

A COMPARATIVE STUDY OF OLED USING VARIOUS THICKNESS OF ELECTRON TRANSPORT LAYER

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ABSTRACT

In this work a number OLED have been presented at various thicknesses of electron transport layer ranging from 5nm to 18nm and study their performance which are fabricated by vacuum deposition method. We find that at particular thickness of ETL layer the luminance efficiency of device structure is maximum. The optimum thickness of Bphen layer used as electron transport layer and the constant thickness of hole injection layer (V_2O_5) were 15nm and 5 nm respectively. With this combination of thicknesses, charge balancing is achieved and luminous efficiency is optimized. Here we obtained maximum value of current density and current efficiency are $170\text{mA}/\text{cm}^2$ and $3.9\text{cd}/\text{A}$ respectively.

KEYWORDS: Electron Transport Layer, Charge Injection, Mobility, Efficiency and OLED

Solid state lighting devices, the charge carriers have to be injected from the anode and cathode but the performance, lifetime, efficiency and stability of these devices are typically governed by the proper thickness of the material layers and electrode/organic interfaces at the electrode contacts. Efficient light emission from OLEDs can be achieved by reducing energy barriers of interfaces between organic layer and electrodes and by balancing hole and electron injection. Now a day's Remarkable technical process have been made to increase the efficiency of OLED. For the first time published a paper on OLED, (C.W. Tang, S.A. Vanslyke) during 1987 and they report a method for fabricating small molecular OLEDs. Since then number of research work, have been carried out and many papers have been published (R.H.Friend et al. 1999, M.A.Baldo et al. 1999, M.Ikai et al. 2001, C.Adachi et al. 2002, G.He et al. 2004, X.H.Yang et al. 2004 and H.M.Liu et al 2005) in the field of OLEDs. Research work on various techniques such as external doping, incorporation of phosphorescent and organometallic compounds alloying of organic materials and thickness variations of organic film layers have been carried out. In fact today's technology allows fabrication of OLED over a flexible plastic substrate with external quantum efficiency of 63% (Z.B.Wang 2011). Recently effect of thickness variation of hole blocking layer has been studied (Y.Masumoto et al. 2000 and L.Zhou, et al. 2010) but these works have been reported with doped layers. Similarly comprehensive study on effect of variation in thickness of hole injection layer has been done (S.M.Tadayyon et al. 2004) and they report on hole injection barrier height. Study on thickness variation of emitting layer (C.H.Hsiao et al. 2010) has also been available in the research literature for phosphorescent

OLEDs with a focus on colour stability. The injection efficiency and mobility of holes are higher as compared to electron injection efficiency and electron mobility (B.J.Chen et al. 1999 and S.Naka et al 2003). Therefore, various techniques have been carried out to improve the electron injection efficiency and mobility of electrons to achieve better charge balancing. Our work is based on the region of electron transport layer (ETL), where improved electron injection is obtained by modulating the charge carrier injection and their mobility. This is done by varying thickness of hole blocking layer (or ETL) at constant hole transport layer. These two layers have opposite functions. There is a specific combination of their thicknesses when they act in tandem to achieve enhanced charge balancing. At this optimized thicknesses the luminous efficiency is maximized at low current density because of better charge balancing. In this work we use Bphen as a ETL and TPD as hole transport layer (HTL). We study the performance of four OLEDs at various thickness of ETL by evaluating their luminous efficiency. Finally we reported the best combination of organic layer (Bphen) film thickness which can optimize the luminous efficiency in our device configuration.

EXPERIMENTAL DETAILS

All devices were fabricated on ITO (Indium doped tin oxide) coated glass and thermally deposited AL was used as cathode. The ITO glass was cleaned in ultrasonic bath of acetone and isopropanol for 15 minutes and the deposition was carried out at a pressure less than 5×10^{-5} torr . All the organic and inorganic layers were evaporated at the deposition rate higher than $10\text{\AA}/\text{sec}$. The devices have an active emissive area of $8 \times 8 \text{ mm}^2$. All the devices were fabricated by using Thermal Vacuum

Evaporation Unit using proper shadow masking system and the corresponding film thickness were recorded by thickness monitor (Model DTM-10). The J-V-L characteristics were measured by digitally controlled source-meter and luminance meter unit. All tests are performed in air at room temperature without any encapsulation and all materials are purchased from Sigma-Aldrich. Chemical structure of Alq3 and TPD is shown below

