A novel red light-emitting material and the characteristics of OLEDs using the same as red dopant

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Abstract

ABCV-Py, a new red fluorescent material, in which two identical electron donor (dimethylamino group) and acceptor (cyano group) moieties are linked to two independent biphenyl groups which share the same core phenyl, has been synthesized for use in OLED application. Performance of red doped electroluminescent devices using ABCV-Py as dopant were measured with various host materials, Alq_3, CBP, DPVBi, and p-terphenyl. The performance of device with DPVBi host material was better than those with other host materials and high doping concentration could be applied on device with ABCV-Py as dopant.

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 display. Since 1989, Kodak has improved the efficiency, chromaticity, and synthesis of the DCM class of compounds as red dopant for organic electroluminescent devices.[1,2] Usually red organic electroluminescent devices are fabricated by doping red dyes into host materials with a larger bandgap.[3] DCM and DCJTB are excellent red emitters.[2,4] However, there still remain some problems for red-emissive molecular materials in OLEDs application with high luminance, high efficiency, saturated emission, and substantial lifetime.[5] One of the key enablers in the development of OLEDs Technology can be attributed to the discovery of guest-host doped emitter system.[2] In this doped system, exciton formation in a guest dopant molecule would result from either energy transfer of an exciton formed in the host to the guest molecule or sequential trapping of a hole and an electron by the guest molecule.[6]

In this study, a new red emitter (2*Z*,2'*Z*)-3,3'-[4,4"-bis(dimethylamino)-1,1':4',1"-terphenyl-2',5'-diyl]bis(2-pyridin-2-ylacrylonitrile) (ABCV-Py) has been designed and synthesized. Various host materials were used to apply ABCV-Py on OLED as a dopant. Unlike typical red dopant, OLED device with ABCV-Py was possible at high doping concentration (~20%).

2. Experimental.

A new red-emissive material, ABCV-Py was synthesized by the reactions of several steps which included synthesis of 2,5-dibromoterephthalaldehyde by oxidation of 1,4-dibromo-2,5-dimethylbenzene, 4,4"-bis(dimethylamino)-1,1':4',1"-terphenyl-2',5'-dicarbaldehyde by catalytic cross Suzuki coupling reaction and, finally, ABCV-Py by Knoevenagel reaction of 4,4"-bis(dimethylamino)-1,1':4',1"-terphenyl-2',5'-dicarbaldehyde with 2-Pyridylacetonitrile.

Red OLEDs were fabricated by the high vacuum thermal deposition (8 x 10^{-7} Torr) of organic materials onto the surface of ITO (30 Ω/□) coated glass substrate. An ITO coated glass was cleaned in an

ultrasonic bath by regular sequence: in acetone, methanol, diluted water and isopropyl alcohol. The cleaned substrate was immediately loaded into the deposition chamber due to avoid from the air contamination. Hereafter, pre-cleaned ITO was treated by O_2 plasma treatment which whose conditions were $2x10^{-2}$ Torr, 125 W and 2 min. Red OLEDs with ABCV-Py as dopant was fabricated. The device with the structure of ITO / 2-TNATA (60 nm)/ NPB (20 nm)/ various hosts : ABCV-Py (30 nm) / BCP(10 nm) / Alq_3 (20 nm) / Liq (2 nm) /Al (100 nm), in which 2-TNATA, NPB, ABCV-Py, BCP, Alq_3 and Liq were used as a hole injection layer (HIL), hole transporting layer (HTL), emitting layer (host-guest system) various hosts : ABCV-Py, hole blocking layer (HBL), electron transporting layer (ETL), electron injection layer (EIL) and cathode, respectively. The doping rates were 1.0 – 1.1 Å/sec on organic materials and 0.1 Å/sec on Liq, approximately. The doping concentration of the dopant was not still optimized. We measured UV-visible absorption and PL spectra of ABCV-Py in chloroform solution using HP model 8453 and a Perkin Elmer LS-50B. The current density (J), luminance (L), luminous efficiency (LE) and commission internationale de l'eclairage (CIE) X and Y coordinates characteristics of device and EL were measured with keithley 238, CHROMA METER CS-100A and Perkin Elmer LS-50B, respectively.

3. Results and discussion

The charge-transporting property and the luminescent performance of emitter depend on the structure of the molecule such as the conjugated structure of the molecule[7], molecular planarity and rigidity. The molecular structure of ABCV-Py was designed to prevent concentration quenching due to aggregation such as attractive dipole-dipole interactions or effective π-stacking. Fig. 1 shows the characteristic molecular structure of a new red fluorophore, ABCV-Py. The red heavy lines on that structure indicate the π -electron resonance pathways between the donor and acceptor groups. Although ABCV-Py has a strong intramolecular charge transfer (ICT) character like typical red dopant such as DCM, its molecular structure is intrinsically different from that of typical DCM. As shown in Fig. 1, ABCV-Py is an almost not polar molecule because it has both equivalent antiparallel electron donating abilities between two dimethylamino groups and those electron withdrawing abilities between two cyano groups in the molecule. Furthermore, the molecular structure of ABCV-Py is highly noncoplanar due to their distorted molecular geometries caused by twisted terphenyl backbone and steric crowding on central benzene ring being a part of that terphenyl. Accordingly, unlike typical red dopant, ABCV-Py can be prevented from concentration quenching and ABCV-Py-doped OLEDs were possible at high doping concentration.

