

## Efficient orange-red OLED using a new DCM derivative as a doping molecule

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### Abstract

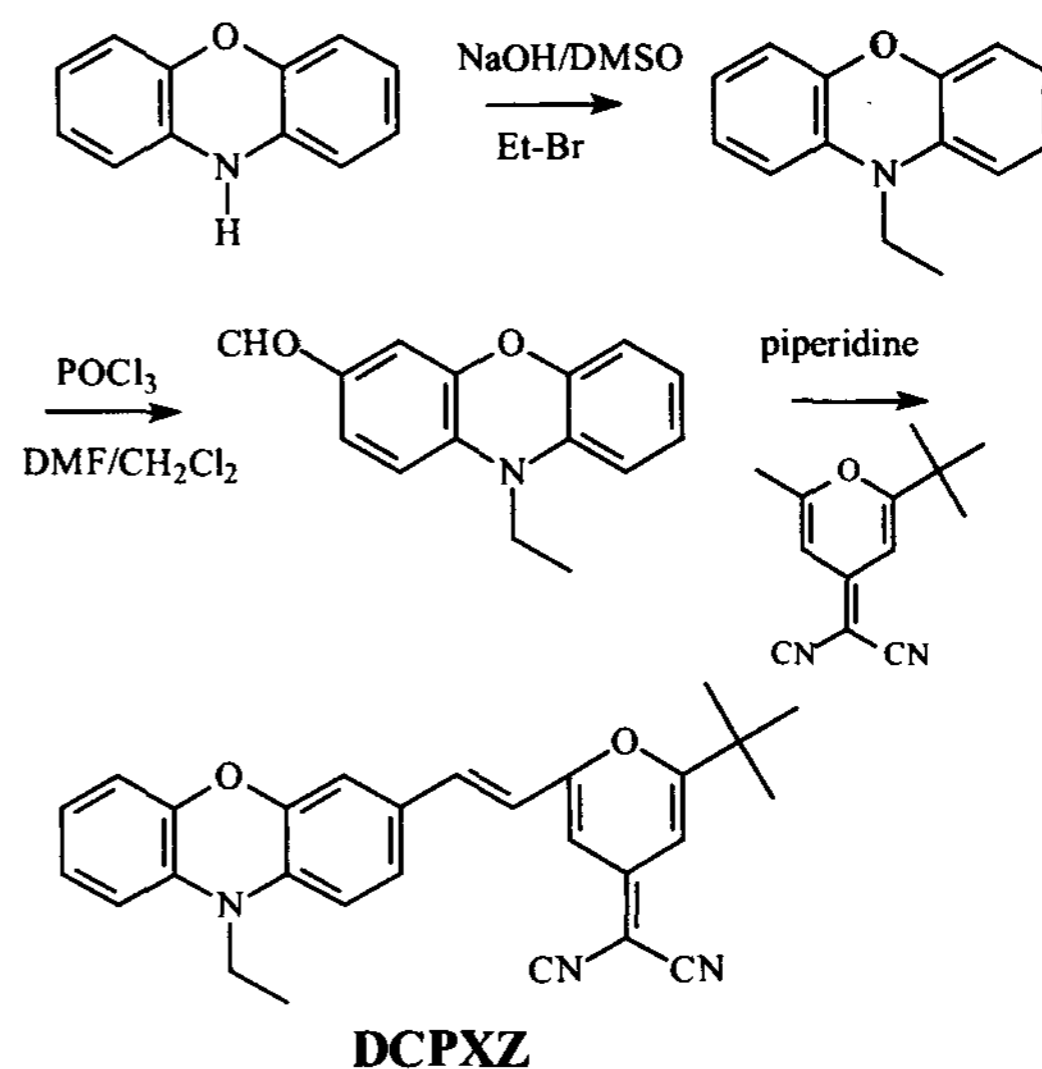
A new DCM derivative containing the phenoxazine moiety (DCPXZ) has been synthesized for use as a red fluorescent dye molecule in organic light-emitting diodes (OLEDs). The photoluminescence and electroluminescence properties of DCPXZ were examined. The maximum photoluminescence of DCPXZ in chloroform solution ( $10^{-5}$  mol) was observed at 616 nm. EL devices were fabricated with the structure ITO/PEDOT-PSS/Cu-PC(15nm)/ $\alpha$ -NPD(45nm)/Alq<sub>3</sub>:DCPXZ(30nm)/Alq<sub>3</sub>(30nm)/LiF(0.5nm)/Al. The maximum EL emission for the 2.0% DCPXZ-doped device was at 608 nm with CIE coordinates (0.57, 0.42). The EL device exhibited a maximum brightness of 15,000 cd/m<sup>2</sup> at 19.4 V and a power efficiency of 1.04 lm/W at a luminance of 100 cd/m<sup>2</sup>.

