A New Thin-Film Encapsulation Structure for Flexible OLED Display with Long Lifetime

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Abstract

A series of adhesion strength modified layer (ML) was introduced to develop the new TFE structures. The new encapsulation structures provided the long-life time performance for the flexible OLED device. No pixel shrinkage or dark spots appeared after storing in an environment of 85% humidity and at 85 ℃ over 20,000 hours. The adhesion strength of the thin film system improved and the risk of peeling decreased.

Author Keywords

Thin film encapsulation, TFE, long-time life, flexible OLED

1. Introduction

Flexible organic light emitting diodes (OLED) is currently under intense investigation because of its excellent image quality, light weight, high efficiency, fast response and wide viewing angels. Short lifetime was still a critical factor. Researchers proposed that the exposure of the emitting light materials and cathode to atmospheric oxygen and water dominated the degradation of the OLED device. Efficient encapsulation of OLED is essential for achieving long lifetime and reliable efficiency. Dam &filler and laser assisted frit sealing were widely used in rigid OLED encapsulation while thin film encapsulation (TFE) was an optimized method for the encapsulation of flexible OLED, especially for the foldable OLED device or the rollable OLED device. Nowadays, TFE with multi-layers structure was used in the mass production of flexible OLED products.

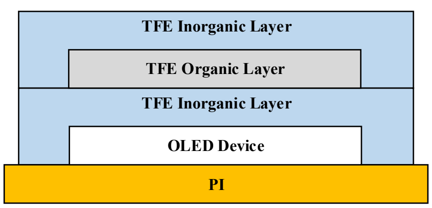

Figure 1 the mass production structure of flexible OLED

Inorganic layers were used to seal the organic light emitting device and serve as a barrier layer preventing or substantially preventing an extraneous material from infiltrating into the organic light emitting device. The organic encapsulation layer had a thickness and served as a protection layer protecting the organic light emitting device from external impact. In addition, the organic encapsulation layer acted as a planarization layer providing a flat top surface.

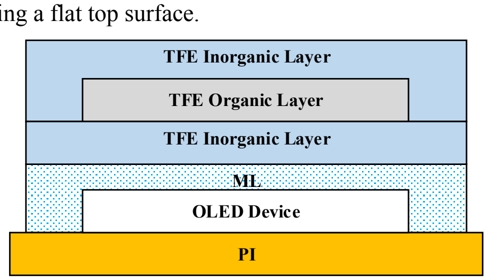

Figure 2 a typical example of the new structures

In this work, a series of new TFE structures was developed with the introduction of adhesion strength modified layers (ML). Modified layers were deposited by Plasma enhanced chemical vapor deposition (PECVD) or plasma enhanced atom layer deposition (PEALD). The modified layers played important roles in balancing the adhesion strength. The higher the adhesion force, the longer the storage times of OLED. The risk of cathode peeling decreased. WVTR values, refractive index, adhesion strength and reliability tests were shown to prove the improvement effect.

2. Methods

2.1 Preparation of the TFE structures:

Sandwiched encapsulation structure (Inorganic Layer/Organic Layer/Inorganic Layer) was prepared as follows. Inorganic layers such as Silicon oxynitride (SiON) or silicon nitride (SiNx) were deposited by plasma enhanced chemical vapor deposition (PECVD) and organic layer was obtained by Ink Jet Printer.

2.2 Fabrication process of the modified layers

The modified layers played roles as transition layer in adhesion strength adjustment. The inorganic layers MLs were deposited by plasma enhanced chemical vapor deposition (PECVD) or plasma enhanced atom layer deposition (PEALD) at the low-temperature conditions (below the 90℃)

2.3 Adhesion test

Nano indentation (NI) method was used to determine the adhesion strength. The adhesion strength of thin films was measured by using scratch test under ramp loading. Load–displacement profile of thin films at continuous indentation cycle without any discontinuity revealed no fracture, cracking event, and defects, which is a consequence of dense microstructure and good adherence of films to the substrate.

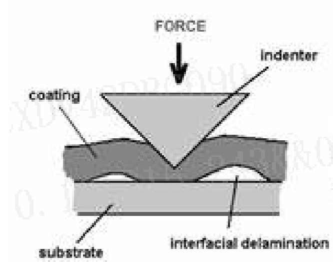

Figure 3 the schematic diagram of NI method

2.4 WVTR value

Mocon II was used to detect the barrier properties before and after the introduction of the modified layers. And the WVTR values before and after bending 20,000 times at a 5mmφ radius were also tested.

