

## Effect of Thickness of Tris (8-Hydroxyquinolato) Aluminum on the Photoluminescence and I-V Characteristic of Organic Light Emitting Structure

<sup>1</sup>Lim Mei Yee, <sup>1</sup>Wan Mahmood Mat Yunus,

<sup>1</sup>Zainal Abidin Talib and <sup>2</sup>Anuar Kassim

<sup>1</sup>Department of Physics,

<sup>2</sup>Department of Chemistry,

Faculty of Science, University Putra Malaysia,

43400 UPM Serdang, Selangor, Malaysia

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**Abstract: Problem statement:** How the thickness of the tris (8-hydroxyquinolato) Aluminum ( $\text{Alq}_3$ ) effect the optical and electrical properties of organic light emitting diode. **Approach:** The optimum thickness, photoluminescence and current-voltage characteristic of  $\text{Alq}_3$  layer on N, N-bis (inaphthyl)-N,N-diphenyl-1,1'-biphenyl-4,4'-diamine (55 nm) layer in Organic Light-Emitting Devices (OLED) structure are reported.  $\text{Alq}_3$  and NPB organic layers are used as Electron Transport Layer (ETL) and as Hole Transport Layer (HTL) in Organic Light-Emitting Devices (OLED). The thin layers of the NPB and  $\text{Alq}_3$  were prepared by thermal evaporation method. **Results:** The  $\text{Alq}_3$  layer was evaporated on the NPB layer for thickness ranging from 16 to 134 nm and photoluminescence and I-V characteristic were studied using fiber optics spectrophotometer (Ocean Optics- USB 2000 FLG) and current-voltage source (Keithley, model 2400). **Conclusion:** It was found that the  $\text{Alq}_3$  with 84 nm thicknesses gives the highest photoluminescence peak at 520 nm wavelengths, as well as the lowest turn on voltage of the device. The optical reflectance spectra for every sample were also reported.

**Key words:** Photoluminescence, hydroxyquinolato, electrical conductivity, optical reflectance

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### INTRODUCTION

Currently, there is great research has been demonstrated in the study of Organic Light-Emitting Devices (OLEDs) for full-color display application (Lim *et al.*, 2010a; 2010b). OLEDs have an organic EL medium consisting of extremely thin layers sandwiched by two electrodes. In a basic two-layer OLEDs structure, one organic layer is specifically chosen to transport holes and the other organic layer is to transport electrons. When an electrical potential difference is applied between the anode and the cathode such that the anode is at a more positive electrical potential with respect to the cathode, injection of holes occurs from the anode into the Hole Transport Layer (HTL), while electrons are injected from the cathode into the Electron Transport Layer (ETL) (Zhao *et al.*, 2006; Coe *et al.*, 2002; Kanno *et al.*, 2004; Yoon *et al.*, 2007).

The advantage of Organic LEDs compared with inorganic LEDs is their ease of manufactured, high efficiency of emission light with the low operating

voltage. There are severally organic material that can be used as HTL such as N, N'-bis (Inaphthyl)-N, N'-diphenyl-1, 1'-biphenyl-4, 4'-diamine (NPB) and N, N'-diphenyl-N, N'-bis (3-methylphenyl) (1, 1'-biphenyl)-4, 4'-Diamine (TPD). NPB is the most widely used as a HTL. NPB can be easily manufactured and is abundantly available in powder form. However, Tris (8-hydroxyquinolato) Aluminum ( $\text{Alq}_3$ ) used as a ETL because  $\text{Alq}_3$  is thermally and morphologically stable to be evaporated into thin films form, easily synthesized and purified, molecularly shaped to avoid exciplex formation (e.g., with N, N'-bis (Inaphthyl)-N,N'-diphenyl-1,1'-biphenyl-4,4'-diamine at the interface) and with green fluorescent it become a good host emitter (Hung and Chen, 2002). Thus, optimum thickness of the  $\text{Alq}_3$  is very important to improve the performance of the OLEDs. Therefore in this study we report the effect of thickness of  $\text{Alq}_3$  on the electrical conductivity, turn on voltage and photoluminescence of the  $\text{Alq}_3$  as hole transport layer in OLED device.

