DCM (0.2%, 5 nm)/DPVBi (20 nm)/Alq_3 (40 nm)/LiF (0.5 nm)/Al. The inset shows the external quantum efficiency and the luminous efficiency as a function of the current density.

4. Conclusion

We have reported efficient white organic light-

emitting devices consisting of a blue-emitting layer of DPVBi and a red-emitting layer of new DCM derivative doped into α-NPD. The electron-hole recombination takes place at the α-NPD/DPVBi interface and the energy transfer from DPVBi to nearby DCM produces white light emission with complementary colors of blue and orange. By controlling the doping concentration of DCM and the DPVBi thickness, we can obtain the CIE coordinates very close to the balanced white point. The devices with the DCM concentration of 0.2 % and the DPVBi thickness of 200 Å show stable CIE coordinates of (0.33, 0.36) under varying current densities. At a luminance of 100 cd/m^2 (current density of 1.84 mA/cm^2 and bias voltage of 8.3 V), the external quantum efficiency is 2.6 % and the luminous efficiency is 2.0 lm/W. The device shows a maximum luminance of 30,270 cd/m^2 at 13.9 V and 1160 mA/cm^2.

5. Acknowledgements

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