### 1. Introduction

Organic light-emitting diodes (OLEDs) have attracted significant interest for their potential use in next generation flat panel displays because of their excellent display characteristics such as ease of fabrication, high brightness, low power consumption, fast response time, and wide viewing angle [1-2]. Red, green and blue light-emitting materials with high efficiency and color purity are necessary for full color displays. A number of green and blue emitters with high luminescence efficiencies and reasonable color purity have already been realized in OLEDs. However, red-emitting materials with satisfactory efficiency and good color purity have yet to be achieved. Red emission by an OLED is usually obtained by doping red fluorescent dye into a host material that has a wider bandgap than the guest red dopant. The advantages of doping include easy color tuning and improved efficiency and stability of devices.

In this present work, we have introduced the phenoxazine moiety as a new class of  $\pi$ -electron donor into a DCM derivative. Phenoxazine is a well-known heterocyclic compound with electron abundant oxygen and nitrogen heteroatoms. Molecules and polymers containing phenoxazine or phenothiazine moieties have recently attracted much research interest because of their unique electro-optical properties and their resulting potential in diverse applications such as chemiluminescence, light-emitting diodes and organic field-effect transistors [3-6]. We report the synthesis of a new DCM derivative containing the phenoxazine moiety, 4-(dicyanomethylene)-2-*t*-butyl-6-(9-ethylphenoxazine-2-enyl)-4H-pyran (DCPXZ), and the fabrication and characterization of an EL device using DCPXZ as a red fluorescent dye. The synthetic route we used to obtain DCPXZ is shown in Scheme 1.

