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A Comparative Study On The Performance Of FTO Based Organic Light Emitting Diode (OLED)

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Abstract
In our work green organic Light Emitting Diodes have been fabricated and study their J-V-L performances. Here N,N'-bis (3- methyl phenyl)- N, N' (phenyl)-benzidine(TPD) is used as hole transport layer(HTL) and Tris(8-hydroxy quinolinato) aluminium (Alq_3) as both emitting layer and electron transport layer(ETL). The performance of the devices explains on the basis of figure of merit (FOM) which is the function of optical transmittance and sheet resistance. The range of thicknesses of hole transport layer is 10nm-50nm and that of emissive layer is 15nm-70nm respectively. Here high luminance has been obtained at the operating voltage less than 20 volt with turn-on voltage 6.7 volt. The performances of the devices are studied by J-V and L-V characteristics. With a combination of 30nm HTL and 44nm ETL organic layer thickness, better charge balancing is achieved and luminous efficiency is maximum. This bilayer organic film provides maximum luminance greater than 2500 Cd/m^2 with a current density 144 mA/cm^2.

Keywords: *Luminance efficiency, optical transmittance, FOM, Luminance and sheet resistance*.

1. Introduction

Organic light emitting diode (OLED) is based on the principle of Electro luminance (EL). This is made by placing a thin film of an organic material between two conductors of different work function. When a voltage is applied, electron and hole are injected into the EL material. When these recombine, light is emitted. The organic layers are highly disordered, amorphous in form and consist of molecular energy levels- the highest occupied molecular orbital (HOMU) and the lowest unoccupied molecular orbital (LUMO). Appropriate selection of anode and cathode materials should be such that their work functions values are closely match the HOMO & LUMO levels respectively. ITO films fabricated on glass substrate are widely adopted as transparent anodes. There are some reports on OLED with polymer anode but also supported by ITO glasses because the thickness and weight of the devices are dominated by the supporting substrate [1, 2, 3]. Tremendous progress has been made in the resent years. OLED technology is expected to show great impact on the future of lighting application & flat

panel display [4, 5]. Because of the suitable properties of Alq3, it is widely used in OLED [6]. Philip R. Dravian developed the bilayer cathode OLED on Alq3 based devices. Haichuan Mu et al. study the film morphology with deposition rate in Alq3 based organic luminescent devices [7]. N. Thejo Kalyani & S.J. Dhoble fabricate the ALQ3 based OLED using Eux $Y_{(1-x)}$ ($TTA)_3$ phen organic complexes[8]. G. Luka et al. study the properties of ALQ3 OLED with undoped zinc-oxide anode layer [9]. Recently L. Zhou et al. developed the improved Alq3 based OLED using bilayer anode combination of Al_2O_3 and ITO [10]. However although the different study of OLED is available in the literature but all of them are ITO related, only few reports are found on FTO [11, 12]. On the other hand fluorine doped Tin Oxide (FTO) though being cost effective than the ITO, it is not widely used to fabricate OLEDs because of its less transparency and conductivity than ITO [13]. Also there is a published reports that indium has a tendency to diffuse into the emissive layer under device operation, [14] which may in turn influence the quantum efficiency and lifetimes of OLEDs. In addition, it is known that the performance of ITO-based OLEDs is highly dependent on the chemical condition of the ITO electrode. On the other hand, in case of FTO anode there is no indium present for possibilities of diffuse into the emissive layer in the OLED. The chemical composition as well as the work function of FTO was found to be independent of the cleaning methods employed [15] which are opposite to ITO. This indicates that FTO is more stable to oxidation than ITO. Here in this paper we address a Alq3 based Organic Light Emitting Diode (OLED) with optimize thickness region of HTL and light emitting layer in which luminance is greater than 2500 Cd/m^2 with turn on voltage less than 10 volt over FTO electrode.

2. Experimental Details

In our experiments Fluorine doped tin oxide (FTO) coated glasses are subjected to a routine cleaning procedure prior to the loading into the evaporator. N,N'-bis (3- methyl phenyl)- N, N' (phenyl)-benzidine(TPD) and Tris(8-hydroxy quinolinato) aluminium (Alq_3) are used as hole transport layer and the electron transport/emissive layer respectively. OLED with the structure FTO/TPD/Alq3/LiF/AL is deposited by thermal evaporation unit (MODEL VT-2015). The film thickness and deposition rate of the organic films and cathode layer were recorded by thickness monitor (MODEL DTM-10). The FTO coated glasses are patterned by using etching technology. All the films are deposited at the base pressure of 5×10^{-5} Torr with deposition rate

greater than 12Å/sec. The J-V and L-V characteristics were measured by digital source-meter unit (SMU) and the Luminance meter unit. The transmittance spectra of TPD and Alq3 films are recorded by UV- double beam spectrophotometer (MODEL LT 2800) and sheet resistance were measured by four probe set-up. All tests were performed in air at room temperature and under darkroom condition without any encapsulation. All materials are purchased from sigma-aldrich (USA) and used without further purification. The fabricated OLD structures are-

Device (1) FTO/TPD (10nm)/Alq3 (15nm)/LiF(3nm)/Al (120nm)

Device (2) FTO/TPD (20nm)/Alq3 (30nm)/LiF(3nm)/Al (120nm)

Device (3) FTO/TPD (30nm)/Alq3 (44nm)/LiF(3nm)/Al (120nm)

Device (4) FTO/TPD (50nm)/Alq3 (70nm)/LiF(3nm)/Al (120nm)

Figure 1 shows the energy band structure of OLED and fig 2 shows the schematic representation of OLED.

