LED Curing for OLED Encapsulation

Application Note

- Excellent irradiance uniformity to improve curing quality
- Low curing temperature to minimize damage to materials and devices
- Compact design to reduce curing station complexity and cost
- Narrow band UVA output is harmless to sensitive OLED material to improve process yield
- Large area coverage to meet high throughput requirement

Introduction

Organic Light Emitting Diodes (OLED) devices are becoming widely desirable and have been referred as "the future of display". An OLED display has several advantages over Liquid Crystal Display (LCD), including simpler structure resulting in better power efficiency, thinner design, better picture quality and faster response time. One of the most exciting features of OLED displays is that they can be made flexible, which is essential for bendable/foldable display devices — an attractive feature for customers and industries in the near future.

However, the actual OLED material can easily get oxidized by even extremely small quantities of atmospheric moisture and oxygen. Thus, a barrier or seal that protects the sensitive OLED material from oxygen and water is very important. As shown in Figure 1 below, a cover glass is traditionally used as encapsulation for conventional rigid glass substrate OLED. The cover glass has to be permanently bonded on the glass substrate to protect the active OLED layers. This is realized by dispensing an epoxy on the edge of the glass and using a UV LED lamp to cure the epoxy and edge-seal the two glass surfaces.

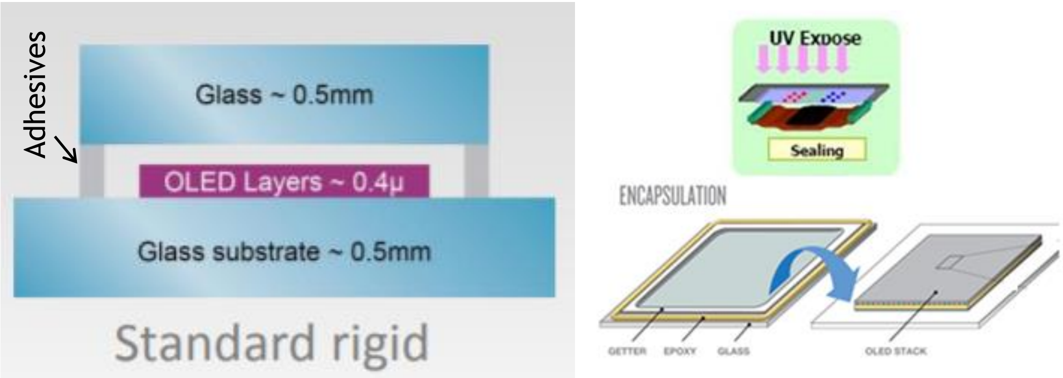

Figure 1: Conventional OLED encapsulation structure and edge bonding process

Process

To make a display flexible, the bottom and top glass plates are replaced by flexible substrates, and a flexible Thin Film Encapsulation (TFE) is a must. TFE technology uses thin film coating to realize lighter, thinner, unbreakable barriers, and most importantly — a flexible/foldable display. The thickness of the barrier layer normally lies in the sub-micro range to meet the low permeation requirement of WVTR < 10^{-6}g/m^2/day but retains the flexibility.

The TFE consists of alternating conformal organic and inorganic layers successively fabricated to achieve low water permeability and high flexibility. While thin inorganic layers work as the barrier layers, organic layers are utilized as "decoupling" layers between inorganic layers to improve the permeation. In addition, organic layers make the structure more robust and flexible since individual inorganic layers in the organic / inorganic multiple layer structure can be kept thinner. The total structure is also more resistant to fragmentation and cracking, when organic layers act as the sealant buffer layer to smooth the substrate.