Scheme 1



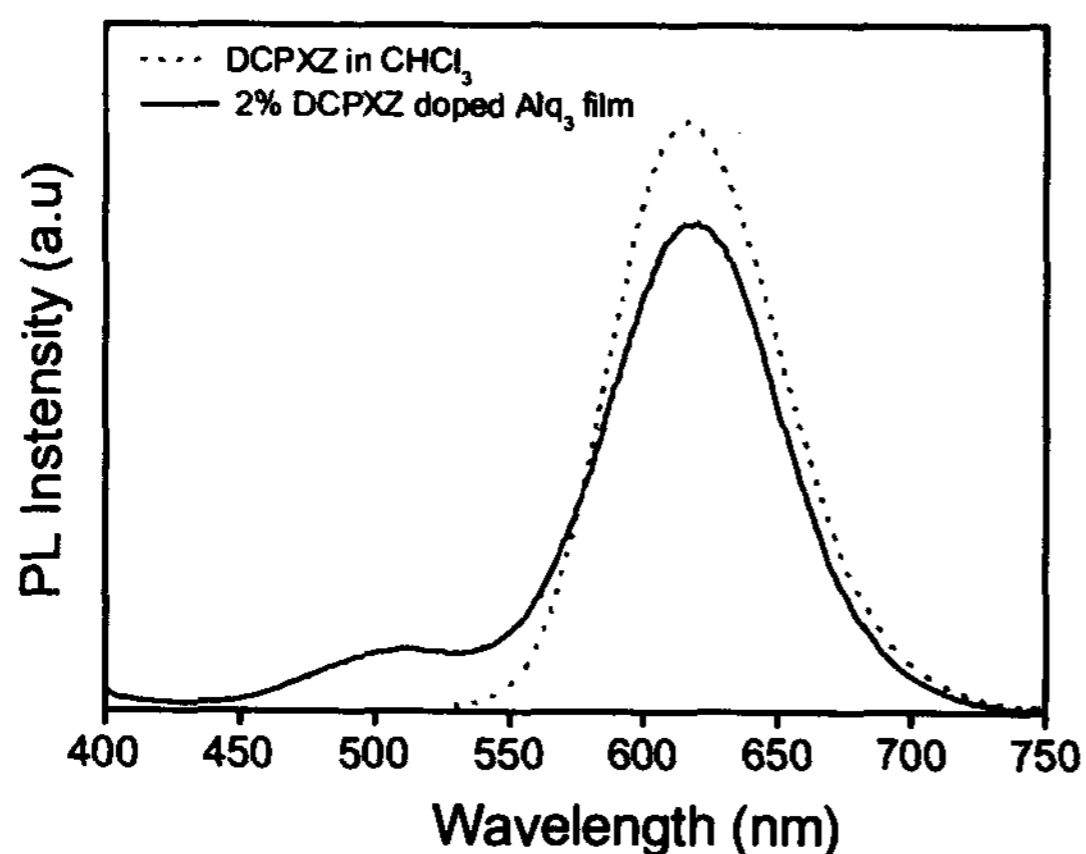


Figure 1. PL emission spectra of 2% DCPXZ doped Alq<sub>3</sub> thin film (solid line) and DCPXZ in chloroform (10<sup>-5</sup> mol) (dot line).

## 2. Experimental

The steady-state photoluminescence (PL) spectra were recorded on a Spex FL3-11. We fabricated a red light-emitting diode with the following structure: indium tin oxide (ITO)/PEDOT-PSS/Cu-PC(15nm)/ $\alpha$ -NPD(45nm)/Alq<sub>3</sub>:DCPXZ(30nm)/Alq<sub>3</sub>(30nm)/LiF(0.5nm)/Al. The device was fabricated on a cleaned ITO glass substrate with a sheet resistance of about 10  $\Omega$ /square. To enhance the device performance, PEDOT-PSS (Baytron P4083) was deposited by spin coating from solution at 4000 rpm for 30 s, followed by drying at 100°C for 1 h in vacuum. Organic layers of copper phthalocyanine (15 nm),  $\alpha$ -NPD (45 nm), Alq<sub>3</sub> doped with DCPXZ (30 nm), Alq<sub>3</sub> (30 nm), LiF (0.5 nm) and Al electrodes were deposited on top of the PEDOT:PSS layer through successive vacuum depositions, without breaking vacuum. The doping concentration of DCPXZ in the Alq<sub>3</sub> host layer was 2.0%. The device performance was studied by measuring its current-voltage-EL (I-V-L) characteristics, spectra, and CIE coordinates. The I-V-L characteristics were measured with a Keithley 236 source-measure unit and a Keithley 2000 multimeter equipped with a PMT through an ARC 275 monochromator. The external quantum efficiency (QE) of the device's EL, defined as the ratio of emitted photons to injected charges, was calculated from the EL intensity measured with a calibrated Si photodiode.

## 3. Results and discussion

PL emission spectra of DCPXZ were obtained in solution and in film state. The maximum PL of a 10<sup>-5</sup> mole chloroform solution of DCPXZ was observed at 616 nm. The PL spectrum of an Alq<sub>3</sub> thin film doped with 2% DCPXZ was also obtained. The solid PL spectrum was almost the same as the solution spectrum and exhibited maximum PL at 616 nm. However, a small emission band due to Alq<sub>3</sub> was observed at approximately 510 nm, which arises because of incomplete energy transfer between Alq<sub>3</sub> and DCPXZ. The PL emission spectra of DCPXZ are shown in Figure 1.

An EL device was fabricated with the following structure: ITO/PEDOT-PSS/Cu-PC(15nm)/ $\alpha$ -NPD(45nm)/Alq<sub>3</sub>:DCPXZ(30nm)/Alq<sub>3</sub>(30nm)/LiF(0.5nm)/Al. PEDOT-PSS and Cu-PC were used as the buffer layers and  $\alpha$ -NPD as the hole-transporting layer. Alq<sub>3</sub> doped with DCPXZ was used as the emissive layer, and undoped Alq<sub>3</sub> was used as the electron-transporting layer. The DCPXZ-doped Alq<sub>3</sub> emission layer was prepared by co-evaporating DCPXZ and Alq<sub>3</sub> simultaneously from two sources at calibrated rates to achieve the desired mass ratio. ITO-coated glass with a sheet resistance of 10  $\Omega$ /square was used as both the substrate and the anode. Thin LiF was used as the electron-injecting layer and Al was used as the cathode. The maximum EL of the 2.0% DCPXZ-doped device was found to be at 608 nm. Figure 2 shows the current-voltage-luminance characteristics of the EL device.

