Ultra-Thin-Encapsulation Layers Fabrication for High-Resolution OLEDs Realized by a Showerhead-type initiated CVD and Plasma Enhanced Atomic Layer Deposition Hybrid System

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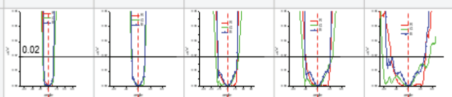
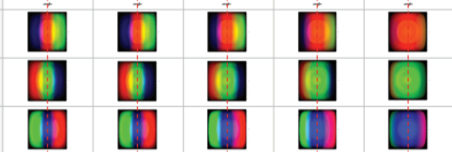
ABSTRACT

We developed a high-performance encapsulation layer for the fabrication of high-resolution OLEDs with UTE(Ultra-Thin-Encapsulation) structure. The UTE structure was achieved by sequential deposition of organic/inorganic layers by iCVD(initiated Chemical Vapor Deposition) and PEALD(Plasma Enhanced Atomic Layer Deposition) processes in a one-chamber system capable of depositing iCVD and PEALD layers. The basic thin film characteristics were investigated systematically. Especially, cross-section analysis clearly illustrated the excellent conformal coverage of arbitrary particles.

1 Introduction

Customers' demand for higher resolution of near-to-eye display grows rapidly. High-resolution OLEDs together with TFT array is regarded as one of the promising device to satisfy the customers' demand. However, it is difficult to manufacture high-resolution FMMs and using WOLED coupled with color filters is recognized as a promising strategy to realize the mass-production of high resolution display. For this purpose, the encapsulation layer thickness must also be minimized to enable down-sizing the high-resolution display.

Table 1 Color viewing angle simulation results according to encapsulation layer thickness

Total Encap. THK [㎛]		4.0	3.0	2.0	1.5	1.0
Polymer THK [㎛]		3.5	2.5	1.5	1.0	0.5
Δ u'v'						
Luminance Image	R					
	G					
	B					
Color Viewing Angle [°]	R	13	16	24	30	42
	G	14	16	28	36	52
	B	12	16	23	30	40

According to the simulation results in Table 1, even when the size of TFT device decreases, color mixing among the pixels often occurs mainly due to the too thick encapsulation layer. Accordingly, the issue of reducing the color viewing angle also arises as well. To reduce the thickness of the entire encapsulation layer, organic layer thickness was reduced greatly by adopting an alternative deposition process, iCVD and PEALD processes[1] to replace the conventional inkjet and PECVD processes, respectively. We named this structure UTE(Ultra-Thin-Encapsulation) and its structure is shown in Fig. 1. The total thickness of UTE was designed to less than 1.5 ㎛.

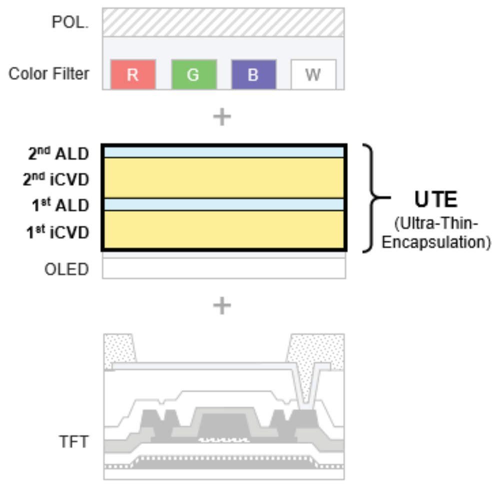


Fig. 1 UTE(Ultra-Thin-Encapsulation) Structure

2 Experiment

As shown in Fig. 2, we fabricated thin-film encapsulation layers using shower-head type system rather than the conventional side-flow type system. There are many holes in the shower-head of the system, and through these holes, initiator, monomer, precursor and reactant gas used in iCVD and PEALD processes are supplied. A nichrome wire was placed just below the shower-head to thermally decompose the initiator.

