White Organic Light Emitting Diode by Insertion of Thin Buffer Layer in Hole Transport Layer

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Abstract: We demonstrate white light emission by the insertion of a buffer layer of red dye 4-(Dicynomethylene)-2-methyl-6-(4-dimethylaminostyryl)-4H-pyran (DCM) in hole transport layer with a blue emitting material bis\{2-(2-hydroxyphenyl) benzoxazolate\} zinc [Zn(hpb)\textsubscript{2}]. By varying the distance of buffer layer from emitting layer CIE coordinates (0.33, 0.47) and (0.33, 0.45) has been measured. Further by replacing DCM dye by rubrene dye CIE coordinate has been further improved to (0.33, 0.39). A maximum luminescence of 4,300Cd/m\textsuperscript{2} has been achieved at 20V.

1. INTRODUCTION:

White Organic Light Emitting Diodes (WOLEDs) have been widely investigated due to its potential applications in making full color OLEDs to be used as in next generation light source for general lighting \cite{1-3}. There have been many studies about developing high performance WOLEDs to improve light emission efficiency, lifetime, and color stability \cite{4-10}. Various materials and device architectures have been reported and WOLEDs with stacked structure gave good device performance compared with other devices \cite{4-10}. Sun et.al developed a hybrid WOLED with fluorescent blue emitter and phosphorescent red and green emitters \cite{4}. A high quantum efficiency of 18.7\% was obtained because both singlet and triplet excitons could effectively contribute to the white emission. Other than those various phosphorescent WOLEDs with different stacked structures were also reported \cite{5-10}.

Zinc complexes have good color tenability properties, high photoluminescence quantum efficiency and good thermal stability \cite{11} and are the ideal choice as host material in OLEDs. Further they are easy to synthesize and have broad spectral features \cite{12}. Rai et.al has reported white light emission by the doping of red dye 4-(Dicynomethylene)-2-methyl-6-(4-(dimethylaminostyryl)-4H-pyran (DCM) in a blue emitting material bis\{2-(2-hydroxyphenyl) benzoxazolate\} zinc [Zn(hpb)\textsubscript{2}] in which white light emission has been achieved by the Forster type energy transfer mechanism \cite{13}. Insertion of buffer layer in hole transport layer is an effective way to achieve the white light emission.

In present work we have fabricated WOLED by inserting a buffer layer of red dye DCM and rubrene in hole transport layer with a blue emitting material Zn(hpb)\textsubscript{2}.

2. EXPERIMENTAL:

The OLEDs were fabricated on Indium-Tin-Oxide(ITO) (treated as an anode) coated glass substrates with a sheet resistance of 20Ω/□ and a thickness of 120 nm which were patterned and cleaned using deionised water, acetone, trichloroethylene and isopropyl alcohol sequentially for 20 min using an ultrasonic bath and dried in vacuum oven. Prior to organic film deposition ITO surface was treated with oxygen plasma for 5 min to increase ITO work function .Organic layers were deposited onto glass substrates under high vacuum(\texttimes10\textsuperscript{-6} torr) at a deposition rate of 0.4Å/s. Thickness of the deposited layers were measured in situ by a quartz crystal thickness monitor. Three OLEDs A, B and C were fabricated in which A and B were fabricated with the device structure
ITO(12nm)/ α-NPD (xnm)/ DCM(1nm)/ α-NPD (ynm)/ Zn(hpb)$_2$(50nm)/ BCP(6nm)/ Alq$_3$(28nm)/ LiF(1nm)/ Al(150nm) (Here x= 26.5 and 27.5nm and y= 8.5 and 7.5nm). The third device C having the structure ITO(12nm)/ α-NPD (27.5nm)/ Rubrene (1nm)/ α-NPD (7.5nm)/ Zn(hpb)$_2$ (50nm)/ BCP (6nm)/ Alq$_3$ (28nm)/ LiF (1nm)/ Al (150nm). Here Zn(hpb)$_2$ was used as emissive layer, DCM and Ruberene as buffer layer, Tris (8-hydroxyquinoline) aluminium (Alq$_3$) (Sigma Aldrich) and N,N’-Di-[1-naphthalenyl]-N,N’-diphenyl)-(1-1’-biphenyl)-4,4’-diamine (α-NPD) (Sigma Aldrich) were used as the electron and hole transporting layers. Lithium Floride (LiF)/Aluminium (Al) and ITO has been used as cathode and anode respectively. The size of each pixel was 5mm×5mm. Photoluminescence was studied using a Fluorolog (Jobin Yvon – Horiba, model-3-11) spectrofluorometer at room temperature. The spectrum has been measured with a high resolution spectrometer (ocean optics HR-2000 CG UV-NIR). The current density-voltage-luminescence (J-V-L) characteristics have been measured with a luminance meter (LMT-1009) interfaced with a keithley 2400 programmable current-voltage digital source meter. All the measurements were carried out at room temperature under ambient conditions.

