Inline concept for thin film encapsulated PLED and smOLED devices

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Abstract

A fully integrated inline OLED production system is presented. The performance of PLED devices that are encapsulated with a thin film multilayer stack are compared to conventionally encapsulated devices with glas/dessicant protection. The observed luminance decay is the same in both cases. The lifetime performance of the thin film encapsulation is measured and critical parameters are discussed. The first smOLED devices produced on the OTB equipment are presented and comparison with other smOLED devices shows very good results.

1. Objectives and Background

OTB Group is specialized in the development of in-line production systems. The inline concept was successfully applied to several industries such as compact disc (CD) and solar cell manufacturing. OTB has developed an expertise in high throughput processing and has invented high speed deposition sources for e.g. inorganic layers. The most significant advantages of inline production are i) a reproducibly high yield since every substrate undergoes exactly the same process steps (no buffers, same temperature, process time, etc) and ii) a small footprint since no cleanroom is needed.

OTB Display is developing polymer LED (PLED) as well as Small Molecule OLED (smOLED) manufacturing equipment. In OTB Display production systems all process steps required to turn patterned backplanes into thin film encapsulated OLED devices have been fully integrated. OTB has chosen for a modular approach in which every process step is integrated in a dedicated module. Modules are linked to one another according to the specific production process flow.

In this article the OTB Display inline thin film encapsulation (TFE) and smOLED production systems will be described in detail and results on the performance of the TFE will be presented. First results of the newly developed smOLED module will be shown.

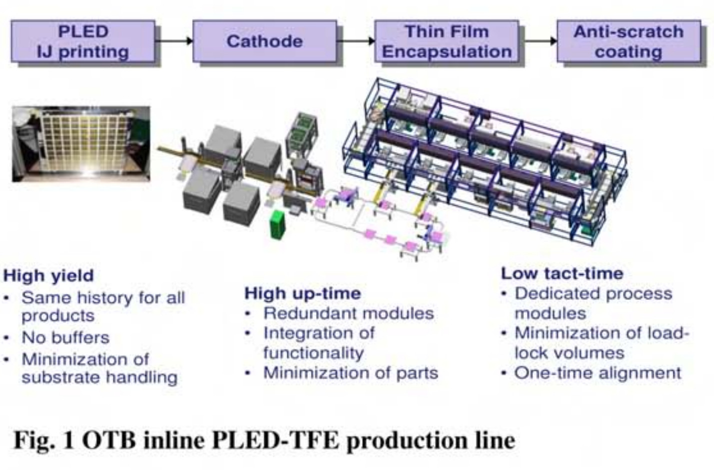

Fig. 1 OTB inline PLED-TFE production line

2 Thin Film Encapsulation

Introduction

An inline tool was developed to process structured substrates (including ITO and metal tracks, printing banks and cathode separators) with a 20" diagonal (14" x 14") into encapsulated PLED devices [1] (Fig. 1). The processes include plasma pre-treatment, PEDOT printing, Red-Green-Blue light emitting polymer (RGB LEP) printing, cathode deposition, and deposition of an encapsulating multilayer stack of inorganic and organic thin films.
Many different thin film encapsulation (TFE) stack designs have been proposed and investigated [2][3][4]. The TFE stack that has been developed at OTB Display consists of alternating silicon nitride and organic polymer layers [5][6] (Fig. 2).

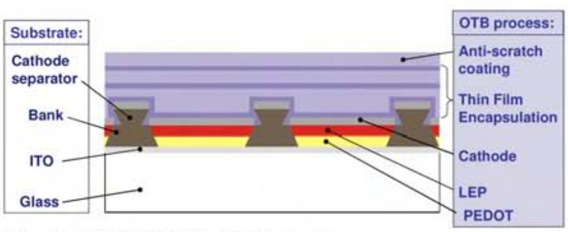

Fig. 2: OTB PLED-TFE stack

TFE Process

The silicon nitride is deposited with a remote inductively coupled plasma source (ICP). The resulting SiN film contains pinholes, whose size and frequency can be influenced by the ICP settings. Each SiN layer is covered with an organic polymer layer. The different polymer layers are inkjet printed with thicknesses varying from 0.3 to 12 µm. These layers partially planarize the vertical structures on the substrate. Furthermore, they work as seed layers for the next SiN layer. Without these seed layers the new SiN layer would mimic the pinhole pattern of the preceding SiN layer and pinholes would grow uninterrupted from the bottom to the top. With these polymer layers the stack is an effective labyrinth with very long diffusion paths.