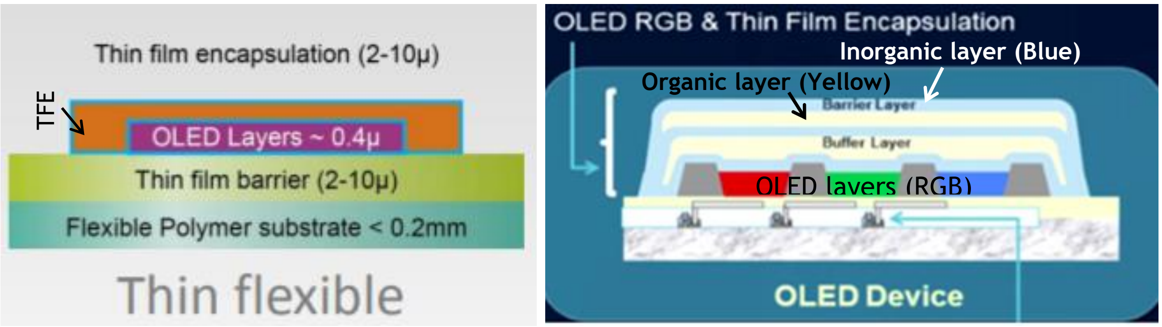

Figure 2: Thin Film Encapsulation for flexible OLED

The TFE fabrication technology includes: 1. Vitex Vacuum Polymer; 2. Inkjet printing (Organic), sputtering (Inorganic); 3. Plasma Enhanced Chemical Vapor Deposition (PECVD)/Atomic Layer Deposition (ALD), etc.

The Vitex process results in flexible encapsulation layers made of alternating Al_2O_3 and polyacrylate layers as shown in Figure 3 below. While the inorganic Al_2O_3 layers are sputtered on to the display via plasma, the organic polyacrylate layers are deposited via flash evaporation of the monomer followed by UV curing. The alternating process is repeated to form the multilayer structure.

Although this encapsulation solution shows excellent performance for flexible devices, the elevated complexity presents many challenges for manufacturing process.

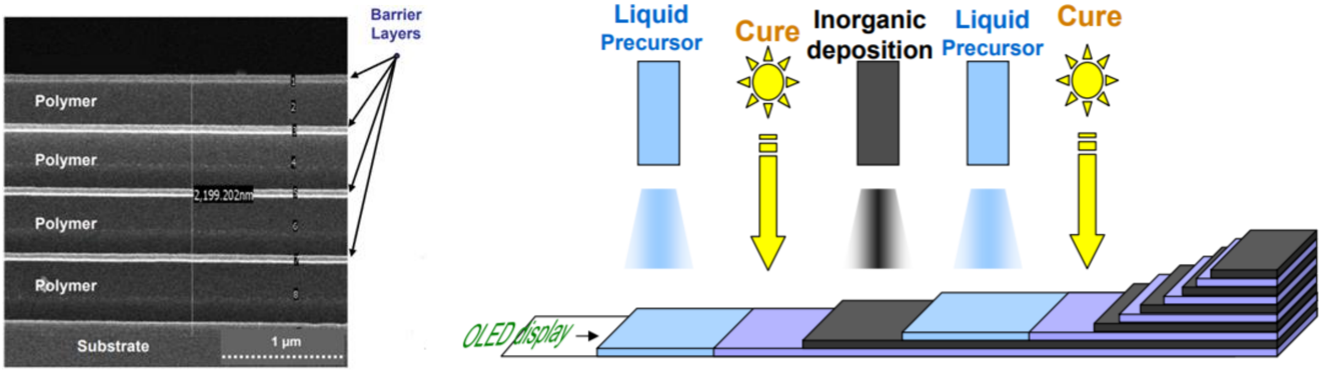

Figure 3: Curing for inorganic deposition in the Vitex process

Inkjet-printing based OLED encapsulation started to outsmart Chemical Vapor Deposition (CVD) based OLED encapsulation in terms of process optimization and accuracy, leading to better performances and productivity. It is claimed that inkjet-printed TFE organic interlayers have very high uniformity which eliminate the non-uniform display to the eye (so called “mura”). In addition, since the printing and post print processing are done in a very low H_2O and O_2 environment, fewer particles are added by the printing process and planarization of the top organic layer is significantly improved to ensure the quality of the second inorganic layer.

As shown in Figure 4 below, after the liquid type organic layer is applied by the inkjet nozzle, a UV curing step is followed to form the crosslink.