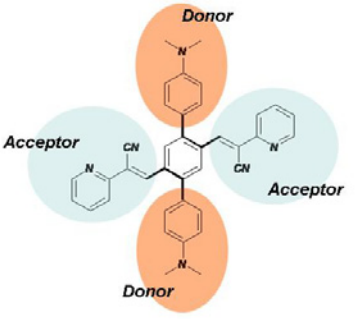

Fig. 1 The molecular structure of ABCV-Py

Fig. 2 shows the normalized UV-visible absorption and PL spectra of ABCV-Py. The UV-visible absorption and photoluminescence (PL) spectra were measured in chloroform solution. The absorption band was peaked at 334 nm with shoulder at 468 nm and fluorescence emission was peaked at 610 nm. There is hardly an overlap between absorption and emission spectrum of emitters, so self-absorption can be avoided, which is a very import advantage of materials for display applications.[7] Fig. 3. shows UV-visible absorption spectrum of ABCV-Py and PL spectra of various hosts.

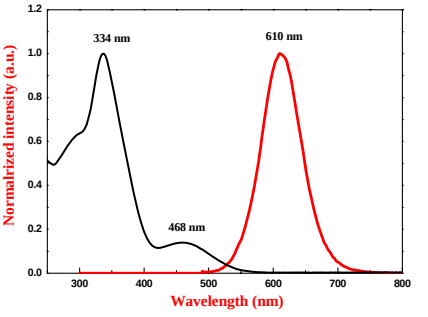

Fig. 2 The UV-vis. Absorption of ABCV-Py and PL spectra of ABCV-Py

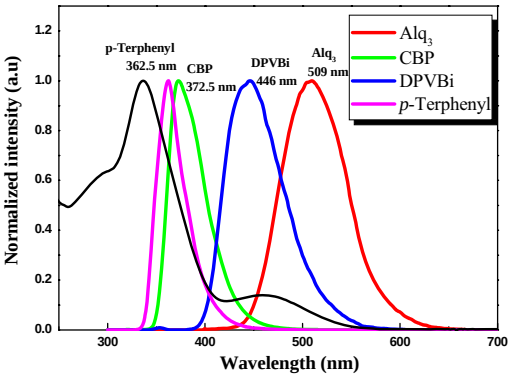

Fig. 3 The UV-vis. Absorption of ABCV-Py and PL spectra of various hosts

Fig. 4 shows the current density-voltage characteristics of the device of ITO / 2-TNATA (60 nm)/ NPB (20 nm)/ various hosts: ABCV-Py (30 nm) / BCP(10 nm) / Alq_3 (20 nm) / Liq (2 nm) /Al (100 nm) with various host materials The device with DPVBi host showed the best luminance of 2900 cd/m^2 at 15 V (Fig. 5). As shown in Fig. 3, there were good overlaps between the PL spectra of *p*-terphenyl, CBP and DPVBi and the absorption spectrum of ABCV-Py. This suggests that efficient Förster energy transfer from those host molecules to the ABCV-Py molecule is possible in this host-dopant system.

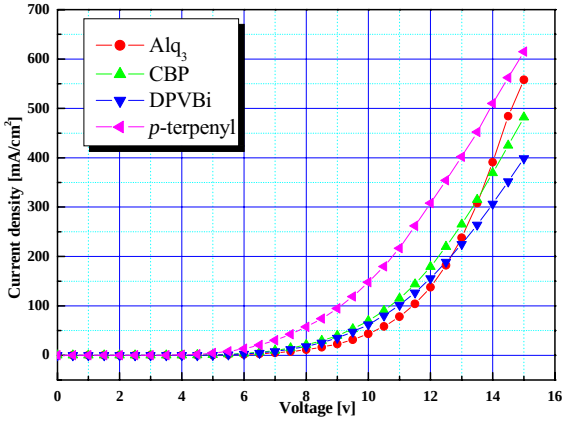

Fig. 4 Characteristics of current density (J) versus voltage

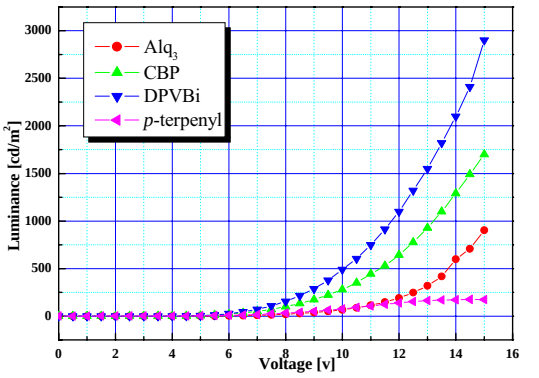

Fig. 5 Characteristics of luminance versus voltage on the devices with different hosts.

