Barix Multilayer Barriers: a key enabler for protecting OLED displays and flexible organic devices

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Abstract

OLED display are extremely sensitive to water and oxygen. Developing a thin film encapsulation for this technology has for a long time been elusive. Vitex has developed a multilayer barrier consisting of alternating inorganic and organic layers which can meet the requirements for a successful protection for such displays.

In this paper we will discuss the basic process, the model, the results on top and bottom emission OLED displays as well as the application of Barix layers on plastic to create flexible OLED displays. We will show that for displays all the requirement for the telecommunication industry can be met and that the we can scale up to a mass manufacturing process.

1. Low temperature oxygen and moisture barriers for flexible organic electronics:

All electronic and opto-electronic devices need protection from the influences of the environment. Vitex is has developed a thin film, transparent and flexible moisture and gas barrier, BarixTM , which can be applied at low temperatures e.g. below 80 C.

And although this type of barrier layer can be applied in many types of applications, by its flexibility, superb barrier characteristics and the low temperature process, it seems to be a key enabling technology for creating plastic flexible substrates and for thin film encapsulation of new generations of organic based electronics: OLED displays [1,2,] organic solar cells, photovoltaics, large area OLED based lighting etc etc.

Vitex is concentrating on a few of the most challenging applications to develop the technology: they are the development of flexible plastic substrates for OLED and LCD displays and the encapsulation of OLED displays on glass. The OLED application is especially challenging since it requires a very low water vapour permeability (WVTR) of less then 5*10-6 gr/m2/day [3]. At this moment displays are being protected by gluing a glass lid with a cavity which is filled with a desiccant on the backside of the display. This effectively doubles the thickness of the display. The purpose of the Barix coating is to reduce the thickness and cost of the displays.

This paper will first discuss the principle of the multilayer coating, its manufacturing and the mechanism, then show the performance as encapsulation of OLED displays and last will show the application of the barrier layer to create and encapsulate flexible OLED displays.

2. BarixTM Multilayer Coating

It is good to consider the requirements for the coating of an OLED display first: the low WVTR of less then 5*10-6 gr/m2/day was already mentioned. Then one should realize that the coating should be really defect free over very large areas (>1 m2 for modern display factories). A single defect in the film will lead to local oxidation of the OLED cathode by water and oxygen resulting in a so called black spot which makes the display useless. The coating should be applied over quite high topography which can amount to several microns for both AM and PM displays, it should be almost stress free as the adhesion of the several organic and inorganic layers in the OLED is rather poor, the process by which it is applied should not have a negative impact on the performance, the temperature in the process should not exceed 100 C and for so called top emission displays the coating should be transparent.

In itself a completely defect free single layer of 100 nm of a variety of oxides might meet these requirements [4] unfortunately the presence of particles, the topography of the display and the low temperature requirement of the process do seem to make this virtually impossible. Pioneer has published some good R&D results with multiple Silicon oxide nitride layers. [5]

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

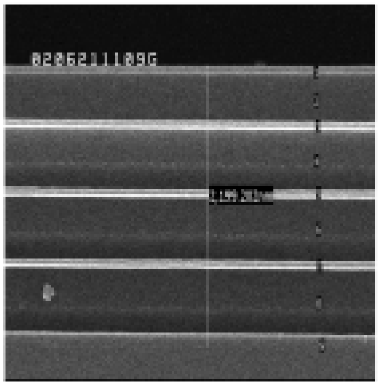

Fig 1. SEM Cross section of a typical Barix multilayer barrier coating. Oxide layers typically are between 30-100 nm and polymer layers 0.25 to 4 micrometers.

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.

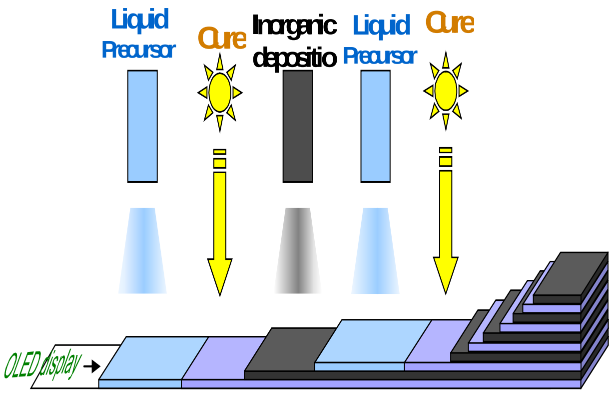

Fig.2 Schematic presentation of the process steps of the Barix encapsulation

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.

3. Performance of the barrier coating on OLED displays.

OLED test pixels and displays on a glass substrate from several sources have been coated at Vitex. Coated samples are tested on the presence of defects such as black spots and bright spots (shorts) by optical microscopy and by testing the electro-optical performance directly before and after coating and after accelerated lifetime testing. For the accelerated lifetime testing the hardest test is the 500 hrs 60C/90 % RH humidity test which guarantees a display lifetime of 10 years for applications like cell phones.

The problem in encapsulation of OLED is that neither the coating nor the coating process should have any negative impact on the OLED's performance. From a schematic of the process step shown in Fig24, it is immediately obvious that most steps are potentially harmful, i.e. damage by: not polymerized monomer, UV radiation, the sputter process for oxides and stress in the layers are all real potential dangers. By optimizing the chemistry and the photo-polymerisation process we can prevent that chemical compounds diffuse out of the film. Damage to the OLED by the UV step has not been observed. In some cases a shift in operating voltage is induced by damage of high energy radiation of the oxide sputtering plasma. We have been successful removing the detrimental effect of the plasma by adding a thin 'protective layer' before the plasma deposition of the oxide.

