

## FABRICATION OF WHITE ORGANIC LIGHT EMITTING DIODE USING PHF DOPED WITH RUBRENE

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**Abstract** A white organic light emitting diode, OLED is one of the approaches to obtain full color flat screen display. OLED devices with the structure of ITO/PHF: rubrene/Al have been fabricated where poly (9,9-di-n-hexylfluorenyl-2,7-dyl), PHF used as blue light emitting host and 5,6,11,12-tetraphenyl-naphthacene, rubrene as an orange dye dopant. Indium tin oxide, ITO used as anode and aluminum, Al as cathode. The PHF and rubrene were dissolved in toluene and was then deposited onto ITO glass substrate by spin-coating technique to serve as emitting layer. A white light emitting device with the Commission Internationale de L'Eclairage, CIE 1964 coordinates of (0.3, 0.33) was obtained by varying rubrene concentration in the PHF solution.

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### Introduction

Organic light emitting diodes (OLEDs) are thin film devices in which organic materials are sandwiched between two electrodes. These devices emit light when electricity is passed through them. OLEDs have gained much attention in both academic and commercial fields because of their attractive characteristics and their potential applications to flat panel display, such as mobile phones, PDA, etc. Organic materials show significant potential in future display applications from small area handheld telecom devices to large area displays due to their high luminance, low fabrication costs and ease in fabricating large area devices (Hung *et al.*, 2002). Current research on OLEDs focuses on the integration of OLEDs into full color, flat panel display and one of the approaches is the use of white OLEDs with color filter array.

Efforts to develop the white OLED include (i) host-guest system (Kido *et al.*, 1994; Kido *et al.*, 1995; Jordan *et al.*, 1995; Kalinowski *et al.*, 1996; Thompson *et al.*, 2001; Zhang *et al.*, 2003; Zhang *et al.*, 2003; Yao *et al.*, 2005), (ii) multilayer structures (Kido *et al.*, 1995; Jordan *et al.*, 1995; Kalinowski *et al.*, 1996; Thompson *et al.*, 2001; Yao *et al.*, 2005), (iii) exciplex emission structures (Ching *et al.*, 1998; Dodabalapur *et al.*, 1994), (iv) microcavity structures (Duggal *et al.*, 2002; Shiga *et al.*, 2003), (v) down-conversion phosphor system (Tsai *et al.*, 2003), and (vi) single molecule structures (John Griffiths, 1976; Paik *et al.*, 2002). Another dimension to this approach is complementary colors where the combination of only two colors can produce a white light (Dipti *et al.*, 2006). Organic molecules generally have very broad emission. Therefore, the combination of emission from colors which are not exactly complementary may also give white light (Yang *et al.*, 2000). Blue are commonly used to dope with a dye dopant because it has a short wavelength. The most frequently used color combinations are blue and yellowish orange (Zheng *et al.*, 2003; Tasch *et al.*, 1997), blue and red (Xiaoming *et al.*, 2005) and greenish blue and orange (Ohmori, *et al.*, 1991).

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This paper reports the fabrication and performance of OLED devices that utilized an emitting layer consisting poly (9, 9-di-n-hexylfluorenyl-2, 7-dyl), PHF as blue light emitting host and 5, 6, 11, 12-tetraphenyl-naphthacene, rubrene as red-orange dopant.