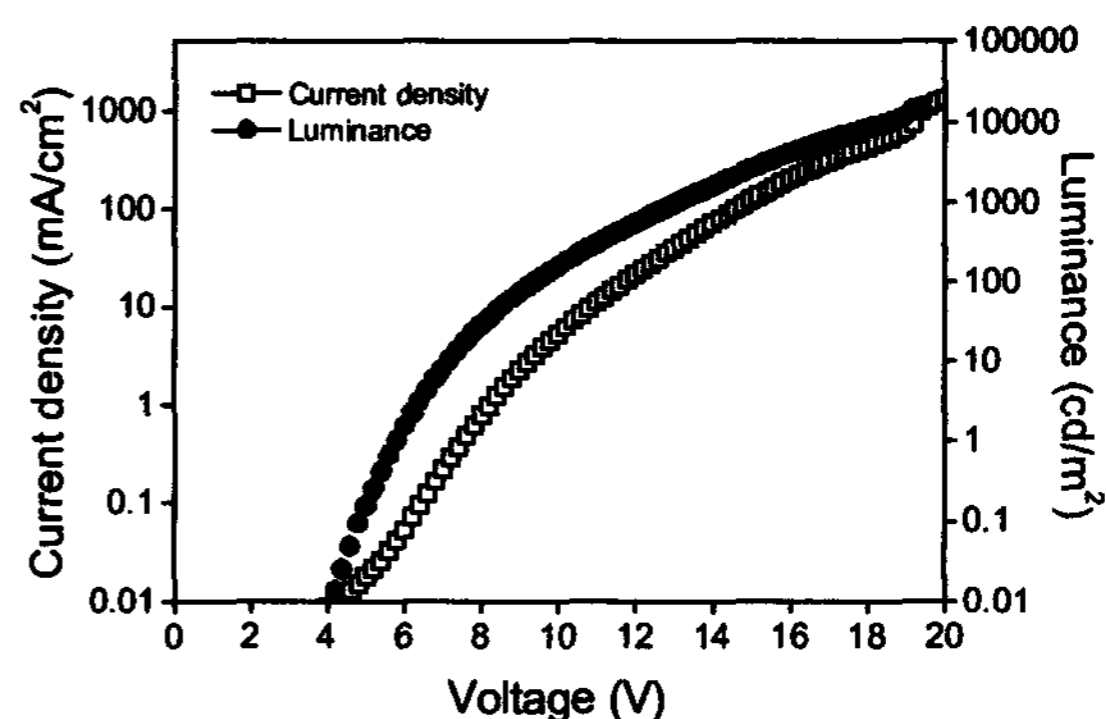


Figure 2. Current density-voltage-luminance curves of the device.

Light emission from this device was observed at voltages greater than 4.8 V ( $\sim 1$  cd/m<sup>2</sup>). The operating voltage at a luminance of 100 cd/m<sup>2</sup> was 9.4 V with a current density of 3.23 mA/cm<sup>2</sup>. The EL device exhibited a maximum brightness of 15000 cd/m<sup>2</sup> at 19.4 V and 983 mA/cm<sup>2</sup>. The CIE 1931 coordinates of the device measured at a brightness of 100 cd/m<sup>2</sup> are  $x=0.57$  and  $y=0.42$ . The external quantum efficiency and luminescence efficiency at 100 cd/m<sup>2</sup> were 1.7% and 1.04 lm/W respectively.

The results from the DCPXZ device are comparable to or better than those of the other devices. Thus the phenoxazine-containing DCM dyes are good candidates for use in organic light-emitting diodes. However, the emission color of the DCPXZ device is far from the standard red. Improvement of the device color purity by structural modification of the DCPXZ-based molecule is therefore needed. Both structural modifications of phenoxazine-based DCM derivatives in order to obtain efficient pure red emission and optimization of the EL device are currently under investigation.

#### 4. Conclusion

We have synthesized a new red fluorescent dye molecule for use in OLEDs. The new DCM derivative containing phenoxazine (DCPXZ) exhibited an orange-red light emission with maximum PL emission

at 616 nm. An OLED using DCPXZ as a dopant with a structure of ITO/PEDOT-PSS/Cu-PC(15nm)/ $\alpha$ -NPD(45nm)/Alq<sub>3</sub>:DCPXZ(30nm)/Alq<sub>3</sub>(30nm)/LiF(0.5 nm)/Al was fabricated and characterized. The EL device with a DCPXZ doping concentration of 2.0% exhibited an efficient orange-red light emission at 608 nm.

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