Thin film encapsulation of thin-cathode organic electroluminescent devices

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Abstract

We have developed a novel thin film encapsulation method for thin-cathode OLED by introducing organic (not polymer)/inorganic multiple thin films to protect device, which is shown to slow down the permeation rate of moisture and oxygen. From the stability test of devices, the projected lifetime of thin-cathode OLED device with thin film encapsulation was similarly to that with glass lid encapsulation.

Keywords: thin-cathode; encapsulation

1. Introduction

In more recent years, several OLED technologies such as transparent OLED [1], stack OLED (SOLED) [2], top-emitting OLED (TOLED) [3, 4] and flexible OLED (FOLED) [5, 6] have been developed. It was well known that some of the organic materials and low work function metals used in these OLEDs are sensitive to moisture and oxygen, which lead to the degradation of devices. At present, the most popular encapsulation technique to protect OLEDs from oxygen and water vapors is to use a glass or metal lid. However, these lids are thick and heavy which limit the applications of OLEDs in mobile and flexible displays.

There also has been considerable interest in developing encapsulation of OLEDs by means of thin films instead of a glass or metal lid. By replacing these lids with conformable thin film layers, the device would be made extremely lightweight and thin. Many researchers have been doing research and development in thin film encapsulation. For example, in SID 2004, F. J. H. van Assche et al. [7] using 3 of plasma deposited silicon nitride layers (a-SiN_x: H) as passivation layers for bottom-emitting OLEDs/PLEDs. In SID 2005, J. J. W. M. Rosink et al [8] developed a multi-stack approach of silicon nitride-silicon oxide-silicon nitride (NONON) PECVD films as a barrier layer for bottom-emitting OLED.

As we know, it is a possible way to encapsulate OLEDs by means of sputtering methods. However, the cathodes of TOLEDs and transparent OLEDs were consisting of reactive thin-metals (thickness less than 20 nm) that might be damaged during sputtering process. Therefore, it is an important research object to sputter passivation layers on thin-cathode OLEDs without destroying the metals. To the best of our knowledge, no report has been documented on thin film encapsulation of thin-cathode OLED by means of organic (not polymer)/inorganic thin films as passivation layer.

In this paper, we describe the results of thin film encapsulation of thin-cathode OLED by means of sputtering in combination with organic thin films methods.

2. Experimental Details

Ca test samples in this experiment were prepared by depositing 200 nm of calcium on clean quartzes then the laminated layers of organic/inorganic were sputtered consecutively. Figure 1 shows schematic diagram for Ca test instrument that was set up for this experiment. The sample with encapsulation films was illuminated by a stable LED light source, and a photodiode was used to detect the variation of optical transmission vs. time.

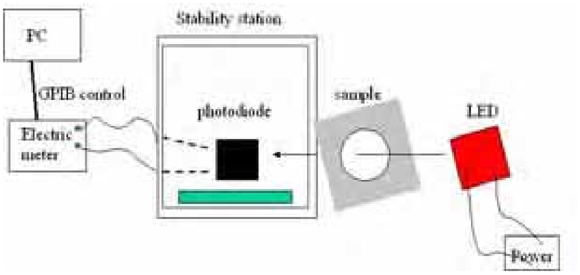

Figure 1
Schematic diagram for Ca test instrument. A LED is stable light source, and a photodiode, which detects the variation of optical transmission vs. time.

The substrates of OLEDs used in this experiment were ITO-coated glass, and the thickness and sheet resistance of the ITO were 100 nm and 35 Ω/□, respectively. Prior to deposition, the ITO-coated glass substrates were cleaned subsequently with acetone, detergent, deionized water, and methanol in ultra-sonic bath to remove the organic contaminants, and then the substrates were treated with oxygen and CF_x plasma for 20 s and 5 s, respectively.

After pretreatment, the organic materials and cathodes were deposited by thermal evaporation in an ULVAC SOLCIET OLED coater at a base vacuum of 10^{-4}~10^{-5} Pa. The device structure of OLED was: ITO/O_2, CF_x plasma/NPB (60 nm)/C545T doped Alq_3 (37.5 nm, 1%)/Alq_3 (37.5 nm)/LiF (1 nm)/Al (200 nm or 20 nm). Before sputtering the passivation layers, 400 nm of 2-methyl-9, 10-di(2- naphthyl)anthracene (MADN) buffer layer was deposited on device to avoid sputtering damage. Then sputtering a 200 nm silicon nitride (SiN) thin film, deposited one layer of organic film and sputtering silicon oxynitride (SiON). Repeated the organic/inorganic procedure five times.

The electroluminescence characteristics of OLEDs were measured with a Photo Research PR650 spectrophotometer and a programmable current source (Keithley 2400). The device lifetime was measured by photodiode connected to a data acquisition instruments and computer.

3. Results and Discussion

3.1 Ca test

Ca test is a method to examine the permeation rate of water vapor and oxygen through the encapsulation thin films. Thin film of calcium, which becomes progressively transparent during reaction with water and oxygen, can be exploited to monitor the permeation rate of the encapsulation films under various conditions. As shown in Figure 2, the transparency of sample with five times of organic/inorganic thin film increased much slower than that without organic thin films, which means the permeation rate of water vapor and oxygen was decreased by inserting organic layers in-between inorganic layers. The results may be explained by considering the thickness increasing of encapsulation layers. The more likely explanation is that the organic layers can effectively fill up the pinholes of inorganic layers.

