A Mass Manufacturing Process for Barix encapsulation of OLED displays: a reduced number of dyads, higher throughput and 1.5 mm edge seal

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Abstract

In this paper we describe a new process for thin film encapsulation of OLED displays which is suitable for mass manufacturing.

1. Introduction

Thin film encapsulation of OLED Displays does bring a lot of advantages over the existing glass lid/metal can plus dessicant encapsulation technology; it would make the devices roughly half as thick, it would reduce the cost, it enables top emission displays and would also reduce the total periphery space of the display.

But although thin film encapsulation would be an attractive feature, it has not been so easy to achieve that goal in a technically and economically feasible way. The requirements to the layers of being; transparent, totally pinhole and crack free over very large (>1 m^2) surface areas, low stress and high robustness while being deposited at low temperatures well below 80 C, have proven to be very difficult to meet.

Early attempts to solve this problem with single layer oxides or nitrides, while obtaining some success on small areas, basically failed because of the presence of particles, crack and defects in the layer and residual stress.

Vitex has proposed a multilayer of organic and inorganic layers, Barix ™, to address and solve these problems. The multilayer consists of thicker (0.25 to 4 micron) polymer layers alternated by thin (200-500 nm thick) layers of oxide or nitride. The polymer layers are being deposited in vacuum as a thin liquid film of an acrylate monomer which is polymerized with UV light. These layers fulfill the following functions: because of their initial liquid state they planarise the substrate and because of the fat surface of these films, provide the almost ideal surface to grow a defect free oxide. The polymer layer furthermore covers particles, decouples defects in the oxide layers so that they are not aligned and function as a stress release layer.

The thin films of oxide serve as the barrier layers to oxygen and water. As demonstrated theoretically by G Graff et al, the main effect of the multilayer is in increasing the lag time between exposing the top layer to water vapour and the water molecules arriving at the interface between the OLED and the Barix™ encapsulation layer.

A cross section of the Barix Multilayer structure is shown in Figure 1. It uses a multilayer system of organic and inorganic layers.

Figure 1

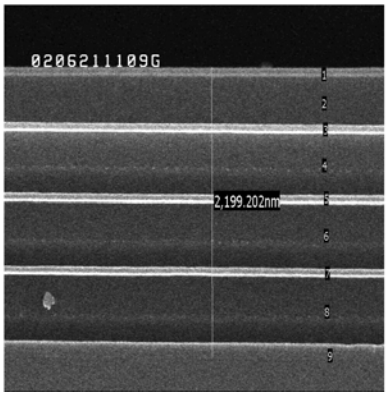

Fig 1. SEM Cross section of a typical Barix multilayer barrier coating. Oxide layers typically are between 30-100 nm and polymer layers 0.25 to 4 micrometers.

The layers are all deposited in vacuum as is show in Figure 2 [6,7,8.] The organic layers are applied as follows: a mixture of photosensitive acrylate monomers is vaporized, condensed on the substrate and quickly polymerized with UV radiation. The inorganic metal oxide layer, mostly Aluminum oxide, is deposited via a reactive sputtering process. Typically the organic layers vary between 0.25 and 4 micron in thickness and the metal oxide layers between 30 to 100 nm. What is really unique about this process is that the organic phase is deposited as a liquid: the film is very smooth (< 2 Angstrom variation) locally and also has extremely good planarizing properties over high topographical structures like ‘cathode separators’ ‘ink jet wells’ and Active Matrix pixel structures. So while the local flatness creates an ideal surface for growing an almost defect free inorganic layer, the liquid takes care of covering topography. It should also be mentioned that while even non-conformal methods to deposit oxides like CVD, have difficulty covering cathode separators without creating voids, they also struggle to coat often more then 4 micron high structures in an acceptable process time.

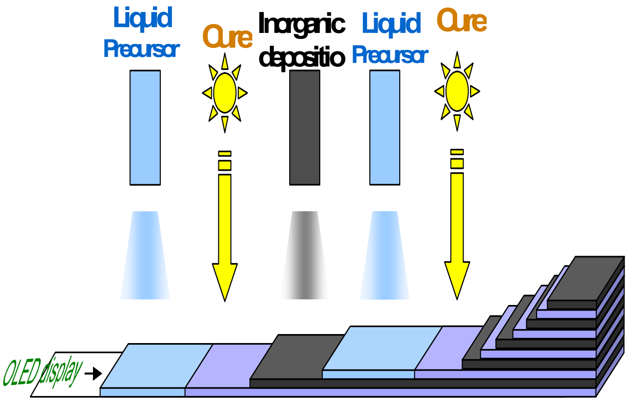

Fig.2 Schematic presentation of the process steps of the Barix encapsulation

The multilayer provides redundancy and since the remaining defects in the inorganic layers are few and far in between and not connected, a very long diffusion path to the substrate results as well.[4]

The organic layers also provide a function of stress release layer in thermal shock testing.