Performance of the thin film encapsulation depends on the intrinsic properties of the layers, of which the correct morphology is one of the key factors. The OTB ICP source has a typical deposition rate range from 1 - 10 nm/s. The properties and uniformity of the SiN layer can be tuned by adjusting the gas flow, plasma power, pumping speed, and surface temperature. The silicon nitride layer was optimized to achieve an optimum Si/N ratio, a high density (>2.4 g/cm^3), and a low hydrogen content.

Test methodes

Lightoutput and leakage currents are measured directly after production to investigate the influence of process parameters on the device performance. Several different lifetime tests are performed on the devices to measure the performance of the TFE. Climate storage tests at 60°C and 90% relative humidity (AHT) show the barrier properties of the stack. A test under dry nitrogen at 60°C shows the internal sources of contamination in the device.

Results

A comparison between devices with glass/desiccant encapsulation and those with a TFE stack shows that the device properties are identical (Fig. 3).

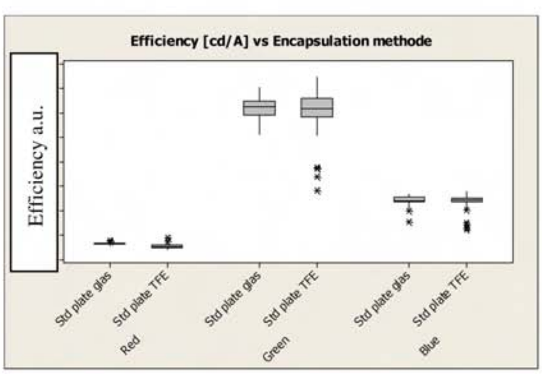

Fig. 3 Comparison Efficiency for TFE and glass encapsulation

Luminescence decay of operational devices is measured and compared to identical glass-capped devices. The observed luminescence decay is due to the intrinsic lifetime of the light emitting polymers. Figure 4 shows this luminescence decay of TFE devices normalized to the glass-capped devices and clearly demonstrates that the lifetime of the OLED devices is no longer limited by the encapsulation method.

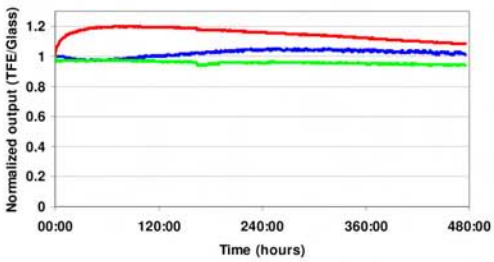

Fig. 4 Comparison lifetimes for TFE devices normalized to glass encapsulated devices

From AHT tests, at first two major problems were detected: pixels from the edges of the display are quenched and the dark spot formation in the middle of the device (fig 5).

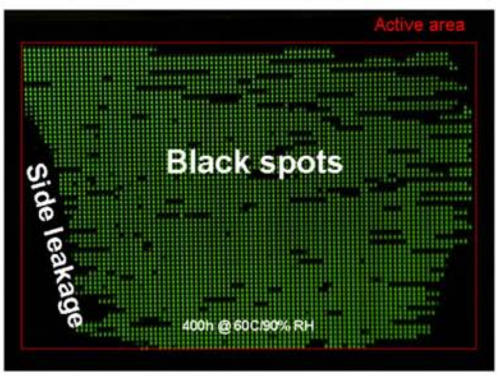

Fig. 5 Forming of black spotsduring 400 hours in 60°C and 90%rh

From tests in hot nitrogen (60°C) it became clear that the latter problem sometimes also occurred in a dry atmosphere, implying that there must also be an internal source for dark spot developing. The theory behind these phenomena is the different leakage paths in the stack, as shown in figure 6.