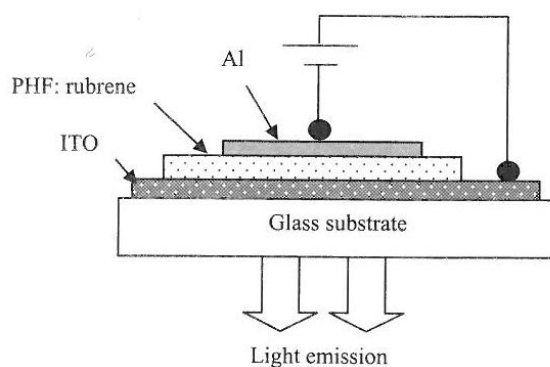
PHF is one of the family member of the polyfluorene that has the greatest potential for blue emitting material in OLED devices. It has very high photo luminescent efficiency with good solubility in common organic solvents, due to the alkyl chains substitution in the fluorine unit (Ohmori *et al.*, 1991). This blue color doped with an orange dye with a variation of rubrene's concentration is normally used to obtain a white light. This device is the simplest device compared to the other approaches because it avoids a multi-layer structure and multi-dopant.

### Material and Methods

OLED devices with a structure of ITO/PHF: rubrene/Al has been fabricated (Fig. 1) where poly (9, 9-di-n-hexylfluorenyl-2, 7-dyl), PHF as blue light emitting host and 5, 6, 11, 12-tetraphenyl-naphthacene, rubrene as red-orange dye dopant. ITO is indium tin oxide that coated on glass substrate as an anode. Aluminium, Al used as cathode. The ITO with a sheet resistance of  $50\Omega/\text{square}$  was obtained from Merck Balzers. The PHF ( $M_w = 300000 \text{ g/mol}$ ) was purchased from H.W Sands Corp., while rubrene ( $M_w = 532.69 \text{ g/mol}$ ) was purchased from Aldrich. The chemical structure of PHF and rubrene are shown in Fig. 2(a) and Fig. 2(b), respectively.

The ITO was etched and patterned to serve as anode. The ITO was cleaned with 2-propanol and acetone. PHF and rubrene were dissolved in 0.5 g toluene. A typical PHF: rubrene concentration ratio is 1.0:  $x \text{ wt\%}$ , with a variation of rubrene by concentration where  $x = 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, \text{ and } 0.09$ . The solution were heated at  $75^\circ\text{C}$  and spin coated onto the ITO glass with spinning speed at 3000 rpm for 40 s.

An aluminium layer as a cathode was deposited onto PHF doped with rubrene layer through a mask by the electron-gun evaporation technique from a Molybdenum crucible at a chamber pressure of  $2.5 \times 10^{-5} \text{ mbar}$ , yielding active areas of  $9.62 \times 10^{-6} \text{ m}^2$  and thickness of 150 nm. Thin films of PHF, rubrene and PHF doped with rubrene absorption spectra and photoluminescent (PL) have been characterized by UV-VIS spectrometer and Perkin Elmer Luminescent Spectrometer respectively. While the performances of the devices were analyzed through the current-voltage (I-V) curve by a Keithley 238 source measurement unit and the electroluminescent spectra were measured by HR2000 Ocean Optic spectrometer. All measurements are done in room temperature.



**Figure 1.** Structure of the OLED device

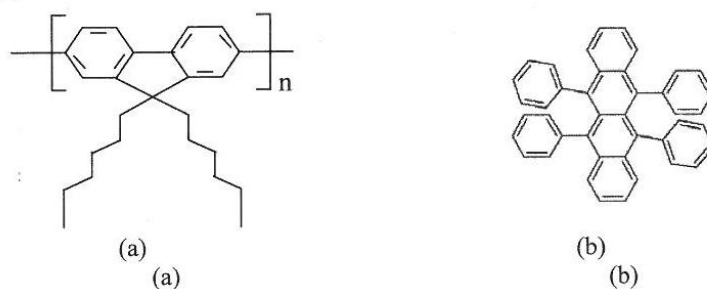


Figure 2. (a) Chemical structure of PHF; (b) Chemical structure of rubrene

### Results and Discussion

The poly (9, 9-di-n-hexylfluorenyl-2, 7-dyl), PHF thin film and 5, 6, 11, 12-tetraphenyl-naphthalene, rubrene thin film have been deposited on a quartz substrate to characterize the photo luminescent, PL and absorption spectra. Quartz substrate was used as a substrate because quartz does not absorb ultraviolet light. Figure 3 shows the PL spectra together with absorption spectra of PHF and rubrene thin films. The emission range of PHF is broad from 420 nm to 480 nm which covers violet to blue. While the peak is 452.66 nm that we may consider it emits blue light. For rubrene the emission range is 550 nm to 600 nm that covers of green, yellow and orange. Its emission peak of rubrene is 578.4 nm which is in the yellow region.