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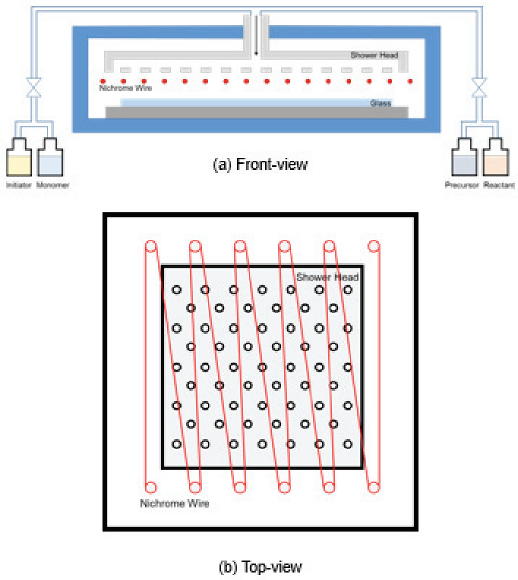


Fig. 2 The Schematic of the iCVD and PEALD Hybrid System

Fig. 3 is the iCV-dX3 System of iSAC Research Inc. (Daejeon, Korea) to which the same concept as Fig. 2 is applied, and the encapsulation layers fabricated were deposited using this hybrid system.

Fig. 3 iCV-dX3 Hybrid System(iSAC Research Inc.)

The iCV-dX3 system is a hybrid system that can process iCVD process and PEALD process in one chamber. The maximum deposition area is 500 ㎜ X 500 ㎜. To compensate for the particles, the iCVD thin film was first deposited, then the PEALD thin film was deposited in the as-dep. state, and then the same thin film processes were repeated to complete the UTE structure. The purge was performed for a sufficient time to minimize interference between the iCVD process and the PEALD process. During the iCVD process, the chiller temperature was 30 °C, the filament temperature was 220 °C, the distance between the shower-head and the stage was 30mm, and the process pressure was 0.5 Torr. During PEALD process, chiller temperature was 50 °C, RF power was 300 W, Precursor 1sec/Purge 4sec/Reactant 1sec/Purge 1sec was performed for 275 cycles, and GPC was 1.98 Å/Cycle.

3 Results and Discussion

For the iCVD thin film used in the UTE structure, TBPO was used as the initiator, and the deposited polymer thin film had RI of 1.485 and the film stress of -1.4 MPa. And the RI of the PEALD thin film was 1.451 and the film stress was 37.86 MPa. The film stress of the UTE thin film using these iCVD films and PEALD films was 4.13 MPa.

In the visible light region(Wavelength 380 ㎚ ~ 780 ㎚), compared to bare glass, the transmittance of the iCVD thin film(Thickness 0.5 ㎛) is 99.12%, the transmittance of the PEALD thin film is 99.39%, and the transmittance of the UTE structure, which is a composite film of iCVD and PEALD, is 99.06%. The average transmittance of each of the 6 UTE structure samples was 99.03%. It was transparent enough to be applicable to top-emission OLEDs.

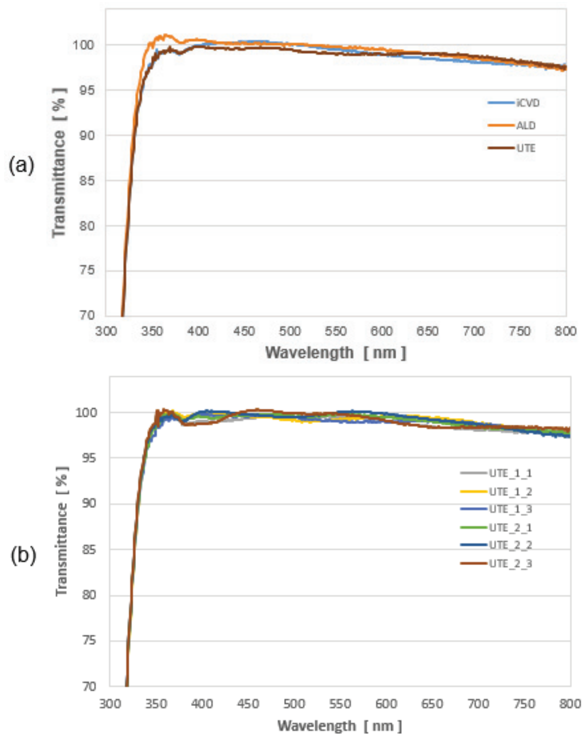


Fig. 4 The Transmittance vs. Wavelength: (a) iCVD, PEALD and UTE Structure, (b) 6 UTE Structure Samples

PEALD single layer showed general conformal deposition characteristics, thickness non-uniformity was ±1.7 %, side step coverage was 89.7 %, and bottom step coverage was 82.6 %. The width of the used Si trench was 5 ㎛ and the depth was 5 ㎛, and the aspect ratio was 1.0.