A proper design of the display inhibits the leakage from the edges of the display. The internal source of dark spots is removed by fine tuning the PECVD process (Fig. 7).

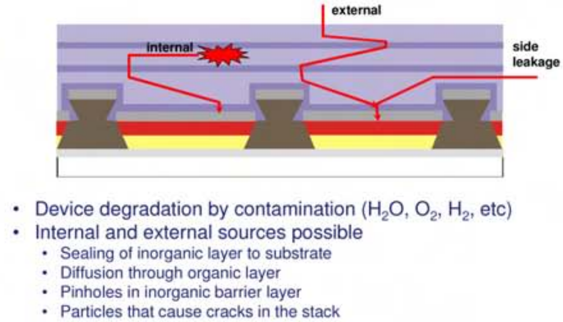

Fig. 6 Model for different leakage paths

The process parameters pressure, gas flow, gas mixture and temperature are optimized for the best barrier properties: density, stress, stochiometry, H content and uniformity. Also the organic layer is optimized by viscosity, curing conditions, T_g and water absorption.

With these process settings the external source becomes important only after 240h at 60°C and 90% rh.

To extend this lifetime, development of stack design and fundamental research to pinholes, stress around particles, and permeability of the stack will be continued. Fig. 8 shows the progress made in this area between December 2005 and June 2006.

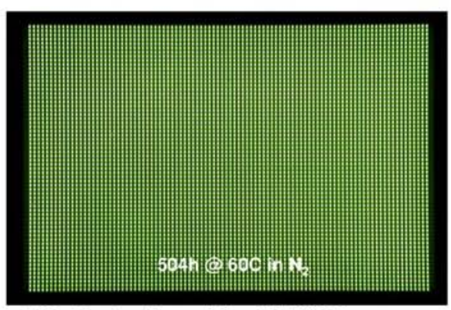

Fig. 7 Optimisation of the PECVD process results in excellent results in dry atmospheres

Conclusion

OTB's inline PLED-TFE prototype line allows uniform and durable encapsulation of PLED devices. Luminescence measurements prove compatibility of TFE with PLED device architecture and processing,

This means that TFE is feasible as an industrial solution for PLED device manufacturing.

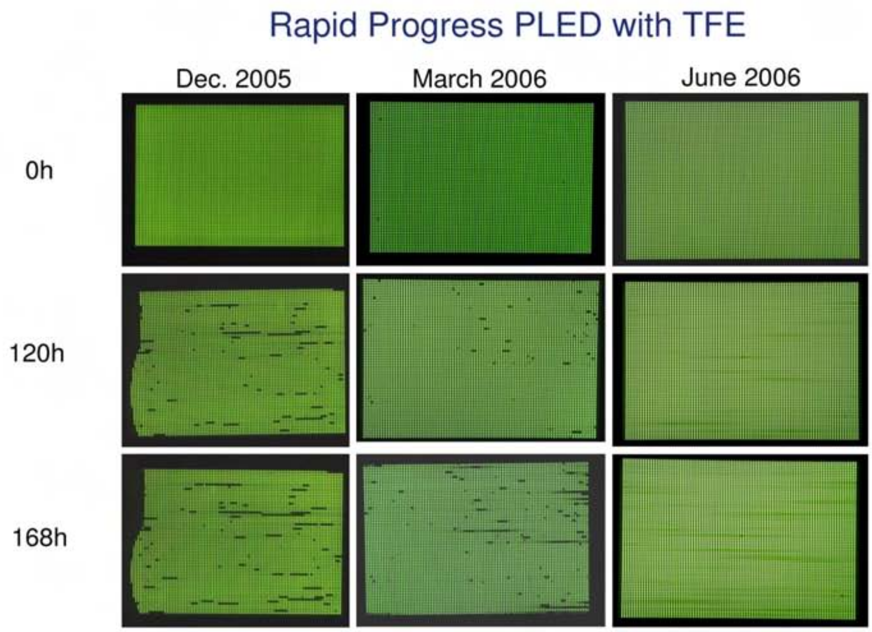

Figure 8: Progress in lifetime results (60°C/90%rH)

