Towards Super Thin OLED TVs: Barix Thin Film Encapsulation of Glass and Flexible Displays

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Water Barrier coatings, Flexible substrates, thin film encapsulation, Lamination of barrier film, manufacturing, industrialisation

Abstract
We will discuss encapsulation of OLEDs on both flexible and rigid glass substrates.
Accelerated testing at 6CC/90RH and 85C/85RH is compared and acceleration factors for OLED and Calcium test samples are discussed.We have tested the stability and performance of our barrier coating to much higher temperatures: up to 140 C. Water Vapor Transmission rates at temperatures from 60 to 140 C are presented. Rates and methods for low cost manufacturing on a large scale are analysed

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.

For making a flexible display, one not only needs a barrier substrate (even a flexible metal foil can be seen as such), but one also needs to protect the display from the other side. This can be done by thin film encapsulation or by sandwiching the display between two barrier films.

But although thin film barrier coatings on plastic and thin film encapsulation are highly desirable, 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 ™ [3,6,7,8], 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[4], 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.

Figure 1

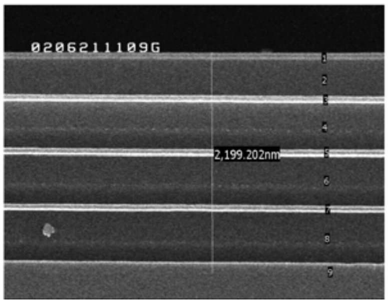

Fig 1. SEM Cross section of a typical Barix multilayer barrier coating. Oxide layers typically are between 30-100 nm and polymer layers 0.25 to 4 micrometers.

The layers are all deposited in vacuum as is shown schematically 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 particles and 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

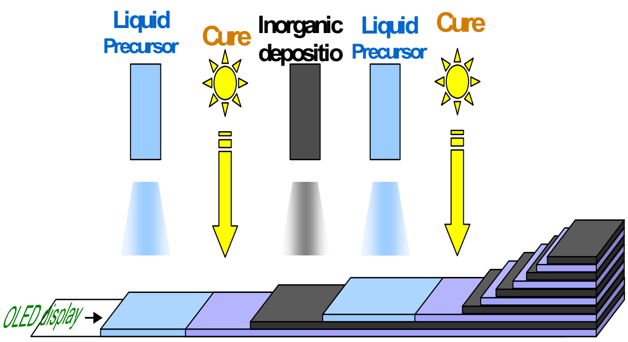

Fig.2 Schematic presentation of the process steps of the Barix encapsulation

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.
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.

The Vitex Barix™ 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.[7,8,9]

Fig 3. Flexible AM Matrix Display by LG.Philips and UDC on metal foil substrate, encapsulated with Vitex Barix encapsulation as shown at SID.

2. Results

Previously we have established with many different types of OLED displays that the lifetime and accelerated testing for a telecom application could be met. We also showed that the accelerated lifetime tests for automotive applications could be fulfilled.

In this paper we will look at aspects of industrialization: how to reduce cost further: two ways of cost reduction will be discussed: i) it will be shown that in many cases two dyads will suffice to meet the requirements ii) another approach is to laminate Barix Barrier Film on top of a water sensitive substrate and create the required results in terms of protection.

Working together with customers we have been able to show : record low edge seal width (MED), Ultra thin displays (SDI), a foldable display (SDI), flexible AM displays (LGD, UDC) (Fig 3) and low cost very flexible indicator type of displays (Add-Vision).

Examples of these new developments will be shown and discussed.

Figure 4
Example of an Add-Vision OLED Display as shown at SID, laminated in between two Barix Barrier Films.

Furthermore the industrialization aspects of the technology will be analyzed:

nrs of layers needed, throughput, cost, industrial base (suppliers of equipment, Barix Barrier Film), systems in the field, commercial applications.

3. Conclusion

We will show that Barix encapsulation can meet the requirements for the next generation of OLED displays: Flexible and TV like displays, in terms of performance, lifetime, edge seal width, cost, industrial availability of barrier film and Barix coating equipment,

4. Acknowledgements

Furthermore we would like to acknowledge the co-operations with ANS, SUNIC, Samsung SDI, Techni-Met, Universal Display Corporation, LG Displasy, Add-Vision, MED and Pacific Northwest National Laboratories.

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