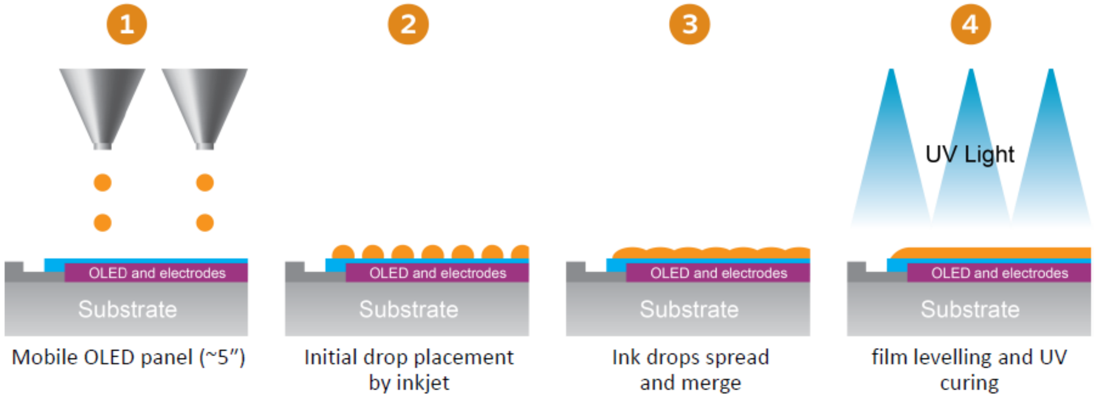

Figure 4: Curing of liquid organic layer in inkjet printing TFE process

ALD process has been developed to produce very thin, conformal films with control of the thickness. It is a sequential self-terminating CVD process which allows for high-quality coating. It generally consists of sequential alternating pulses of gaseous chemical precursors that react with the substrate. During each gas-surface reaction (half reactions), the precursor is pulsed into a chamber under vacuum for a designated amount of time to allow fully reaction with the substrate surface. Subsequently, the chamber is purged with an inert carrier gas to remove any unreacted precursor or reaction byproducts. The process is cycled until the appropriate film thickness is achieved.

ALD process has many promising features but it suffers from slow deposition rates. No UV LED curing is required in this process.

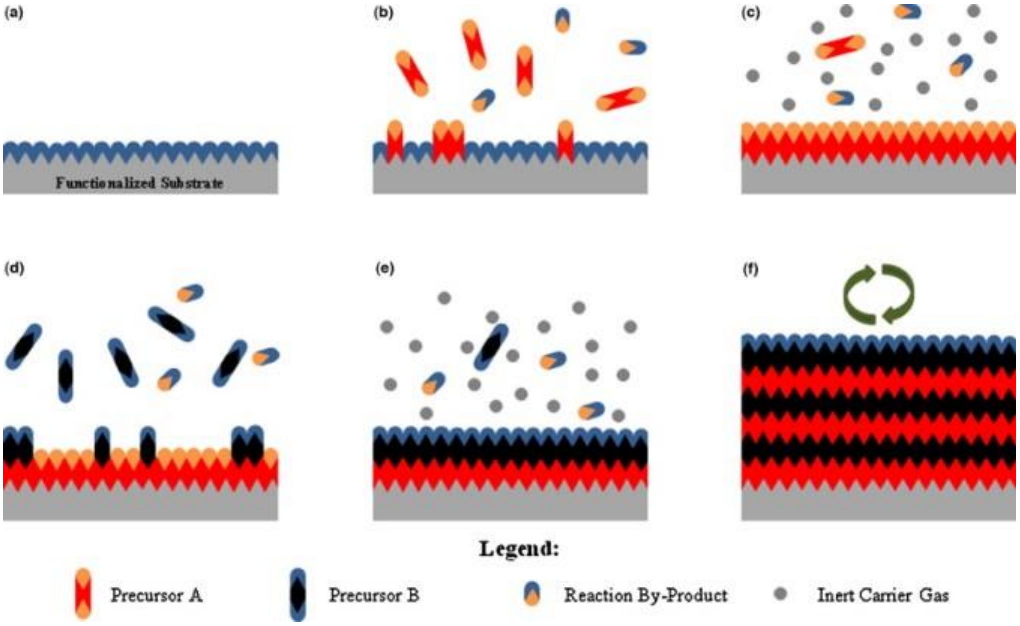

Figure 5: ALD TFE process

Benefits of using Phoseon's UV LED light source

As TFE process is a sequential multi-layer fabrication process, long TAKT time is a major hurdle to improve throughput, so reducing the process time became a huge win consideration. In addition, improving process yield is extremely important to realize scale for manufacturing. All of these technical and commercial factors motivated the industry to shift to a solid-state UV LED source to cure the TFE organic layer.