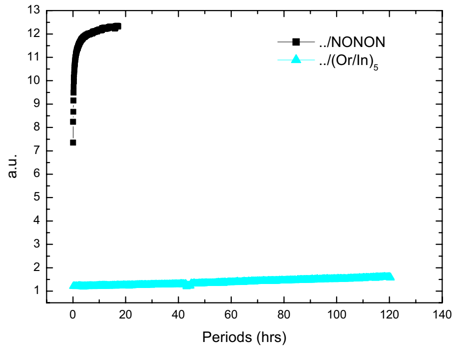

Figure 2
Comparing of optical transmission with and without organic thin films. N means SiN and O means SiON. The structure of samples are quartz/Ca (200 nm)/$(organic/inorganic)_5$.

3.2 Encapsulation of OLEDs

. The brightness of thin film encapsulated and glass lid caped bottom-emission OLEDs driven at 20 mA/cm^2 are 1870 cd/m^2 and 1805 cd/m^2, respectively. From the stability data shown in Figure 3, at initial brightness of 100 cd/m^2, projected lifetime of the device with thin film encapsulation is 11,500 hours, which is similarly to the 11,100 hours that is obtained with glass lid encapsulation.

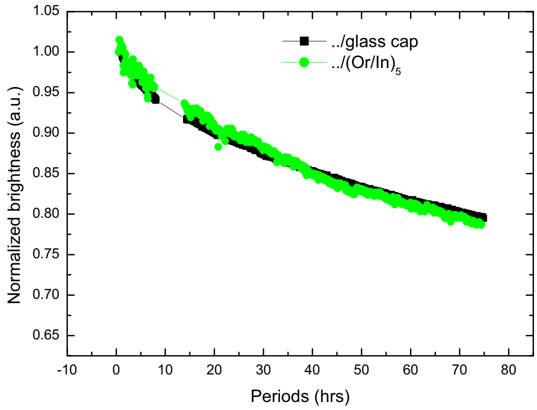

Figure 3
Lifetime comparison of OLED with thin film encapsulation and with glass lid.

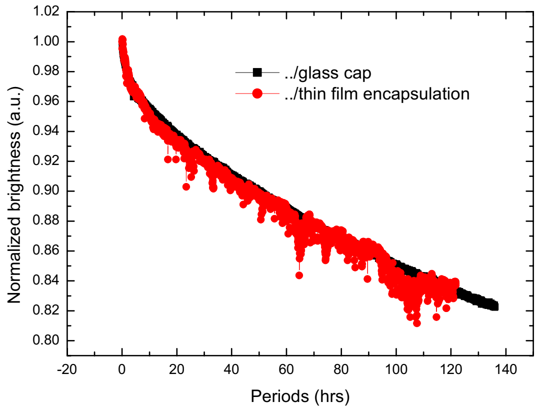

Figure 4
Lifetime comparison of thin-cathode OLED with thin film encapsulation and with glass lid.

Figure 4 shows the lifetime comparison of thin-cathode OLEDs with thin film encapsulation and with glass lid. The device structure of thin-cathode OLED was: ITO/O$_2$, CF$_x$ plasma/NPB (60 nm)/C545T doped Alq$_3$ (37.5 nm, 1%)/Alq$_3$ (37.5 nm)/LiF (1 nm)/Al (20 nm). From the stability data shown in Figure 4, projected lifetime of the device with thin film encapsulation is similarly to that with glass lid encapsulation.

4. Conclusion

In the development of OLED for flat panel display applications, encapsulation is very important. It can protect OLED displays from attack by moisture and oxygen and hence extend the lifetime of the display. Since top-emitting and transparent OLEDs have considerable advantages in OLED area, in order to realize the full potential of OLED technology, the encapsulation of thin-cathode OLED is one of the most important research topics of today. To the best of our knowledge, no report has been documented on thin film encapsulation of thin-cathode OLED by means of organic (not polymer)/inorganic thin films as passivation layer. We demonstrate for the first time that the organic thin film can be an effective passivation layer to cover the pinholes formed in sputtered film providing a new methodology of thin film encapsulating thin-cathode OLEDs.

5. Acknowledgements

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6. References

[1] G. Gu, V. Bulović, P. E. Burrows, S. R. Forrest, M. E. Thompson, *Appl. Phys. Lett.* **68**, 2606 (1996).

[2] P. E. Burrows, V. Khalfin, G. Gu, S. R. Forrest, *Appl. Phys. Lett.* **73**, 435 (1998).

[3] S. F. Hsu, C. C. Lee, S. W. Hwang, C. H. Chen, *Appl. Phys. Lett.* **86**, 253508 (2005).

[4] S. F. Hsu, C. C. Lee, S. W. Hwang, H. H. Chen, C. H. Chen, A. T. Hu, *Thin Solid Films,* **478**, 271 (2005).

[5] A. N. Krasnova, *Appl. Phys. Lett.* **80**, 3853 (2002).

[6] S. N. Lee, S. F. Hsu, S. W. Hwang, C. H. Chen, *Curr. Appl. Phys.* **4**, 651 (2004).

[7] F. J. H. van Assche, R. T. Vangheluwe, J. W. C. Maes, W. S. Mischke, M. D. Bijker, F. C. Dings, M. F. J. Evers, W. M. M. Kessels, M. C. M. van de Sanden, *SID 04 Digest*, 695 (2004).

[8] J. J. W. M. Rosink, H. Lifka, G. H. Rietjens, A. Pierik, *SID 05 Digest*, 1272 (2005).