There are two emission mechanisms of OLEDs from a doped material (Hideyuki *et al.*, 1998) that is (i) Föster energy transfer and (ii) trapping. It can be described using an energy level diagram at Fig. 4. The highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) of rubrene is located in the energy gap of PHF. When holes and electrons are injected from anode and from the cathode respectively, the recombination occurs in the PHF doped rubrene layer. When the recombination occurs at PHF sites, it will emit a blue light. But, because of dipole interaction between host and dopant, the emission energy from the host is transferred to the dopant and excites dopant electron from ground state across its LUMO level. It is observed from Fig. 3 that the absorption spectrum of rubrene is overlap with PL of PHF which indicates that Föster energy transfer is occurred between PHF and rubrene. In the other mechanism, some of injected electrons can be captured by rubrene as a trap in the host material since rubrene has higher electron affinity than PHF. When the excited electrons in dopant material reach the ground state, it will emit an orange light. A correct combination amount of blue and orange light will produce a white light. We expected that both energy transfer and trapping mechanisms will contribute to the emission of white light.

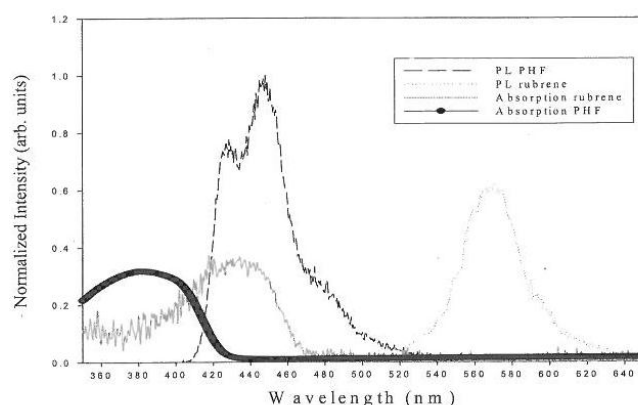
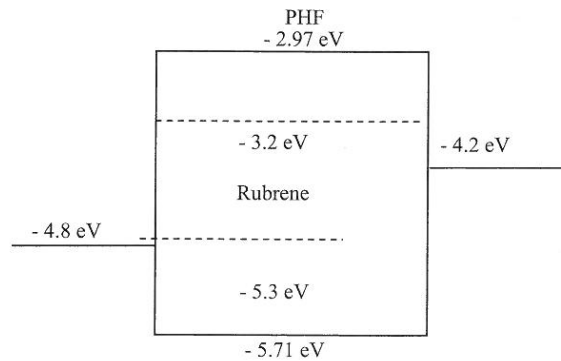
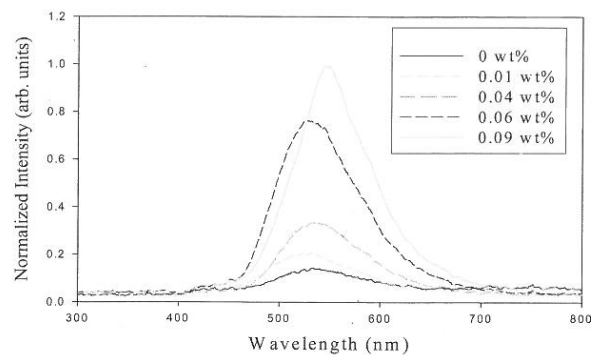


Figure 3. Photo luminescent and absorption spectra of the PHF and rubrene thin films