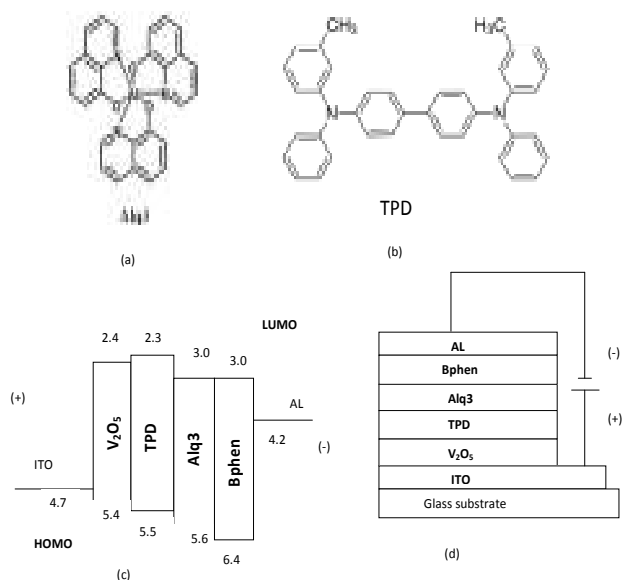


Figure 1: (a) chemical structure of Alq3, (b) chemical structure of TPD, (c) energy level alignment of OLED and (d) schematic presentation of OLED.

RESULTS AND DISCUSSION

We have fabricated the standard OLEDs using V₂O₅ as hole injection layer(HIL), N,N'-bis (3-methyle phenyl)-N,N'(phenyl)- benzidine(TPD) as hole transport layer(HTL), Tris (8-hydroxy quinolinato) aluminium (Alq3) and 4,7-diphenyl-1,10-phenanthroline(Bphen) are used as emitting layer and electron transport layer(ETL) respectively and compared their J-V-L characteristics of OLEDs with different thickness of ETL at constant HIL layer. The structures of the bottom emitting OLEDs used in this study are:

Device: A. ITO/V₂O₅ (5nm) /TPD (40nm)/Alq3 (50nm)/Bphen(5nm)/Al (110nm)

Device: B. ITO/V₂O₅ (5nm)/TPD (40nm)/Alq3 (50nm)/Bphen(8nm)/Al (110nm)

Device: C. ITO/V₂O₅ (5nm)/TPD (40nm)/Alq3 (50nm)/Bphen(12nm)/Al (110nm)

Device: D. ITO/V₂O₅ (5nm)/TPD (40nm)/Alq3 (50nm)/Bphen(15nm)/Al (110nm)

Device: E. ITO/V₂O₅ (5nm)/TPD (40nm)/Alq3 (50nm)/Bphen(18nm)/Al (110nm)

The current-voltage and the luminance-voltage characteristics of OLED having configuration ITO / V₂O₅ (5nm) / TPD (40 nm) / Alq3(50nm)/ Bphen(varying thickness)/Al (110 nm) respectively is shown in Fig: (2).

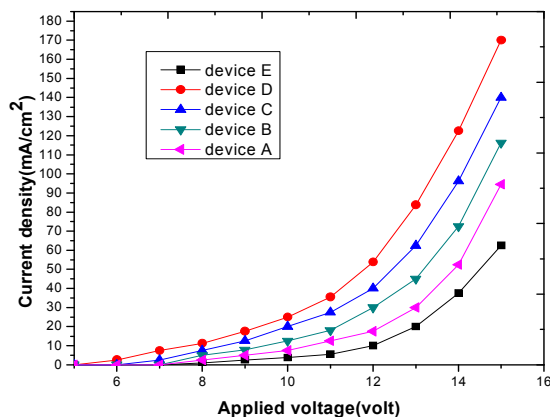


Figure 2(a): Graph of applied voltage and current density

Fig 2: (a) represents the graph of current density vs applied voltage and (b) represents the graph of Luminance vs applied voltage.