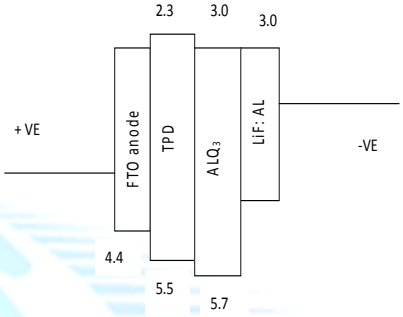

Fig (1):Band structure of OLED device

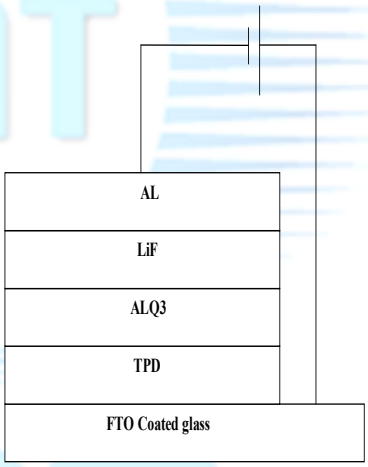

Fig (2): Schematic presentation of OLED

3. Results and discussion

In this work we fabricated the four different sets of bilayer TPD/Alq3 organic thin films with different thickness range and study their transmittance and absorbance (400-700nm) properties along with sheet resistance of respected bilayer film in

detail. We find that when the thickness of hole transport layer (HTL) and emissive layer (EML) layer is continuously increases, then there is a decreasing tendency of optical property is observed. This implies that optical transmittance is decreases with increasing thickness of respected layer. On the other hand within the range of 30-45 nm thickness of organic layer, device property is suitably enhanced. That is although optical properties are continuously decreases with increasing the thickness of organic layer but the device performance is enhanced within a particular thickness limit. This is due to the higher value of figure of merit (FOM) of the bilayer film, which is an important parameter for study the performance of transparent conducting films. The FOM is defined as FOM= T^{10}/Rs, where T is the optical transmittance and Rs is the sheet resistance [16]. Since higher value of figure of merit indicated the better transparent conducting film, so in our work TPD (30nm)/Alq3 (44nm) bilayer film provides better result to us. Here luminous intensity becomes more than 2500 Cd/m^2 at this range of thickness. This implies that within this limit of thickness, the injection of charge carrier is suitably enhanced as a result of which recombination of electrons and holes takes place more perfectly (i.e. proper balancing of degree of opposition faced by positive and negative charge carrier though the organic layer) and maximum light output will be achieved .Table 1 shows the percentage of transmittance and absorbance value of four different set of TPD/Alq3 bilayer organic films with sheet resistance value at different thickness. The transmittance spectra of these bilayer TPD/Alq3 organic films are plotted against the different wavelength is shown in figure 3. From this table it is clear that although the value of surface resistance and optical transmittance is decreased but figure of merit is more enhanced up to the optimize thickness region. After that its value is continuously tend to decreases because of which device performance is reduces. This result verifies earlier report [17].

Table 1: Summary of the result

Serial no	Thickness of TPD/Alq3 bilayer films	Transmittance (%)	Absorbance (arb.)	Sheet resistance (Ohm/square)	Figure of merit (Ω^{-1})
Set 1	10/15(nm)	91	0.0410	18.35	21.22×10^{-3}
Set 2	20/30(nm)	88	0.0555	11.89	23.42×10^{-3}
Set 3	30/44(nm)	83	0.0890	6.37	24.33×10^{-3}
Set 4	50/70(nm)	78	0.1079	4.14	23.68×10^{-3}