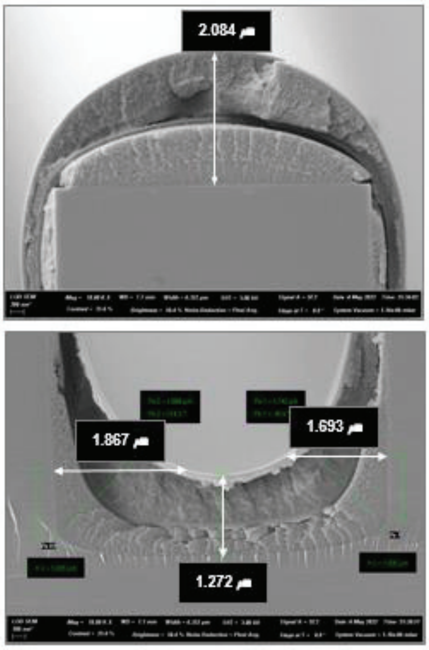
On the other hand, in Fig. 5, the iCVD single layer had a side step coverage of 61.0 % and a bottom step coverage of 32.6 %. The poor step coverage in the bottom area is considered to be that the monomer supply did not reach the inside of the trench depending on the iCVD process conditions[2]. As for the step coverage, it is considered to be advantageous for particle covering that the side part appears higher than the bottom part.

In an iCVD single layer, the coating thickness is not constant and is shown as a function of position in the horizontal direction. The thickness is rapidly changing at the step edge of the trench, and it is deposited thinner at the bottom. These edge properties are considered to be due to the properties of the material and the interaction between the substrate and the material.

(a)
(b)

Fig. 5 Trench Cross-section of iCVD Single Layer: (a) Top, (b) Side & Bottom

(a)
(b)



(c)

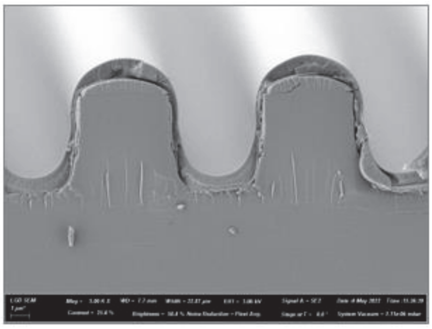


Fig. 6 The Cross-section of UTE Structure on Trench Wafer: (a) Top, (b) Bottom, (c) Top & Bottom

In Fig. 6, the side step coverage of the UTE structure was 85.4 % and the bottom step coverage was 61.0 %, and it was confirmed that the iCVD thin film was deposited in a non-conformal shape, unlike the conventional one. In this deposition condition, it can be seen that in the top part of the trench wafer, the middle position is thick and both edge side positions are thinly deposited. Conversely, in the bottom part of the trench wafer, the middle position is deposited thinly and the side positions is deposited thickly. Comparing with the single layer characteristics, this phenomenon is estimated to be due to the effect of etching by plasma during the PEALD process and the process conditions of iCVD materials.

Comparing the UTE structure with the PEALD process using plasma compared to the iCVD single film without the plasma process, it can be seen that the edge position of the polymer film is etched a lot. These characteristics appeared throughout the trench wafer.

In Fig. 6 (c), at P_m/P_{sat}=0.23, the 1st iCVD upper thickness was 893 nm, the lower thickness was 428 nm, the 2nd iCVD top thickness was 930 nm, and the bottom thickness was 700 nm. The depth and width of the trench were 5 μm, respectively, and the aspect ratio was 1.0. The bottom of the trench is deposited with a meniscus-like shape, which can show this characteristic depending on P_m/P_{sat} ratio, and as P_m/P_{sat} increases, the step coverage decreases[3].

We checked how well the UTE structure can cover particles that may occur during processing. Basically, if the inorganic layer is first deposited, seam may occur if the particles are present, so the iCVD process, which is a polymer film, was first deposited. In this way, even if there are particles generated during the process, it was possible to cover the particles with a polymer layer without a seam.