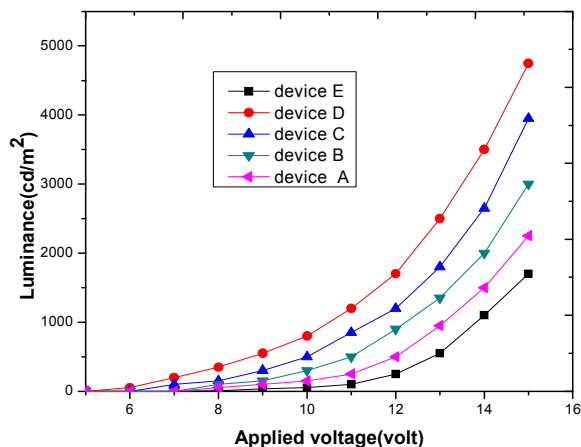


Figure: 2(b) Graph of applied voltage and luminance

The relationship between current density vs current efficiency and current density vs Luminance is given by fig 3 (a) and 3(b) respectively.

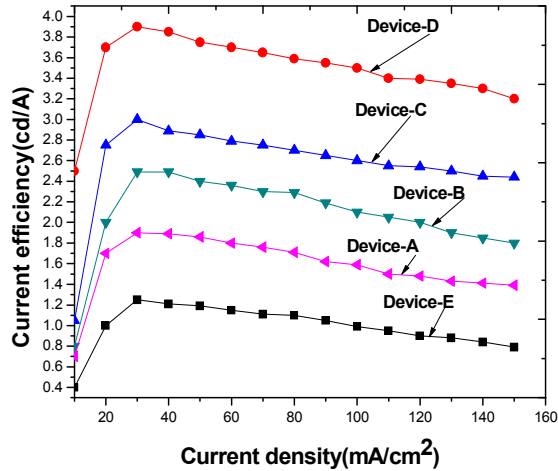


Figure 3(a): Graph of current density and current efficiency

Fig. 3(a) displays the current density-current efficiency characteristics of each device; Device D exhibits a maximum efficiency of 3.9 Cd/A at current density of 35mA/cm². Similarly as shown in fig 3(b) a maximum luminance as high as 4500 cdm⁻² at current density of 150 mA/cm² which represents the brightest and best green OLED in our work. To see the effect of thickness variation of ETL (i.e.Bphen) on device performance, we keep the thickness of all layers constant except Bphen layer thickness which was varied between 5 nm and 18 nm. The effect of thickness variation of electron transport later is explained below:

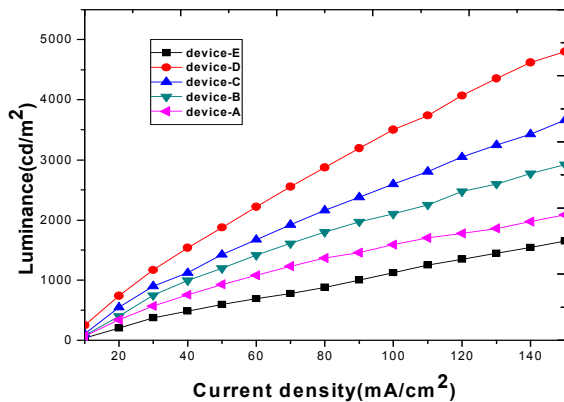


Figure 3(b): Graph of current density and luminance

Energy levels alignment diagram of our OLED are given in Fig.1 (c). At the interfacial junction of Bphen and Alq3 layers their HOMO energies values are 6.4 eV and 5.6 eV respectively. Due to large energy barrier (0.8 eV) between HOMO levels of Bphen and Alq3, it is difficult to travel the positive charge carrier towards the cathode through ETL layer. But however this layer does not provide the same amount of resistance for the moving of electrons from cathode to the Alq3 layer through it. Therefore the degree of opposition faced by both electrons and holes for their travel through Bphen layer is different. Also the degree of opposition is depends on thickness of ETL layer [16]. A thin Bphen layer is poor in hole blocking ability, whereas a thick Bphen layer can effectively block the passage of holes through it. Therefore this ETL layer provides a critical path for the travel of electrons and holes and thus the thickness of this layer play an important role in determining the relative motion of holes and electrons within emissive layer. Table (1) shows the performance of the OLED devices at their different thickness of film deposition. Now if we increases the thickness of Bphen layer (above 15 nm) then there is higher probability of shifting the recombination zone from emitting layer to the ETL layer as reported earlier (H.Tang et al. 2003 and H.Yoshida et al 2011) where excitons will have higher probability of undergoing non-radiative decay near the cathode and will result in lesser luminous efficiency. Also there is a chemical reaction which takes place between the interface of Al and Alq3 interface (M.G.Mason, C.W.Tang and L.S.Hung 2001), which results in release of Alq3 anions. These anions are responsible for the improved injection of electrons from cathode (H.Heil, J.Steiger, S.Karg and M.Gastel 2001) to the emissive region. However if thickness of Bphen layer is increased beyond critical thickness (15nm) then the layer of Alq3 is deeply covered below the Bphen layer. Therefore very thick Bphen layer will decrease the progress of this chemical reaction and which affect the injection of electrons into emitting layer. In this work optimum thickness of ETL layer is 15 nm where maximum number of electron and hole pairs undergoes recombination to produce the highest green luminance. The standard deviation (which is a measure of the spread of their efficiency in a set of data at different voltages from their mean value) of current efficiency and luminance of different OLED devices at their different film thickness are given by following graph. This graph clearly provide the all the information regarding the