2.5 Optical property test

Refraction index and extinction coefficient detected by

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Ellipsometer (J.A.Woollam, M-2000X). Transmission Ratio determined by UV spectrophotometry.

2.6 Reliability test

Encapsulation effect was illustrated by reliability test at accelerated climate conditions of 85°C/85% relative humidity. Whether there was pixel shrinkage was observed in certain intervals.

3. Results and Discussion

Modified layers fabricated by the PECVD or PEALD could be one or more of the SiCN, SiOx, SiON, SiNx, Al2O3.

ML helped enhancing the reliability of the OLED device in RA test with the increasing of the interfaces. Furthermore, ML acted as adhesion strength transition layers. Through balancing the adhesion strength, the reliability performance was improved and peeling risks decreased.

The modified layers played important roles in balancing the adhesion strength. The higher the adhesion force, the longer the storage times of OLED.

3.1 The Characteristics of the modified layers

The introduction of the ML had no negative influence on the WVTR value because that it presented the water vapor barrier properties in the front direction. As shown in the table 1, different type of the layers possessed different refractive index. Tunable refractive index could provide more innovations space to researchers. Furthermore, WVTR value remained in the same order after the addition of the modified layers.

Table 1. The characteristics of the MLs

Items	unit	ML1	ML2	ML3	ML4
Transmission Ratio	%	99.3	98.1	91.5	96.4
refractive index	/	1.45	1.55	1.75	1.84
Stress	Mpa	-88.6	35.5	-21.3	-77.9

Bending performance for flexible OLED was one of the most important properties to evaluate the flexible display. Figure 4 showed the WVTR test sample deposited the new TFE films (a) and the bending test (b). After bending 10,000 times at 3 or 5mmφ bending radius, no failure was proved by WVTR value measured by Mocon II. Taking the new TFE structure with ML1 as an example, the WVTR test results could be achieved to 1.48×10^{-4}g.m^{-2}/d for OLED device reliability after inside bending 10,000 times at 3 mm φ bending radius.

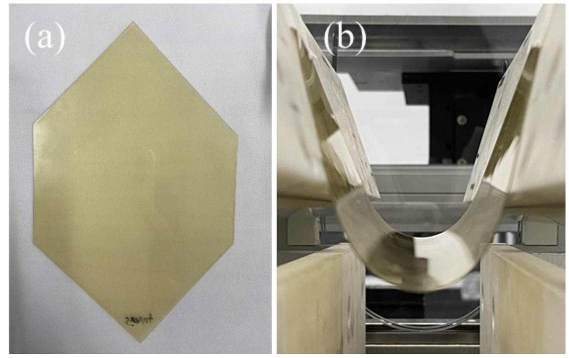

Figure 4 the WVTR test sample (a) and bending status (b)

3.2 Adhesion strength

Adhesion strength depended on many factors, including electrostatic forces, the chemical bond which was might occur between the coating film and substrate, moisture-aided diffusion and so on. Figure 1 illustrated a series of adhesion strength deposited in the low temperature (below 90 centigrade). The new TFE structure with one modified layer was defined as "structure 1 (S1)" while "S2" consisted of two modified layers.

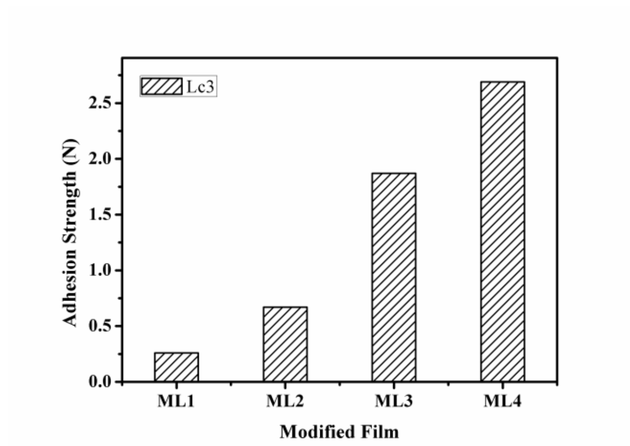

Figure 5 the adhesion strength after the introduction of the MLs

Modified layers helped to decreased the catastrophe of mechanical properties (such as adhesion strength, stress and CTE (coefficient of thermal expansion)) mismatch, therefore increasing the adhesion strength. ML1 or ML2 possessed relative lower adhesion strength and could be used to regulate the adhesion strength between layers. With properly selecting, the introduction of a modified layer between the substrate and silicon nitride resulted in a remarkable increase of the film adhesion. As shown in the figure 5&6, based on ML3 adding one or more ML1 could enhance the adhesion strength from 1.87N to 3.68N. The increasing ratio was over 90%.