First, the narrow-band LED light source does not include large amounts of visible and infrared radiation generated by the microwave-excited mercury source, which eliminates a considerable amount of heat that might be harmful to the substrate. In addition, to achieve higher throughput, higher UV power is required, causing the mercury bulb temperature to increase. The resulting infrared radiation impinging on the substrate or device caused substrate degradation and accelerated device damage. Replacing the mercury system with a UV LED system results in improved organic layer yield and a more reliable system; this ultimately translates to lower cost capital equipment.

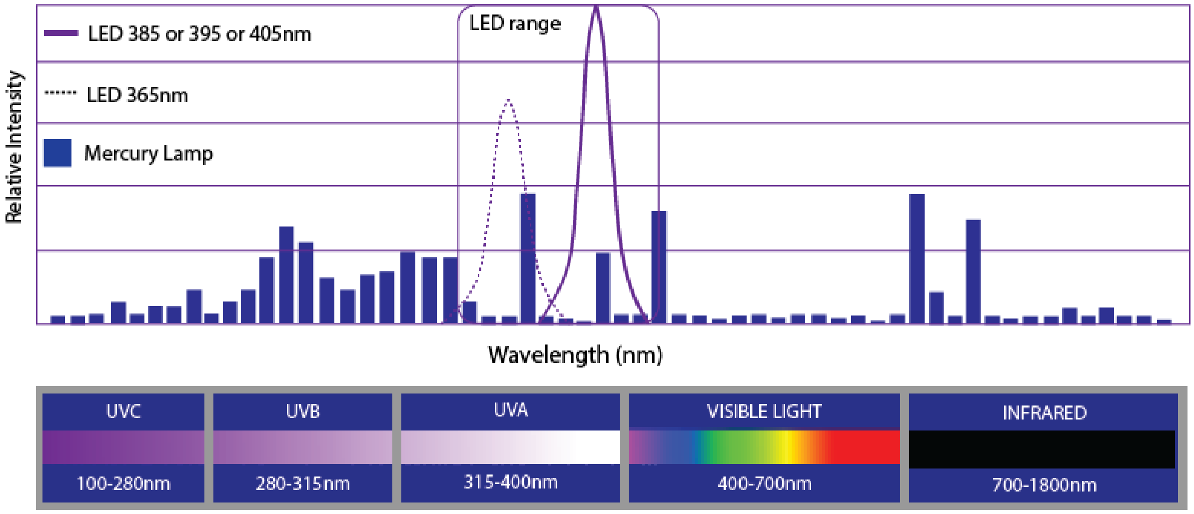

Figure 6: UV LED vs. Mercury: UV LED = narrow band of high power UVA output

Phoseon UV LED light sources offer high irradiance and high dose to ensure the desired curing result. Phoseon has already partnered with major OLED encapsulation equipment makers to integrate the optimized LED curing solution into the TFE process. The processed OLED displays have been supplied to top-brand display makers for various display applications.

As discussed before, reduced TAKT time for TFE process is essential to improve OLED production throughput. Area curing to the entire substrate runs much faster compared to an LED scanning method as it eliminates the light source moving time and thus is favored by many equipment providers. However, to meet high uniformity requirements (normally >90%) across the large substrate area is major challenge. Based on expertise and experience, Phoseon has successfully commissioned an area cure solution to a major equipment maker, as shown in Figure 7 below. The solution included a customized reflector to achieve more than 90% uniformity in irradiance across the area of 1400mm x 800mm. The entire curing process can be finished within 10s of seconds.