standard deviation value of all the OLEDs at different electron transport layer during the working period.

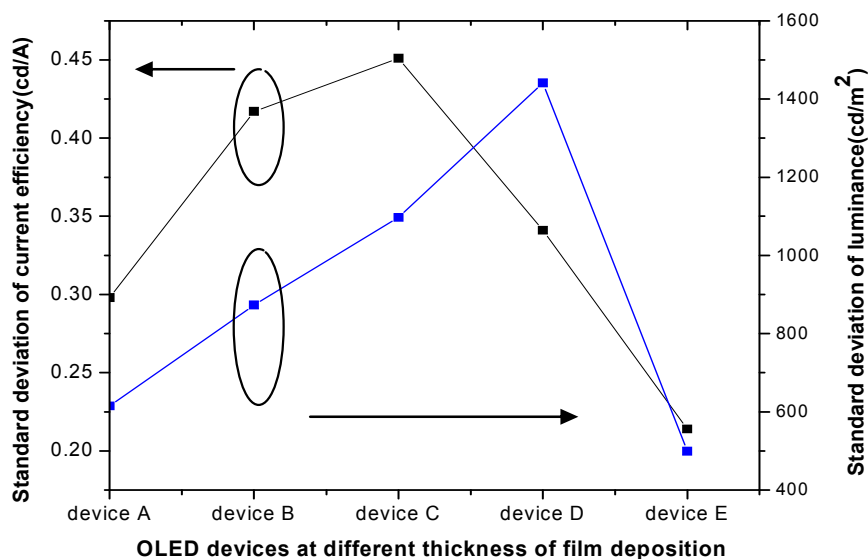


Table 1: Luminance and efficiency characteristics for the devices with different thicknesses Bphen layer

| S.N | Bphen layer thickness | Maximum Luminance (cd/m ²) | Turn-on voltage(volt) | Maximum Luminous efficiency (cd/A) | Standard deviation of current efficiency (cd/A) |
|-----|-----------------------|--|-----------------------|------------------------------------|---|
| 1 | 5nm | 2085 | 7.3 | 1.90 | 0.298 |
| 2 | 8nm | 2925 | 7.0 | 2.49 | 0.417 |
| 3 | 12nm | 3660 | 6.5 | 2.89 | 0.451 |
| 4 | 15nm | 4800 | 5.4 | 3.90 | 0.341 |
| 5 | 18nm | 1650 | 7.6 | 1.25 | 0.214 |

From this table it is seen that the turn-on voltages are 7.3, 7.0, 6.5, 5.4 and 7.6 for the devices with Bphen layer thickness in 5nm, 8nm, 12nm, 15nm and 18nm respectively. Thus the turn-on voltage of 8nm, 12nm and 15nm is to be lower than that of the device with 5nm ETL layer. But after the critical thickness turn-on voltage is tend to increases due to the decreasing of the chemical reaction. Therefore it can be concluded that the thickness of electron transport layer has a direct effect of device performance by controlling the flow of charge carrier through the organic layer.