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**Corresponding Author:** Wan Mahmood Mat Yunus, Department of Physics, Faculty of Science, University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia Tel: + (603)89466684 Fax: + (603)89454454

**MATERIALS AND METHODS**

In this experiment, we used Alq<sub>3</sub> as the ETL and N, N'-bis (inaphthyl) - N, N'-diphenyl-1, 1'-biphenyl-4, 4'-diamine (NPB) as the HTL, Indium Tin Oxide (ITO) as the anode Aluminum (Al) as a cathode, respectively. Devices with a structure of ITO/NPB (55 nm)/lq<sub>3</sub> (T nm)/Al (300 nm), where T was chosen as 16, 33, 50, 67, 84, 101, 118 and 134 nm, were fabricated (Fig. 2). NPB and Alq<sub>3</sub> compounds were purchased from Sigma-Aldrich. The organic materials were deposited by thermal evaporation onto Indium Tin Oxide (ITO) glass substrates with a sheet resistance of about 15 Ω at room temperature in a high vacuum chamber (Fig. 1). The ITO glass was immersed in ultrasonic bath with acetone for 10 min. Then, the ITO glass was rinsed in deionized water for 10 min and then blow dry with nitrogen gas. This procedure was used to remove organic contamination and particles from the ITO surface.

Current-voltage measurement was carried out using current-voltage source (Keithley, model 2400). The thickness of the layers was measured by disk profile machine (Tencor P-12). The Photoluminescence (PL) of the films was measured using Spectrofluorometer (Ocean Optics 2000 FLG). Spectrophotometer and Micro Autolab Type III Potentiostat were used to for measuring energy band gap and cyclic voltametry study.

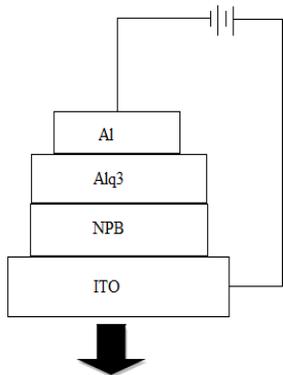


Fig. 1: The structure of OLED device

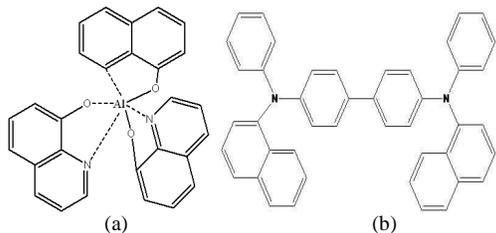


Fig. 2: Molecular structure of (a) tris (8-hydroxyquinolino) aluminum (Alq<sub>3</sub>) and (b) N, N'-bis(Inaphthyl)-N, N'-diphenyl-1,1'-biphenyl-4,4'-diamine, (MPB)

**RESULTS**

Photoluminescence is the reemission of light after absorbing a photon of higher energy (Bouzid *et al.*, 2005). Figure 3 shows the photoluminescence spectrum for devices with various thickness of Alq<sub>3</sub>.

The reflection spectra in Fig. 4 and 5 were taken during an OLED process in which double layers were stacked on the substrates: A Hole Transport Layer (HTL) and an Electron Transport Layer (ETL).

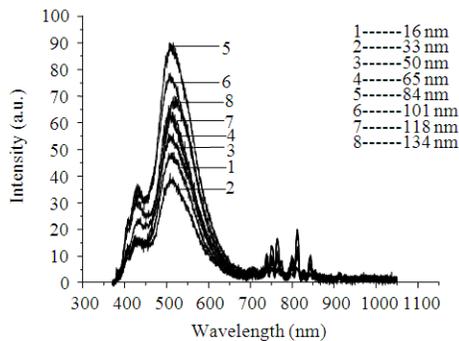


Fig. 3: Photoluminescence spectrum for different thickness of Alq<sub>3</sub> with 55nm of NPB