The binding characteristics of electroluminescence materials mainly consisted of the Van der Waals force which was much weaker than chemical forces. It led to the weak adhesion performance of the electroluminescence materials. Figure 6 displayed the change of the adhesion strength of the conventional OLED device, weak intermolecular forces had obvious negative effects. After introducing the modified layers, adhesion strength grown significantly. Compared ML2+S2 with the reference structure, the adhesion strength rose and the increasing rate was even over 90%. The relative lower adhesion strength acted as an ML to reach the performance matching. When combined properly brought significantly enhancement.

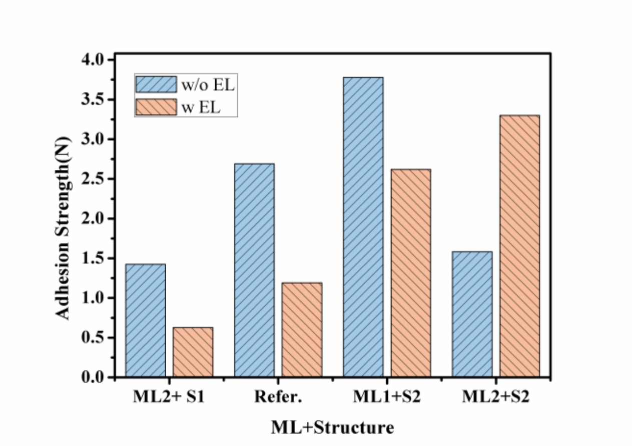

Figure 6 the adhesion strength of the structure with EL materials

In the previous study, the better the adhesion strength, the longer the reliability and the lower peeling risk. With the introduction of the modified layers, the appearance time of OLED reliability failure.

3.3 RA Test results

For the commercial OLED products, the specification of reliability time was over 240 hours in the steady - state temperature humidity - bias life test (the 85/85 test). A thermal and humidity storage (THO) reliability

Figure 7 was the summary of reliability test results in this work. The barrier property of the new TFE structure with modified layers enhanced remarkably. After storage in an environment of 85% humidity and at 85 ℃ over 2000 hours, the pixel shrinkage and the dark spots were not observed.

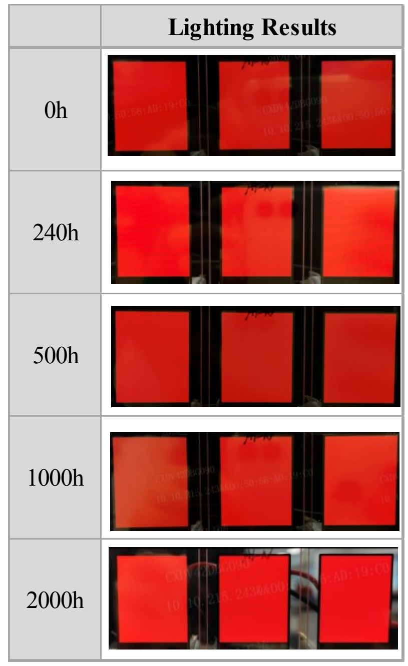

Figure 7 the reliability test results

Concretely speaking，new TFE structure with two modified layer had a great advantage in prolonging the failure occurred. Figure 8 explained the action principle, ML between the TFE inorganic layers decreased the stress and balanced unstable state. The second interlayer tunned the mismatch between EL materials and TFE.

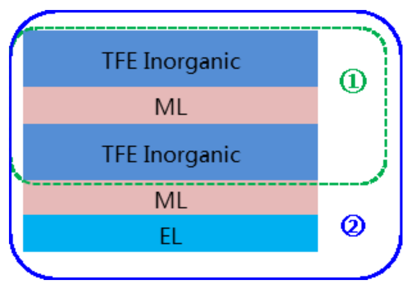

Figure 8 the schematic of the function of MLs

4. Discussion

In this work, a series of new TFE structures were developed with the introduction of adhesion strength modified layers. The modified layers played important roles in balancing the adhesion strength. The adhesion strength increased over 90% from 1.87N to 3.68N. Stored in an environment of 85% humidity and at 85 ℃ over 2000hours, the pixel shrinkage and the dark spots were not observed. The risk of cathode peeling decreased. With the remarkable promotion in reliability, the new structures could be applied in outdoor mobile device, vehicle products or application scenarios required long-life time.

5. References

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