**Figure 4.** The energy levels diagram of the devices

Figure 5 shows the emission spectra of ITO/PHF: rubrene/Al devices with variation of rubrene concentration. It was observed that blue band (0 wt% rubrene) gradually decreased with the increase in the doping concentration of rubrene. White emission was obtained in the device with 0.06 wt% doping concentration of rubrene. This device has broad emission spectrum range compared to the other emissions. The broad spectrum range of 400-700 nm indicates the white emission range. As the concentration of rubrene was further increased, the amount of orange color also increased; hence the color of emitting light deviated from white. It was also observed that the intensity of light emission is increased with doping concentration of rubrene. Higher rubrene concentration means that the distance between rubrene molecules and PHF-rubrene molecules become smaller. This will produce more trap sites in the host material and more energy are transferred from host to guest. Hence, the intensity of the emitted light will be increased (Zheng *et al.*, 2003).



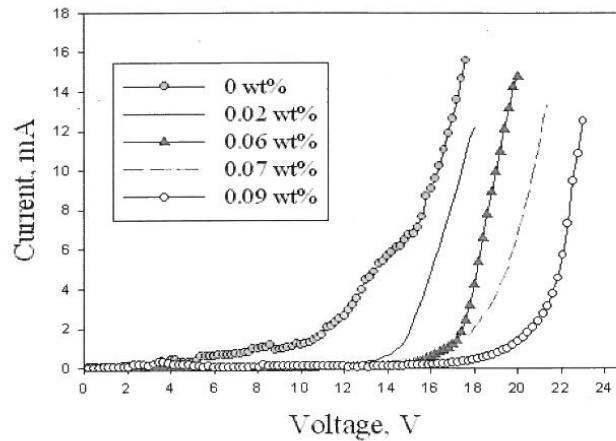
**Figure 5.** The emission spectra of the devices

Table 1 summarizes the results from The Commission Internationale de L'Eclairage, CIE 1964 coordinates measurement. The white point in CIE coordinates system is defined as (0.33, 0.33). The nearest white emission was obtained in the device with 0.06 wt% rubrene where its CIE coordinates was (0.3, 0.33). The results demonstrate that a white emission can be realized through the incomplete energy transfer of blue emitting host PHF to orange dopant in the same emitting layer (Zheng *et al.*, 2003) The CIE coordinates showed that a white color could be optimized by adjusting the dopant concentration.

**Table 1.** CIE coordinates of PHF doped by rubrene with variations concentration of rubrene

concentration, wt%	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.09
<i>X</i>	0.23	0.25	0.28	0.28	0.28	0.3	0.33	0.33
<i>Y</i>	0.24	0.26	0.39	0.34	0.39	0.33	0.39	0.4

Figure 6 shows the current-voltage (I-V) characteristic of ITO/PHF: rubrene/Al devices with four variations of rubrene concentration. Using Fowler-Nordheim theory, the turn-on voltage can be calculated from the I-V curve (Parker *et al.*, 1994). The turn-on voltage of the device without rubrene is 10.0 V, while the device with a rubrene concentration of 0.02 wt% was predicted at 13.0 V. It was observed that the turn-on voltage increased with the rubrene concentration. Further research to reduce the turn-on voltage of the devices by inserting a buffer layer between the anode and PHF doped rubrene layer is in progress.



**Figure 6.** Current-Voltage (I-V) characteristics of devices with 0.02 wt%, 0.06 wt%, 0.07 wt%, and 0.09 wt% rubrene.

### Conclusion

OLED device with single layer structure of ITO/PHF: rubrene/Al has been successfully fabricated with variations in the concentration of rubrene. It was found that the concentration of rubrene determined the performance of the devices and the CIE coordinates. The device with 0.06 wt% rubrene concentration produced the nearest CIE coordinates to white light where  $x = 0.3$ ,  $y = 0.33$ , and the turn on voltage was at 14.0 V.

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