White Organic Light-Emitting Diodes Using a New DCM Derivative as an Efficient Orange-Red Doping Molecule

Jong-Don Lee[1], Do-Hoon Hwang[1], Nam Sung Cho[2], Sang Kyu Lee[2], Hong-Ku Shim[2] and Chang Hee Lee[3]

[1]Department of Applied Chemistry, Kumoh National Institute of Technology, Kumi 730-701, Korea

[2]Center for Advanced Functional Polymers, Department of Chemistry and School of Molecular Science (BK21), Korea Advanced Institute of Science and Technology, Taejon 305-701, Korea

[3]School of Electrical Engineering and Computer Science, Seoul National University, Seoul 151-744, Korea

Phone : +82-54-478-7821, E-mail : dhhwang@kumoh.ac.kr

Abstract

A new DCM derivative containing a phenothiazine moiety, 4-(dicyanomethylene)-2-t-butyl-6-(9-ethylphenothiazine-2-enyl)-4H-pyran (DCPTZ), has been synthesized as an orange-red fluorescent dye molecule for organic light-emitting diodes (OLEDs). EL devices with the structure of ITO/PEDOT-PSS/α-NPD/Alq_3:DCPTZ/Alq_3/LiF/Al have been fabricated with changing the doping concentration of the DCPTZ. Maximum EL spectra of the devices ranged from 580~620 nm depending on the doping concentration of the dye molecule. An EL device with 0.5 % doping concentration showed CIE coordinate (0.51, 0.47) at luminance of 100 cd/m^2. White light-emitting devices with the structure of ITO/PEDOT-PSS/ α-NPD/α-NPD:DCPTZ/DPVBi/Alq_3/ LiF/Al have been also fabricated. The thickness of blue light-emitting 1,4-bis(2,2-diphenylvinyl)benzene (DPVBi) layer was changed to obtain a white light-emission. A white light-emission from the device was observed when the thickness of the DPVBi layer became thicker than 10 nm.

Introduction

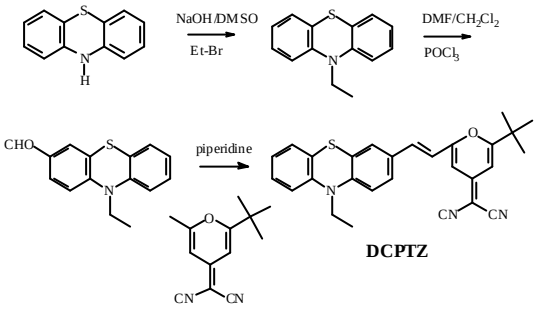
Organic light-emitting display (OLEDs) have attracted significant interests as the next generation flat panel display due to their excellent display characteristics such as ease of fabrication, high brightness, low power consumption, fast response speed and wide viewing angle[1,2]. Red, green and blue light-emitting materials with high efficiency and standard color are necessary for full color displays. A number of green and blue emitters with high luminous efficiencies and reasonable color purity have already been realized in OLEDs. However, for the red emitters, issues of efficiency and color purity still remain[3].

White organic light emitting diodes have attracted significant research interest due to their applications in full color displays combined with color filters, in backlights for liquid crystal displays, and in meeting various other lighting requirements[4]. Especially the importance of full color OLED using white light-emitting diodes has been increased because of the limitation of conventional shadow-mask patterning technique in precision for large size displays. White light emission requires the mixing of two complementary colors or three primary colors from different molecules.

4-(Dicyanomethylene)-2-methyl-6-[p-(dimethylamino)styryl]-4H-pyran (DCM) and DCM derivatives have been known as a well-known excellent red emitter in OLEDs. Many DCM derivatives have been developed for improved efficiency and color purity as red doping molecules in OLEDs. Generally DCM derivatives

are composed of electron accepting 4- (dicyanomethylene)-4H-pyran moiety and electron donating arylamine derivatives. 4(Dicyanomethylene)-2-methyl-4H-pyran, 4-(dicyanomethylene)-2-(tert-butyl)-4H-pyran and 4-(dicyanomethylene)-chromene moieties have been used as the π-electron acceptors in DCM derivatives. 3-(Dicyanomethylene)-5,5,-dimethylcyclohexene was also used as an another π-electron acceptor for a DCM homologue, 3-(dicyanomethylene)-5,5-dimethyl-1-(4-dimethylamino-styryl)cyclohexene (DCDDC)

Scheme 1



In this present work, we introduced phenothiazine moiety as a new class of π-electron donor in DCM derivative. Phenothiazine is a well-known heterocyclic compound possessing electron abundant sulfur and nitrogen heteroatoms.