An extensive model for the diffusion through this type of barriers has been developed by G Graff et al.[4]

The main findings of this study are that i) high quality inorganic films coupled with a multilayer architecture are necessary to achieve OLED barrier requirements (large spacing between defects) ii)Lag time (transient diffusion), not steady state flux, dominates gas permeation in these multilayer thin films systems. iii) Consideration of steady state , alone, is not sufficient to describe and predict the performance of multilayer barrier films one must consider the transient regime.

2. Results

The Vitex Barix$^{\text{TM}}$ process has been shown to meet telecommunication application specifications for a wide variety of OLED displays: passive and active matrix displays, bottom, top and transparent displays and it works equally wel for small molecule, polymer and phosphorescent OLEDs.
Most of these results were obtained with using 5 to 6 dyads (a combination of one polymer and one oxide layer) and using an edge seal width (distance between the edge of the active area and the edge of the barrier layer) of 3 mm.

In this paper we will focus on making this process better suitable for mass manufacturing purposes.
We have a developed a process which uses:

- Only 2 to 3 dyads and has >95% yield
- Can deposit an oxide layer over a 400 by 400 mm substrate in 40 seconds, while maintaining good barrier properties and not causing any damage to the OLED display
- Uses only an edge seal width of 1.5 mm

Reduction of the number of dyads

Fig 3 shows the yield of 1*1 cm^2 OLED pixels as a function of time in 60C/90RH accelerated ageing conditions, in the case of 2, 3 and 6 dyads.
For each experiment 150 OLED pixels were tested. (yield is defined is <10 % efficiency loss, no blackspots visible to the naked eye, perfect uniformity)
As can be seen from the graph, the two dyad process has few early failures but the three and 6 dyad process behaves the same and has 100% yield.

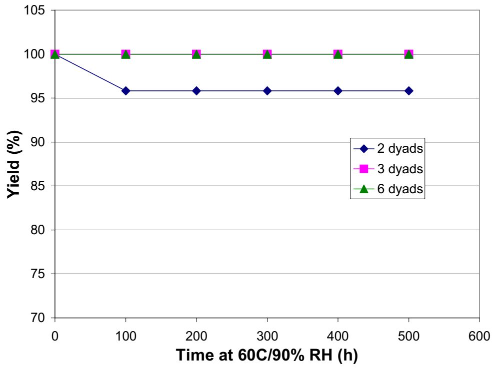

Fig 3
Yield of encapsulated OLED pixels ($1 cm^2$) in 60C/90RH conditions for 2, 3 and 6 dyads

It should be noted that in all these pixels had a 3 mm edge seal and that no edge seal failure has been observed.

We have also demonstrated that such a low nr of dyad process works on passive matrix structures with 4 micron high cathode separators.

Fast oxide process

In order to meet the requirements of ever larger substrates we have developed a much faster oxide process. The oxide process is the rate limiting step in the overall process. The polymer process can run in an R2R machine at rates of 3.5 meters/minute.

By a modification of the sputter conditions a process has been developed which is five times faster then the previous standard process and has a rate of 0.6 meters per minute.

In itself it is not hard to increase the sputter rate but a good barrier process must fulfill the following conditions:

- No damage to the OLED
- No damage to the barrier layers
- Same barrier performance as 'slow' process
- No loss of efficiency or faster blackspotgrowth then the previous process

Table 1 shows that these conditions can be met:

Oxide Process	Oxide Rate	OLED IVL Damage	Barrier on Ca	Barrier on OLED
SOP	1	OK	OK	OK
#1	1.7x	OK	OK	OK
#2	2x	OK	OK	OK
#3	3x	OK	OK	OK
#4	2.7x	OK	OK	OK
#5	5x	OK	OK	OK

In the presentation more details about the optical and electrical evaluation criteria will be given.

Edge Seal of 1.5 mm

In order to maximize the active area of the display with respect to the total footprint, shrinking the periphery of the display is a major target.
In previous work we have been able to show that by using different size masks for the polymer (smaller) and the oxide (wider) layers it is possible to protect the display against diffusion of water from the sides.
In this work we show that it is not only possible to shrink the width of this 'edge seal' to 1.5 mm, but do this even with a 2 or 3 dyad process.

Figure 4
Picture of a 1 cm^2 OLED pixel with an 'edge seal' of 1.5 mm, after ageing more then 500 hrs 60C/90RH

3. Conclusion

We have developed an improved Barix encapsulation process which can meet the requirements posed by large scale mass manufacturing of OLED displays.

4. Acknowledgements

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