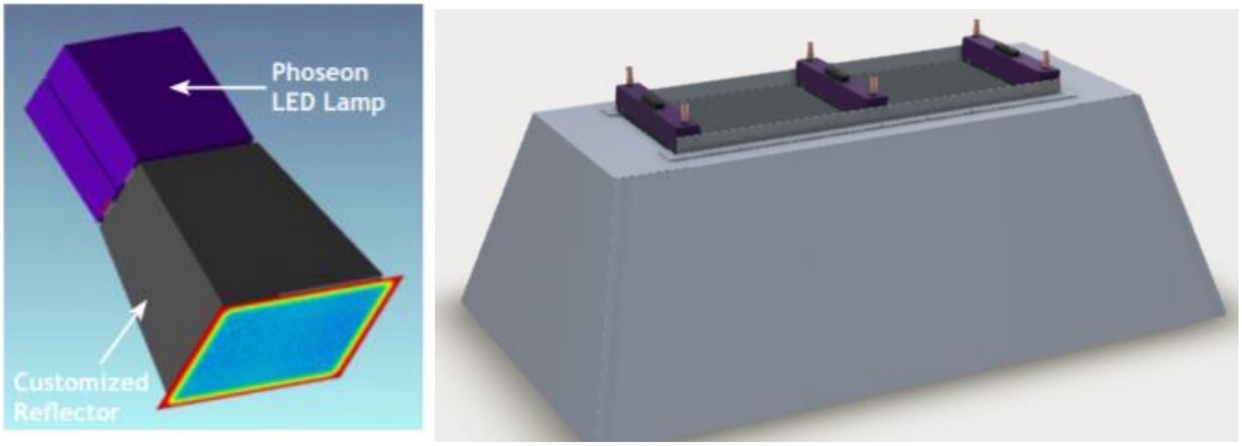

Figure 7: Area cure LED system design

For other applications where a smaller form factor design is a top priority, moving the LED light system and adopting the method of scanning over the substrate is more appropriate. As shown in Figure 8 below, Phoseon engineered a curing solution with multiple light sources scaled to form wider, uniform coverage. The light source system traveled along the substrate at a designated speed to finish the curing process. This solution achieved above 90% irradiance uniformity along the substrate width, with total area coverage of more than 1000mm x 1500mm. The overall height of the system is less than 200mm to meet the stringent space constraint.

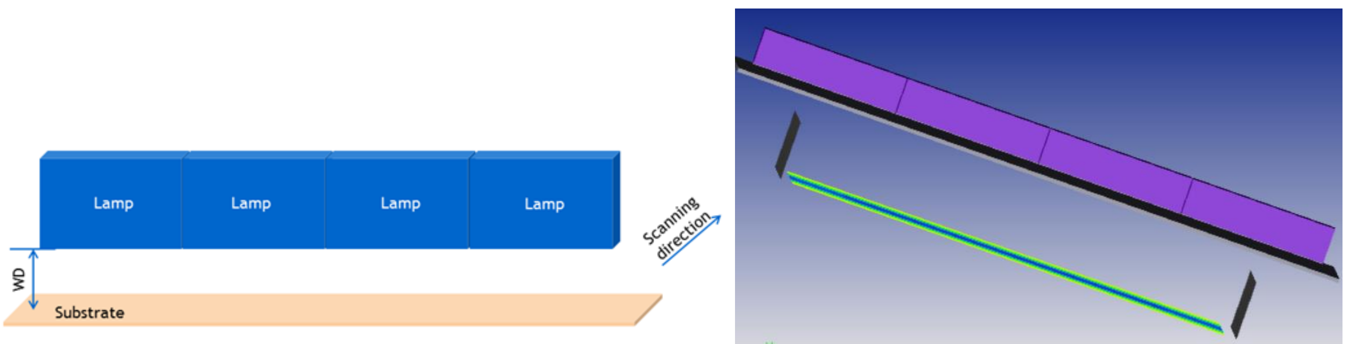

Figure 8: Scanning cure LED system design

References

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Glossary

OLEDs – Organic Light-Emitting Diodes are LEDs in which the emissive electroluminescent layer is a film of organic compound that emits light in response to an electric current. OLEDs do not require a backlight and so are thinner and more efficient than LCD displays.

TFE- Thin Film Encapsulation is the technology to apply conformal barrier layers on top of OLED in preventing water vapor and oxygen permeation into the device.

TAKT time – TAKT is the German word for the baton that an orchestra conductor uses to regulate the tempo of the music. It is the average time between the start of production of one unit and the start of production of the next.

WVTR – A measure of the passage of water vapor through a substrate in the unit of g/m^2 per day.

PECVD - Plasma Enhanced Chemical Vapor Deposition

ALD - Atomic Layer Deposition

Phoseon Technology: 100% LED Focused. Patented. Innovative. Reliable.