3 Small molecule OLED

General.
The majority of OLED display manufacturing is based on small-molecule OLED technology. Next to the inline Polymer OLED manufacturing equipment, which was described in the previous section, OTB Display offers inline equipment for small molecule OLED (smOLED) displays.
The disadvantages of conventional evaporation systems are: poor material utilization (<5%), poor control of deposition rate and composition, high thermal exposure and low deposition rates.
The OTB smOLED deposition system uses a newly developed inline source, based on flash evaporation. This source enables inline-production systems for low cost smOLED displays, with high deposition rates, high material utilization of >50%, and multi component deposition from a single source.
The OTB process is based on white OLEDs with color filters. No subpixel masking is needed, resulting in lower tact-times, possibilities for large display dimensions and low cost manufacturing.

OTB smOLED R&D test-system
Based on the inline modules for cathode deposition and TFE, OTB has built a highly flexible smOLED test module for process development and feasibility studies (Fig. 9) .
The R&D system is designed modularly and consists of a transport chamber (identical to the ones used in the inline machine for TFE) equipped with the two process chambers needed for the pre-treatment and organic layer deposition
The pre-treatment process (left chamber) is based on a remote inductively coupled plasma source (ICP) and can be used for O2 plasma cleaning and CFx deposition (if required). In the second chamber (right) , the HTL layer, the light emitting layers (white), and ETL are deposited on the substrate by the linear source in the same way.

Fig. 9: OTB small molecule R&D test-system.

Smoled Process

The structured substrates with color filter are loaded in the loading/pre-treatment chamber and pretreated with a O2 plasma. Depending on material formulation, optionally a uniform CFx layer can be deposited with the same plasma source. To eliminate cross-contamination, the inline production system will have separate chambers for pre-treatment and CFx deposition.

After the pretreatment process, the substrate is transferred through the high vacuum transport chamber to the OLED deposition chamber. When the substrate is in place, a mask is automatically aligned in front of the glass.

The selected evaporation-source is switched on, and after a short stabilization time the first organic layer is deposited by moving the lineair source along the substrate. Next the source is shut-down and the second source is selected. After all organic layers are deposited the carrier is undocked from the deposition chamber and transferred to the unloading module.

Startup and shutdown times are limited to <1 min for each organic layer.

Vertical inline deposition source.

The source used in the OTB system is capable of depositing multi component materials. Compared to the conventional systems were multiple sources are needed for depositing one single layer, the source used in the OTB system can deposit complex, multi component materials (>3 components) with excellent dopant control and high deposition rates of up to 50 times higher than conventional point-source. Using a single source compared to multiple sources also reduces substrate heating

Results.

The R&D system was build early this year and the first 2-layer undoped single pixel devices were made Feb '06 (Fig. 10).

Next a white formulation was used to produce passive matrix 96x64 OLED displays based on white emitting stacks with colour filter, which were shown on the SID in San Francisco, June 2006 (Fig. 11).

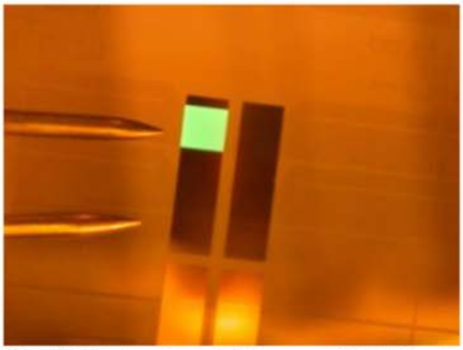

Fig. 10: First undoped 2 layer smOLED device (February 2006)

Fig. 11: Passive matrix smOLED device (June 2006)

Inline production system.
Based on the experience and know-how, obtained with the OTB R&D system, dedicated process modules are being developed for pre-treatment and small-molecule deposition. These modules are fully compatible with the existing OLED /TFE production line and can be placed directly in the inline machine, replacing the pre-treatment and IJ-printing modules of the PLED process. Combined with the existing cathode and TFE modules, OTB offers the customer a fully integrated inline solution for small molecule devices. On top of the advantages of the inline concept the OTB smOLED module offers high throughput, low cost of ownership, and efficient material utilization.

5. References

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