3. RESULTS AND DISCUSSION:

Photoluminescence spectrum of Zn(hpb)$_2$ and DCM were measured with film deposited on quartz substrates and shown in Fig.1. PL spectrum of Zn(hpb)$_2$ shows broad features with blue emission at 478nm and DCM shows red emission at 571nm. From Fig. 1, it is observed that the combined PL spectrum of the two materials cover almost the entire visible spectrum and hence theses materials have been used to fabricate White Organic Light emitting Diodes (WOLEDs).

Figure 2 shows the schematic energy level diagram of device structure used in this study. The distance of buffer layer from Zn(hpb)$_2$ layer was variable. In these devices holes were injected from ITO electrode and electrons from Al electrode.

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![Fig.1 Photoluminescence spectrum of Zn(hpb)$_2$ and DCM.](image1.png)

![Fig.2 Schematic energy level diagram of device structure.](image2.png)
layer. But this trapping does not play any role to decide the recombination zone because after this all the electrons have to recombine to the counter electrode. Distance of DCM layer from Zn(hpb)$_2$ layer is variable. The distance of DCM layer from Zn(hpb)$_2$ layer and barrier for holes at DCM/α-NPD interface are deciding the recombination zone in OLED.

Fig. 3 shows the Electroluminescence (EL) spectrum of devices A, B and C. Curve a and b of Fig. 3 shows EL spectrum of the devices with DCM layer placed at a distance of 8.5 nm and 7.5 nm respectively from Zn(hpb)$_2$ layer. From Fig. 2, it has been observed that the holes, flowing from ITO electrode, were getting trapped in DCM layer due to the barrier (0.53eV) at DCM/α-NPD interface. Further, the holes crossing this barrier have to travel a variable distance in α-NPD layer before recombining in Zn(hpb)$_2$ layer. Thus the contribution of the recombination inside DCM layer is dominant. From the curve ‘a’ and ‘b’, we can observe that by decreasing the distance of DCM layer from Zn(hpb)$_2$ the contribution of recombination in Zn(hpb)$_2$ has been increased. The measured CIE coordinates for device A and B were (0.33, 0.47) and (0.33, 0.45). Further to balance the EL spectra to achieve white light emission DCM has been replaced by rubrene dye whose HOMO and LUMO values are 3.2eV and 5.4eV respectively. The HOMO value (5.4eV) of rubrene causes a less barrier (0.2eV) at rubrene/α-NPD interface. As a result the contribution of recombination in Zn(hpb)$_2$ layer has been increased significantly. Measured CIE coordinates for device C were (0.33, 0.39).

Fig. 4 shows the IVL characteristics of devices A, B and C. From fig it is observed that the maximum luminescence of 4,300 Cd/m$^2$ has been achieved for device C.

![Fig.3 Electroluminescence spectrum for devices A, B, C shown by curves a, b, c respectively.](image)

![Fig.4 Current-Voltage-Luminescence characteristics of device A, B, C.](image)

### 4. CONCLUSION:

White organic light emitting diodes have been fabricated by inserting a buffer layer of red dye in hole transport layer. Color coordinates (0.33, 0.47), (0.33, 0.45) and (0.33, 0.39) have been measured for three devices. A maximum
luminescence of 4300Cd/m² has been achieved at 20V.

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