CONCLUSION

In our work we varied the thickness of ETL (i.e. Bphen) layer, in the range from 5 nm to 18 nm at constant

hole injection layer. Even though these two layers have opposite functions, but by fine tuning their proper thicknesses better charge balancing can be achieved in the emissive region. The optimum thickness of electron transport layer is 15nm with 5nm of hole injection layer. The enhancement in device performance is attributed to a lower energy level difference between the cathode and emissive layer which are proved by J-V and L-V characteristics. In this standard configuration of OLED structure high luminous efficiency that we achieved is 3.9 Cd/A.

REFERENCES

Chen B.J., Lai W.Y., Gao Z.Q. and Lee C.S., 1999. "Electron drift mobility & electroluminescent

- efficiency of Alq₃", *Appl. Phys. Lett.*, **75**:4010.
- Adachi C., Thompson M.E. and Forrest S.R., 2002. "Architectures for efficient electrophosphorescent OLED devices", *IEEE J. Sel. Top. Quantum Electron*, **8**:372.
- Hsiao C.H., Liu S.W. and Chen C.T., 2010. "Emitting layer thickness dependence of color stability in phosphorescent organic light emitting devices", *Org. electron*, **11**:1500.
- Tang C.W. and Vanslyke S.A., 1987. "Organic electroluminescent diodes", *Appl. Phys. Lett.*, **51**:913.
- He G., Pfeiffer M., Leo K., Hofmann M., Birnstock J., Pudzich R. and Salbeck J., 2004. "High-efficiency & low voltage p-i-n electrophosphorescent OLED with double-emission layer", *Appl. Phys. Lett.*, **85**:3911.
- Heil H., Steiger J., Karg S. and Gastel M., 2001. "Mechanism of injection".
- Liu H.M., He J., Wang P.F., Xie H.Z., Zhang X.H., Lee C.S., Sun B.Q. and Xia Y.J., 2005. "High-efficiency polymer electrophosphorescent diodes based on an Ir(III) complex", *Appl. Phys. Lett.* **87**:221103.
- Tang H., Liao H. and Zhu L., 2003. "Influence of hole blocking bathocuproine layer on emission of organic light emitting devices", *Chem. Phys. Lett.*, **381**:605.
- Yoshida H. and Sato N., 2011. "The depth profile of core energy levels: electronic structure of the buried organic/metal interfaces examined by X-ray photoemission & target factor analysis", *Chem. Phys. Lett.*, **511**:146.
- Baldo M.A., Lamansky S., Burrows P.E., Thompson M.E. and Forrest S.R., 1999. "Very high-efficiency green OLED devices based on electrophosphorescence" *Appl. Phys. Lett.*, **75**:4.
- Mason M.G., Tang C.W. and Hung L.S., 2001. "Interfacial chemistry of Alq₃ & LiF with reactive metals", *J. Appl. Phys.*, **89**:2756.
- Ikai M., Tokito S., Sakamoto Y., Suzuki T. and Taga Y., 2001. "Highly efficient phosphorescence OLED devices with an exciton-block layer", *Appl. Phys. Lett.*, **79**:156.
- Zhou L., Li X., Feng J. and Song S., 2010. "High-brightness band spectrum white organic electroluminescent device obtained by designing light emitting layers as also carrier transport layer", *J. Phys. Chem. C.*, **114**:21723.
- Friend R.H., Gymer R.W., Holmes A.B., Burroughes J.H., Marks R.N., Taliani C., Bradley D.D.C., Dos Santos D.A., Bredas J.L., Logdlund M. and Salaneck W.R., 1999. "Electroluminescence in conjugated polymer", *Nature*, (London) **397**:121.
- Tadayyon S.M., Grandin H.M. and Griffiths K., 2004. "A study of the interfacial band energies", *Org. Electron*, **5**:157.
- Naka S., Okada H., Onnagawa H. and Yamaguchi Y., 2003. "Carrier transport properties of organic materials for electroluminescent device operation", *Synth. Met.*, **331**:111-112.
- Yang X.H. and Neher D., 2004. "Polymer electrophosphorescence devices with high power conversion efficiencies", *Appl. Phys. Lett.*, **84**:2476.
- Masumoto Y. and Mori T., 2000. "Application of organic bathocuproine-based alloy film to OLED", *Thin solid films*, **516**:3350.
- Wang Z.B., Helander M.G., Qiu J. and Puzzo P., 2011. "Unlocking the full potential of OLEDs on flexible plastics", *Nat. Photonics*, **5**:753.