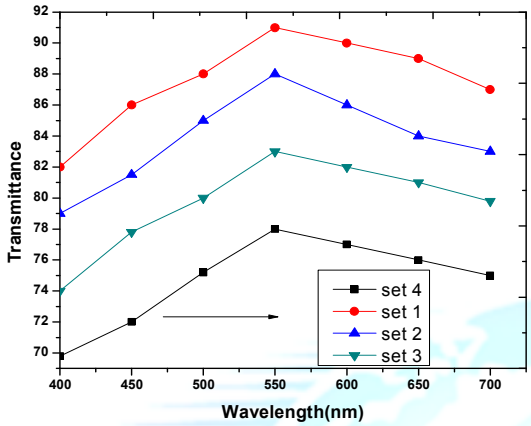

Figure (3): Graph of transmittance and wavelength

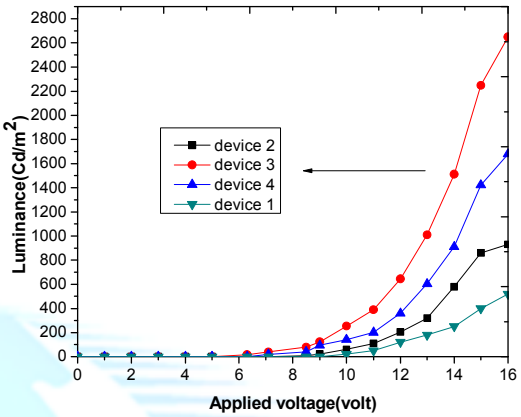

Figure (5): Graph of luminance and voltage

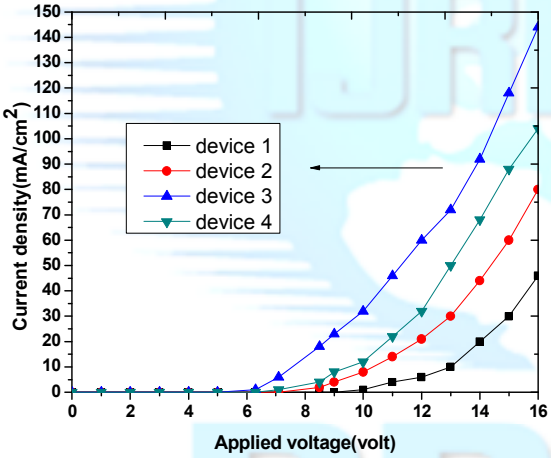

Figure (4): Graph of current density and voltage

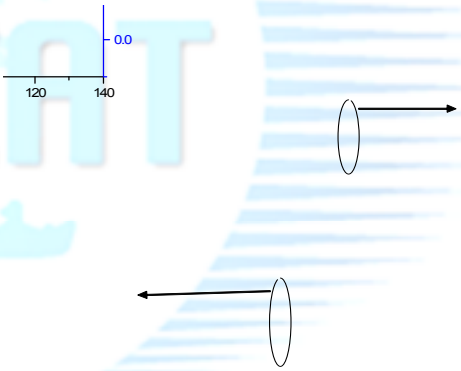

Figure (6): Graph of variation of luminance and efficiency with current density

Figure (3) shows the spectrum of optical transmittance and wavelength of different set of bilayer organic thin film. From this graph it is clear that transmittance is decreases with the increasing thickness of organic layer thickness. Similarly figure (4) gives the variation of current density and applied voltage in which device (3) shows the maximum value.

Here figure (5) shows the graph of luminance and applied voltage in which device (3) gives the highest brightness due to its highest FOM value [18]. On the other hand figure (6) gives the variation of luminance and current efficiency with respect to the current density of the optimized device (3). In this case we obtained the diode characteristics with a turn on voltage

S.N	OLED devices	Turn-on voltage (volt)	Maximum luminance (cd/m^2)	Maximum current density (mA/cm^2)
1	Device 1	10.12	520	46
2	Device 2	8.50	930	80
3	Device 3	6.71	2650	144
4	Device 4	7.72	1680	104

Table 2: Summary of the property of the OLED devices at different thickness

less than 8 volt. It is because of the fact that at this range of organic layer thickness, film (in nanometer range) morphology is suitably enhanced due to the decreasing of pinhole density and increasing ordered film pattern within the optimized region of organic layers thickness as we use higher growth rate [19, 20] and also proper balancing of charge carrier injection as mentioned above. But after optimized thickness it was found that the device turn-on voltage was slightly increased. This is because of the reducing of charge carrier tunneling at the interface region. Following table 2 shows the property of all the OLED devices in which device 3 shows the better performance compared to other devices.

From this table it is clear that the performance of the device 1 is poor that of the other devices (i.e. low current density and luminance); this may be due to the lack of hole and electron blocking function of organic layer at their too thin film thickness. Because when the thickness is very low then most of the charge carrier simply passed though the organic layer without any recombination leading to low current density and luminance. In our case device 3 received the highest device performance due to proper balancing of degree of opposing force for both the charge carrier along with highest figure of merit (FOM) value.

Conclusion:

We have reported a high luminance green OLED with brightness greater than 2500 Cd/m^2 with turn on voltage 6.7 volt. The structure of the devices has a direct impact on the balancing probability of electron and hole recombination in the emissive region. With larger the thickness of the hole transport layer (HTL) and emissive layer (EML), the luminance property is enhanced up to the critical region. We obtain the maximum value of luminance (2650 Cd/m^2) at the optimal thickness of 30 nm and 44nm

for TPD and Alq3 layer respectively with current density 144 mA/cm^2 and luminous efficiency 1.80 Cd/A.

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