The performance of device with DPVBi and CBP host materials were better than those with other host materials. In spite of expectation of good Förster energy transfer, device with *p*-terphenyl host showed bad performance. Fig. 6 shows the EL spectra of the device with DPVBi and CBP host materials at 12V.

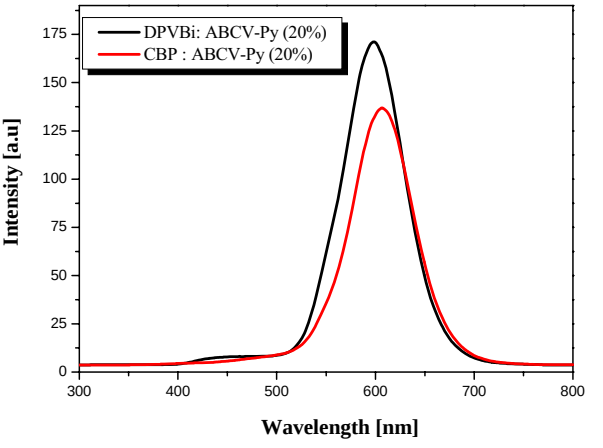

Fig. 6 EL spectra of red-emitting devices with DPVBi and CBP as host materials.

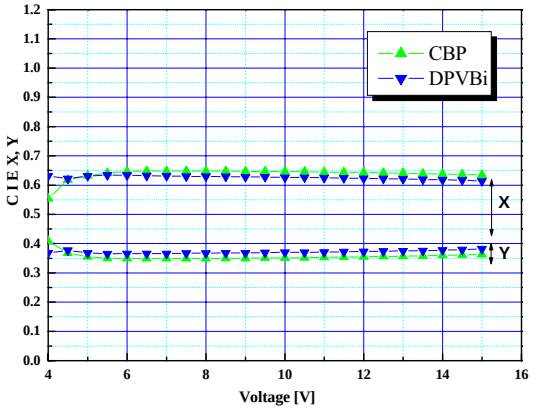

Fig. 7 Commission internationale d'Eclairage ($CIE_{x,y}$) coordinates on the devices with different hosts.

Commission Internationale d'Eclairage ($CIE_{x,y}$) coordinates for device using DPVBi and CBP host materials exhibited (0.62, 0.37) and (0.64, 0.35) at 10 V in Fig. 7, which were comparable with (0.64, 0.33) of National Television System Committee (NTSC).

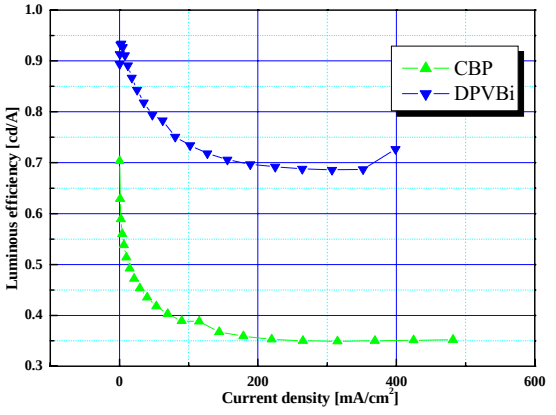

Fig. 8 Characteristics of luminous efficiency (LE) versus current density (J)

We demonstrated the new red light emitting material, ABCV-Py, could be used for pure red OLED as a dopant material. In this study, considerably good performance of device with the novel red dopant was obtained. Compared with traditional DCM ($CIE_{x,y}$=0.58, 0.41, 1032cd/m^2 (18 V)), the device with DPVBi as host material and ABCV-Py as dopant exhibited better color purity ($CIE_{x,y}$=0.64, 0.33) and brightness (2900 cd/m^2 at 15 V). While the performance of ABCV-Py-doped OLED is still not the best, these results supported that the new material, ABCV-Py, could be a candidate for use in OLED as a red emitter. Also, the improvement of color purity of device with ABCV-Py can be possible by modification of electron donor (containing dimethylamino group) and acceptor (containing cyano group) moieties within ABCV-Py molecule.

4. Summary

In this work, a new red-emissive material, ABCV-Py was designed and synthesized. Its structure was designed to suppress concentration quenching in order to apply it on doped-OLED device at high doping concentration. We used various host materials such as Alq_3, CBP, DPVBi and *p*-terphenyl, to optimize the efficiency with a new red fluorescent material, ABCV-Py. Proper host materials were decided by measurements of their optical characteristics and the performance of device with DPVBi host material was better than those with other host materials. Finally, although the performance of device with ABCV-Py was still not the best, it well supported that ABCV-Py could be a candidate for a red emitter in OLEDs.

5. References

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