Thin film Encapsulations of Flexible Organic Light Emitting Diodes

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Abstract. Various encapsulated films for flexible organic light emitting diodes (OLEDs) were studied in this work, where gas barrier layers including inorganic Al₂O₃ thin films prepared by atomic layer deposition, organic Parylene C thin films prepared by chemical vapor deposition, and their combination were considered. The transmittance and water vapor transmission rate of the various organic and inorganic encapsulated films were tested. The effects of the encapsulated films on the luminance and current density of the OLEDs were discussed, and the life time experiments of the OLEDs with these encapsulated films were also conducted. The results showed that the transmittance are acceptable even the PET substrate were coated two Al₂O₃ and Parylene C layers. The results also indicated the WVTR of the PET substrate improved by coating the barrier layers. In the encapsulation performance, it indicates the OLED with Al₂O₃ /PET, 1 pair/PET, and 2 pairs/PET presents similarly higher luminance than the other two cases. Although the 1 pair/PET encapsulation behaves a little better luminance than the 2 pairs/PET encapsulation, the 2 pairs/PET encapsulation has much better life time. The OLED with 2 pairs/PET encapsulation behaves near double life time to the 1 pair encapsulation, and four times to none encapsulation.

1 Introduction

Due to the simplicity, organic light emitting diodes (OLEDs) can be easily built on not only glass substrates but also flexible substrates. However, the short lifetime and low efficiency of the flexible OLEDs are still the major problem to be solved. It is distributed to the penetration of oxygen and water vapor to the organic layers through the substrate and the encapsulated film [1-3].

The basic encapsulation method is used glass and epoxy adhesive in a N₂-filled glove box. However, the glass is not suitable for flexible encapsulation because of its rigid nature. The polymer substrates are the most promising candidate for the flexible encapsulation. The water vapor transmission rate (WVTR) of the polymer substrate is substantially below the requirement of OLED encapsulation. Therefore, polymer substrates coated barrier thin films to improve the WVTR are essential for flexible OLED encapsulation [4, 5].

Inorganic thin films have shown the potential to be the barrier layer for flexible OLED encapsulation [6]. Although these inorganic thin films have low WVTR, the defects of pinholes cannot be avoided because of the limitation of the vacuum deposition process. An organic-inorganic multi-barrier become an alternative to prevent the defects. [7-11]

In this work, to prevent the penetration of water vapor into the OLEDs, various encapsulated films for flexible OLEDs were studied, where gas barrier layers including inorganic Al₂O₃ thin films prepared by atomic layer

deposition, organic Parylene C thin films prepared by chemical vapor deposition, and their combination were considered. The transmittance and water vapor transmission rate of the encapsulated films were tested. The effects of various encapsulated films on the luminance and current density of the OLEDs were compared. The life time experiments of the OLEDs with these encapsulated films were also conducted in the final.

2 Specimen Preparation

The structure of the OLED is shown in Fig. 1, where a flexible PET substrate, an ITO anode, a PEDOT:PSS (Clevios AI4083) hole injecting layer (HIL), a NPB hole transporting layer (HTL), an Alq₃ emitting layer (EL), an aluminum cathode, and a PET cover were stacked in sequence. The ITO-coated PET substrate with size 300×200×0.175 mm was treated by standard cleaning procedure including ultrasonic bath and oxygen plasma before deposition. To fabricate the OLED, a PEDOT:PSS film was deposited on the ITO/PET substrate by spin coating at the first. The specimen was followed by drying process at 70 °C for 10 min. And then, the NPB and Alq₃ were thermally evaporated with 1 Å/s deposition rate. And, an aluminum cathode was successively evaporated. Finally, the device was covered with the encapsulated film and packaged by UV glue, and cured by UV light for 1 hour.

To prepare the encapsulated films, Al₂O₃ thin films were fabricated on the PET substrates by ALD. The

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precursor and purging gas of the ALD reactor are controlled by switching valves and flow past the substrate surface and into a mechanical pump. The substrate temperature at 60 °C, and the precursor pulse time with 10 msec were considered, where the chamber pressure is controlled at 9×10^{-3} Torr. The precursor H_2O , purging N_2 gas, precursor TMA, and purging N_2 gas are controlled to flow into the chamber in sequence. The Al_2O_3 film sequentially grows with 10 msec precursor of H_2O , 6000 msec of N_2 purging, 10 msec precursor of TMA, and 6000 msec of N_2 purging. The film thickness is controlled as 50 nm, consequently near 500 cycles were needed.

Parylene C thin films with 100 nm thickness were deposited by a chemical vapor deposition system. Parylene C powders were evaporated at 150 °C and pyrolyzed at 650 °C. The deposition temperature was room temperature and the deposition time was 1 hour.

In this work, five encapsulated types were considered, including none, PET, Al_2O_3 /PET, Parylene C / Al_2O_3 /PET, and Parylene C / Al_2O_3 /Parylene C / Al_2O_3 /PET, respectively. In the following discussion, the fourth and fifth types are simply denoted as 1 pair/PET and 2 pairs/PET.

Figure 1. Sketch of the flexible OLED.