Recently molecules and polymers containing phenothiazine moiety have been attracted because of their unique electro-optical properties for diverse applications such as chemiluminescence, light-emitting diodes and organic field-effect transistors. We report the synthesis of a new DCM derivative containing phenothiazine moiety, 4-(dicyanomethylene)-2-t-butyl-6-(9-ethylphenothiazine-2-enyl)-4H-pyran (DCPTZ), and fabrication and characterization of orange-red and white EL devices using the molecule. The synthetic route for the DCPTZ is shown in Scheme 1.

Results

We fabricated orange-red light-emitting diodes with ITO/PEDOT-PSS/α-NPD(50nm)/Alq_3:DCPTZ(30nm)/Alq_3(30nm)/LiF(0.5nm)/Al. The doping concentration of DCPTZ was ranged from 0.2 to 2.0 %. The overlap area of the Al and ITO electrodes was about 2.5 mm^2. The device performance was studied by measuring its current-voltage-EL (I-V-L) characteristics, electroluminescence (EL) spectra and CIE coordinates.

The brightness and efficiency of the devices using DCPTZ are excellent but the color purity of the devices is not satisfactory as a red for full color applications. DCPTZ is, however, expected be an efficient doping molecule for generating white light emission.

We fabricated multiple layer white light-emitting diodes using the DCPTZ doped Alq_3 layer as the orange-red emitter and 1,4-bis(2,2-diphenylvinyl)benzene (DPVBi) layer as the blue emitter. The device structure of white EL devices fabricated in this study was ITO/ PEDOT-PSS/α-NPD/α–NPD:DCPTZ(5nm:0.2%)/DPVBi(xnm)/ Alq_3(40nm)/ LiF(0.5nm)/Al. The structure of the white EL device is shown in Figure 1.

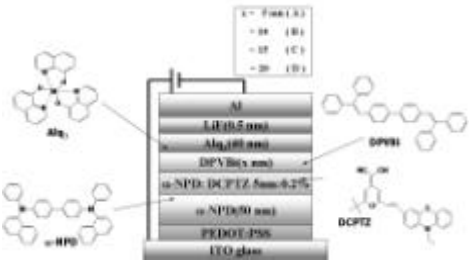
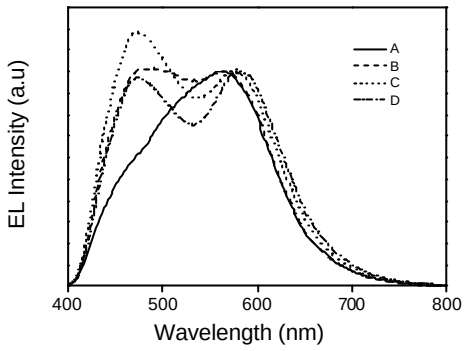


Figure 1. Schematic diagram of the multi-layer white EL devices constructed for this study.

We fabricated four different devices changing the thickness of blue light-emitting DPVBi layer: (from 5 to 20 nm).



The EL spectra of the devices are shown in Figure 2. Figure 2. EL spectra of the white EL devices with blue-emitting DPVBi layers of various thicknesses

The emission band from the blue light-emitting DPVBi layer at about 460 nm was not strong in the device (A). The blue emission band at this position, however, increased when the DPVBi layer was thicker than 10 nm, and the devices became to show a white light-emission. The devices with the DPVBi thickness layer than 10 nm show CRI in the range between 70 and 83. The high CRI of these devices offers a great potential for using general lighting applications.

Conclusions

We synthesized a new DCM derivative containing phenothiazine moieties as a ? -electron donor. The OLEDs using DCPTZ as a fluorescent doping molecule, and with a structure of ITO/PEDOT-PSS/? -NPD (50nm)/Alq_3:DCPTZ(30nm)/ Alq_3(30nm)/ LiF(0.5nm)/Al configuration have been fabricated and characterized. An EL device with 0.5 % doping concentration showed an efficient orange-red light emission. White light-emitting devices with the structure of ITO/PEDOT-PSS/α-NPD/ α-NPD:DCPTZ(5nm:0.2%)/DPVBi(xnm)/Alq_3(40nm)/LiF(0.5nm)/Al have been also fabricated. The device showed efficient white light-emission with a good color purity with a high color rendering index and a good stability of color coordinates.

References

[1] Nalwa, H.S.; Rohwer, L.S., *Hanbook of Luminescence, Display Materials and Devices*, Volume 1, Organic Light-Emitting Diodes, American Scientific Publisher, California, **2003**.

[2] Shirota, Y.; *J. Mat. Chem.* **2000**, *10*, 1.

[3] Chen, C.T. *Chem. Mater.* **2004**, *16*, 4389.

[4] Dodabalapur, A.; Rothberg, L.J.; Miller, T.M. *Appl. Phys. Lett.* **1994**, *65*, 2308.