High density information Active Matrix displays are using a different type of OLED structure, a so-called top emission structure where the OLED no longer emits through the glass substrate but in the other direction through a transparent cathode. Also in this case we have been successful in applying the Barix coating without changing the performance of the display.

To test the long term stability of the coating, displays are being subjected to accelerated life time testing. For displays from several different sources the encapsulation meets the requirements of the telecommunications specifications e.g. after 500 hrs 60C and 90 % RH the pixel size has been reduced by less then 10% and there is no black spot growth.

Figure 3 shows a Passive Matrix display from Philips Electronics with the Barix coating.

Fig 3 Shows a Barix encapsulated Passive Matrix display from Philips. Note that the encapsulated backside is made visible with a mirror.

Together with Tokki Corporation Vitex has launched a pilot machine for this process, the G200.

4. Flexible Substrates for displays.

By applying the Barix coating on a plastic substrate, we can create a flexible substrate with a WVTR which is lower then 5*10-6 gr/m2/day [9]. These coated substrates which are known under the trade name Flexible GlassTM can be made in the vacuum coater which is used for the batch wise encapsulation of OLED displays, the Guardian machine (G200) or on a roll coater which is being used as a pilot for large scale industrial manufacturing.

To test the quality of the barrier coated substrates, we apply Calcium buttons and then cover these with a Barix coating. By monitoring the changes in optical transmission and the occurrence of pinholes in the Calcium[7] it is possible to check if the barrier film has no defects and meets the requirements of a WVTR of less then 5*10-6 gr/m2/day.

Figure 4 shows 4 2*2 cm Calcium buttons on a PET film in such an experiment. The film is shown after 580 hrs 60C/90% RH testing. As can be seen the Calcium buttons are still flawless.

We have also been successful in making flexible OLED displays in a co-operation with Universal Display Company.

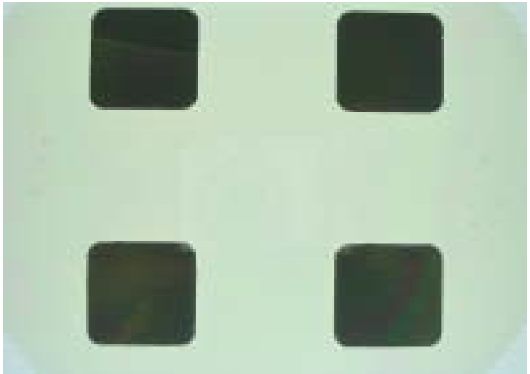

Fig 4. 4 2*2 cm Calcium buttons made on a substrate of 125 micron thick PET which was covered with 5 Barix dyads. The Calcium buttons were then encapsulated with the Barix coating. The Figure shows that after 480 hrs testing at 60 C/90 % RH the Calcium buttons are still completely intact.

5. Conclusion

Barix multilayer barrier coatings is a transparent flexible coating which can be applied at low temperature. The coating can successfully meet the extremely high requirements for encapsulation of OLED displays. Barix coated displays can now meet the tests for the telecommunication applications.

By applying this coating on plastic films, a flexible substrate is created which will protect electronic and electro-optical devices against even the most severe environmental influences.

6. References

[1] 1) C.W. Tang and S.A. van Slyke, Appl. Phys. Lett. **51,** 913 (1987)

[2] 2) J.H. Burroughes, D.C. Bradley, A.R. Brown, R.N. Marks, K. MacKay, R.H. Friend and A.B. Holmes, Nature, 347, 539 (1990)

[3] 3) P. E. Burrows, et. al., Proc. SPIE 4105, 75 (2000)

[4] 4) G.L. Graf, R.E. Williford, P.E. Burrows, JAP, **96,** (4), 1840, (2004)

[5] 5) H. Kubota, S Miyaguchi, S Ishizuka, T Wakimoto, J Funaki, Y. Fukuda, T Watanabe, H. Ochi, T.Sakamoto, T. Miyake, M. Tsuchida, I. Ohshita, T. Tohma, J. of Luminescence, 56, 87-89(2000)

[6] 6) Affinito, J. D., Gross M. E., Coronado C. A., Graff G.L., Greenwell E.N., Martin P.M. , "A new method for fabricating transparent barrier layers , Thin Solid Film, 290-291, 63-67

[7] 7) Moro, Lorenza L.; Krajewski, Todd A.; Rutherford, Nicole M.; Philips, Olga; Visser, Robert J.; Gross, Mark E.; Bennett, Wendy D.; Graff, Gordon L. Proceedings of SPIE-The International Society for Optical Engineering (2004), 5214(Organic Light-Emitting Materials and Devices VII), 83-93. CODEN: PSISDG ISSN: 0277-786X. Journal written in English. AN 2004:172600 CAPLUS (Copyright 2004 ACS on SciFinder (R))

[8] 8) R. J. Visser, 3rd International Display Manufacturing Conference, IDMC 2003 Conference, February 18-21, 2003, Taipei, Taiwan

[9] R.J. Visser in "Organic Electroluminescence Materials and Technologies" ed. Y. Sato, CMC books, 141-153 (2004) ISBN4-88231-442-8

[10] 9) Nisato G., Kuilder M., Piet Bouten, Moro L., Philips O., Rutherford N., "Thin film Encapsulation for OLEDs: Evaluation of multi-layer barriers using the Ca test", Society for Information Display, 2003 International Symposium, Digest of Technical Papers, Vol. XXXIV, P-88

[11] 10) "Thin film encapsulated flexible organic electroluminescent displays," Appl. Phys. Lett. (2003), 83(3), 413-415

[12] "Thin Film Encapsulated Flexible OLED Displays," Soc. Inform. Display Internatl Symp., Dig. Tech. Papers (2003), 34, 868