Afterwards, the PEALD process was deposited as a protective film to protect the OLED from oxygen and moisture, and this process was repeated twice. We tried to lengthen the penetration path of oxygen and moisture as much as possible.

According to the FIB image of Fig. 7, it was confirmed that the four films composed of organic and inorganic layers covered the particles well without a seam between the particle and the substrate surface. As expected, it was confirmed that the UTE structure removes the seam path through which oxygen and moisture can penetrate even in the presence of the particles.

(a)

(b)

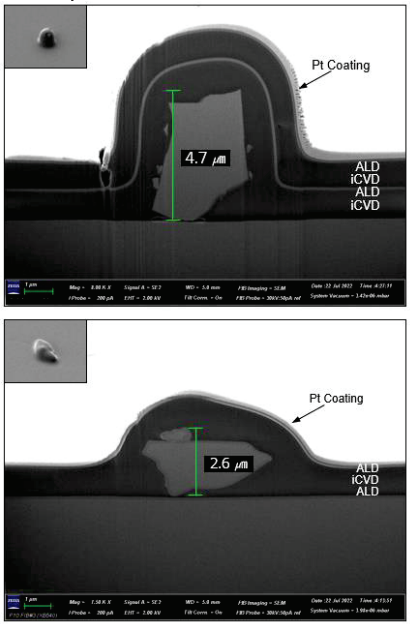
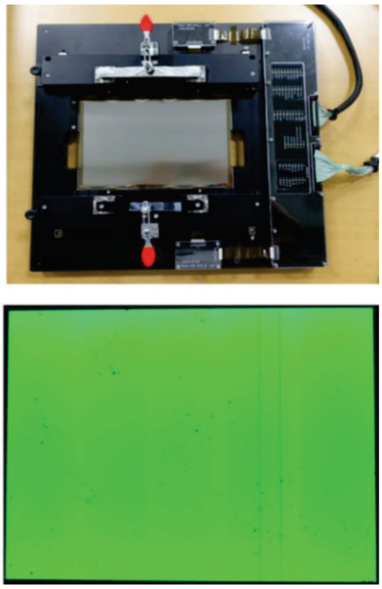


Fig. 7 The FIB Cross-section: (a) UTE 2.0 Layers, (b) UTE 1.5

After confirming the particle covering ability of UTE structure, we made the 11-inch panel using UTE structure instead of the normal encapsulation structure. As shown in Fig. 8, 11-inch panel is well operated with UTE structure. And we investigated one of the dark spots in the panel(Fig. 8 (b)). By FIB image, the particle was well covered with UTE structure. This means that even if there are the particles on the panel, the UTE structure covers the particles well and removes the moisture permeation path even if the thickness of the UTE structure is thin.

(a)

(b)



(c)

(d)

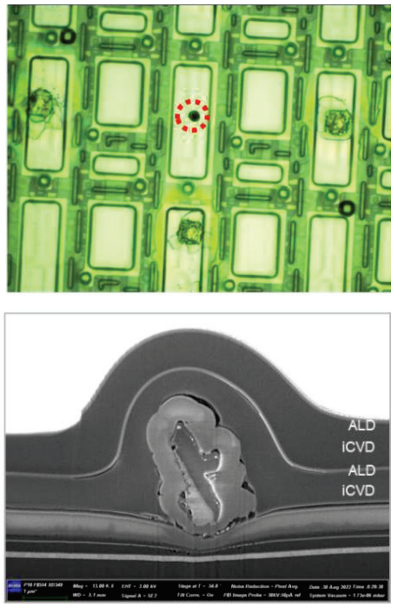


Fig. 8 UTE Panel Fabrication: (a) On/Off test Jig, (b) 11-inch panel, (c) The dark spot in the 11-inch panel, (d) FIB image of the dark spot

4 Conclusions

In this study, we proposed a thin encapsulation film using UTE structure by iCVD and PEALD process for high-resolution OLEDs. A UTE structure was fabricated with a showerhead-type one-chamber hybrid system to investigate single layer properties and step coverage, and this UTE structure was shown to cover the particles without a seam, confirming the possibility of product application.

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