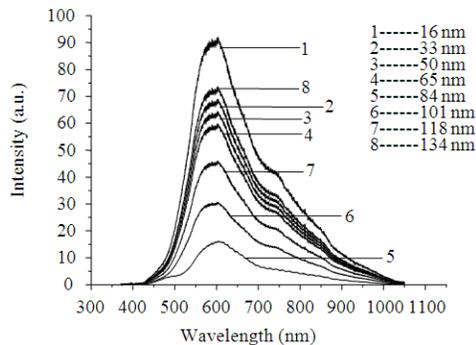


Fig. 4: The reflectance light for different thickness of Alq<sub>3</sub> with 55 nm of NPB

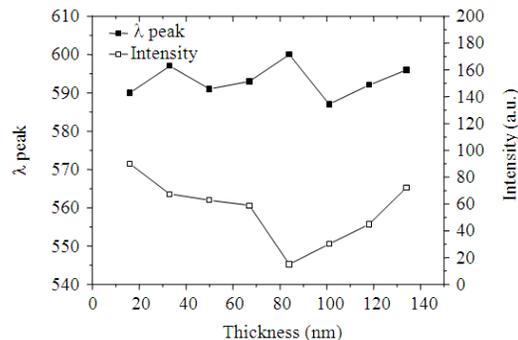


Fig. 5: λ<sub>peak</sub> and relative intensity of reflectance of different thickness of Alq<sub>3</sub> with 55 nm of NPB

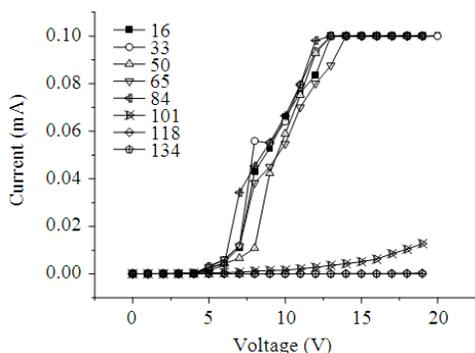


Fig. 6: Current versus voltage characteristics for devices with various thickness of Alq<sub>3</sub>

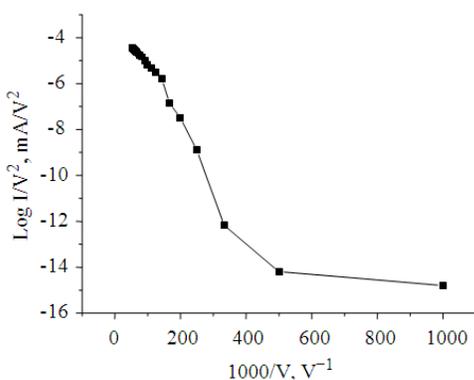


Fig. 7: The corresponding Fowler-Nordheim plot for 84 nm Alq<sub>3</sub> and 77 nm PVK PLED device

The 55 nm of NPB as HTL while the Alq<sub>3</sub> as ETL from 16 until 134 nm. The spectra were measured after each layer deposition. The most dominant features common to all the spectra are the maximum shifting towards higher wavelengths with the increasing the thickness of Alq<sub>3</sub> until 84 nm. Further increase the thickness of Alq<sub>3</sub> until 101 nm, the maximum shifting towards lower wavelengths.

Figure 6 gives the I-V characteristics of the double layers OLEDs with various thickness of Alq<sub>3</sub> with 55 nm of NPB. It can be found that the current initially decrease with the increasing of Alq<sub>3</sub> thickness. As the thickness goes up to 84 nm, the current turns to increase.

Figure 7 shows the Fowler-Nordheim plot for the devices indicated straight line, which implies that the current were due to field emission. Figure 8 show the turn on voltage versus the thickness of Alq<sub>3</sub> for OLEDs devices. It can be observed that the turn on voltage initially shifts towards higher voltage as the Alq<sub>3</sub> thickness increase from 16-65 nm. Then, the turn on voltage drop to 5.1 V when the Alq<sub>3</sub> thickness is 84 nm.