3 Result and Discussion

Optical transmittance of the encapsulated films were measured by using an UV/VIS/NIR spectrophotometer (BWTEK BTC112) with normal incidence in the visible wavelength ranged from 400 to 800 nm, taking the air as reference. The results are shown in Fig. 2, where the average transmittance of the PET substrate is 88.162%, PET coated Al_2O_3 is 87.05%, 1 pair/PET is 86.56%, and 2 pairs/PET is 84.65%. Obviously, the transmittance decreases as the barrier layer increases. However, there is only 1~5% transmittance loss by adding the barrier layers.

Figure 2. Transmittance of the encapsulated films.

The water vapor transmission rate (WVTR) of the encapsulated films is shown in Fig. 3. It shows the average WVTR of PET is 11.08 g/m²/day, where Al_2O_3 /PET is 3.44 g/m²/day, 1 pair/PET is 3.36 g/m²/day, and 2 pairs/PET is 2.77 g/m²/day. The results indicate 2 pairs/PET has the best water and vapor barrier performance, which is 4 times better than the bare PET. It also reveals that the PET substrate coated with a barrier layer will efficiently improve the water-vapor resistance.

Figure 3. Water vapor transmission rate (WVTR) of the encapsulated films.

Luminance of the OLEDs with various encapsulated films is shown in Fig. 4. The results show that the OLEDs work as the applied voltage higher than 3V, and the luminance increases quickly as the voltage increases. It shows the luminance of the OLED without the encapsulated film is 111.82 cd/m² at 8V, and the luminance of OLED with PET, Al_2O_3 /PET, 1 pair/PET, and 2 pairs/PET are 162.18, 540.58, 557.23, and 544.93 cd/m² at 8V, respectively. It indicates the OLED with Al_2O_3 /PET, 1 pair/PET, and 2 pairs/PET presents similarly higher luminance than the other two cases. This phenomenon is consistent with the result of WVTR

shown in Fig. 3, revealing the barrier performance of the bare PET is as poor as no encapsulated film.

Figure 4. Luminance of the OLEDs with various encapsulated films.

The Current density vs. voltage diagram of the OLEDs with various encapsulated films is shown in Fig. 5, which is similar to the luminance diagram shown in Fig. 4. The Luminance and corresponding images of OLEDs with various encapsulated types at 8V are list in Table 1. Each luminant area of the OLED is 2×2 mm. The images

indicate the OLED without encapsulation or with bare PET encapsulation presents lots of black points, and the case of 2 pairs/PET encapsulation has the best emitting patterns.

Figure 5. Current density vs. voltage diagram of the OLEDs with various encapsulated films.

Table 1. Luminance and corresponding images of OLEDs with various encapsulated films at 8 V.

Encapsulated type					
	None	PET	Al ₂ O ₃	Parylene C Al ₂ O ₃	Parylene C Al ₂ O ₃
Luminance (cd/m ²)	111.82±9.5	162.18±3.2	540.58±33.8	557.23±49.2	544.93±36.0
Image

The life time of the OLEDs with various encapsulated films is shown in Fig. 6. The life time of the OLED is indicated by the normalized luminance (L/L_0) that presents by the ratio of the luminance after usage hours (L) to the luminance at the finished moment (L_0). For the OLED without encapsulation, the normalized luminance is 0.26 for 12 hrs, 0.10 for 24 hrs, and 0.03 for 36 hrs. For the OLED with PET encapsulation, the normalized luminance are 0.37, 0.16, 0.08, and 0.02 for 12, 24, 36, and 48 hrs, respectively. The OLEDs with Al₂O₃ /PET and 1 pair/PET encapsulation behave the similar life time. The OLED with 2 pairs/PET presents the best life time,

where the normalized luminance are 0.80, 0.66, 0.53, 0.43, 0.33, and 0.03 for 12, 24, 36, 48, 60, and 120 hrs, respectively. Note that, although the 1 pair/PET encapsulation behaves a litter better luminance than the 2 pairs/PET encapsulation, the 2 pairs/PET encapsulation has much better life time. The OLED with 2 pairs/PET encapsulation behave near double life time to the 1 pair encapsulation.

Figure 6. Life time of the OLEDs with various encapsulated films

4 Conclusions

Four types of encapsulated films to prevent the penetration of water vapor into the OLEDs were studied, including inorganic Al_2O_3 thin films prepared by atomic layer deposition, organic Parylene C thin films prepared by chemical vapor deposition, and their combinations. The results showed that the transmittance are acceptable even the PET substrate were coated two Al_2O_3 and Parylene C layers. The results also indicated the WVTR of the PET substrate improved by coating the barrier layers. In the encapsulation performance, it indicates the OLED with Al_2O_3 /PET, 1 pair/PET, and 2 pairs/PET presents similarly higher luminance than the other two cases. Although the 1 pair/PET encapsulation behaves a litter better luminance than the 2 pairs/PET encapsulation, the 2 pairs/PET encapsulation has much better life time. The OLED with 2 pairs/PET encapsulation behave near double life time to the 1 pair encapsulation, and four times to none encapsulation.

Acknowledgement

The support from the National Science Council through Grant NSC 102-2221-E-129-002-MY3 is gratefully acknowledged.

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