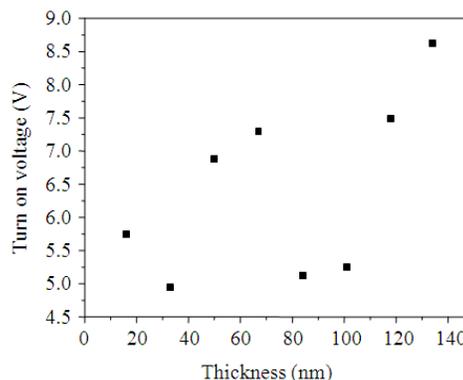


Fig. 8: Turn on voltage for OLED devices with different thickness of Alq<sub>3</sub>

### DISCUSSION

It can be observed that the thickness of the Alq<sub>3</sub> strongly effect the luminescent intensity. The luminance, initially increases from the 16 until 101 nm of the blocking-Alq<sub>3</sub> layer, then drops as the thickness increases further. In terms of efficiency, the device with 84 nm of the blocking-Alq<sub>3</sub> layer shows the highest luminescence intensity. The observed results can be explained in terms of the hole-blocking effect by the Alq<sub>3</sub> layer to balance the electron and hole current. With 84 nm of the blocking-Alq<sub>3</sub> layer, the balance is optimized, while a further increase in thickness causes most of the holes to be blocked at the hole transport layer. However, the intensity reflectance light increase when the thickness of Alq<sub>3</sub> increase from 84-134 nm.

The Alq<sub>3</sub> molecules indeed trap the electron at a low thickness layer. The current at 84 nm of Alq<sub>3</sub> is higher than the other thickness. Hence, the maximum current efficiently is improved in term of the balance electron and hole current is achieved.

Further increase the thickness of Alq<sub>3</sub>, the turn on voltage increase to 8.6 V. The increase in turn on voltage is due to the increase in trap density, where many electrons are trapped in the bulk. Thus, higher voltage is required to transfer the electrons to the interface of NPB and Alq<sub>3</sub> and the electron enhance the injection.

Figure 9 shows a band diagram of ITO/NPB (55 nm)/Alq<sub>3</sub> (84 nm)/Al (300 nm), device. The optical energy band gap of the NPB was 2.8 eV between the HOMO energy level, 5.1 eV, measured by cyclic voltametry and the LUMO, 2.3 eV, calculated from absorption spectrum, which was consistent with the result of the optical threshold (Muller *et al.*, 2006).

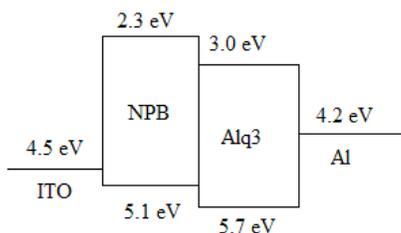


Fig. 9: Band diagram of ITO/NPB (55 nm)/Alq<sub>3</sub> (84 nm)/Al (300 nm) device

The energy diagram is essential to understand and optimize the device performance. The Alq<sub>3</sub> HOMO level is around 5.7 eV, indicating that a small energy barrier (~0.6 eV) for hole injection exists when compared with the HOMO level for NPB. The HOMO of NPB is above the HOMO of Alq<sub>3</sub>. This makes holes easily enter the ETL. In addition with the LUMO of Alq<sub>3</sub> is below the NPB, it will enhance the electron confined in the ETL (Hung and Chen, 2002). This latter is 0.6 eV below the ITO Fermi level. On the other hand, an electron energy barrier of about 1.2 eV is present between the Al electrode Fermi level and the Alq<sub>3</sub> LUMO level, suggesting that for the OLEDs studied in this study, holes are more efficiently injected than electrons. With the 84 nm of Alq<sub>3</sub>, the luminescence of the OLEDs can be enhanced to have a desirable EL color as well as high luminance efficiency.

### CONCLUSION

The OLEDs with the ITO/NPB/Alq<sub>3</sub>/Al have been successfully fabricated using thermal evaporation method. The characteristics of the device were carried out using fiber optics PL, I-V two-point probe and a single beam spectrophotometer. The device with 84 nm of Alq<sub>3</sub> produced the lowest current turn on voltage which is 5.1 V and gives the highest intensity of the light emission.

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