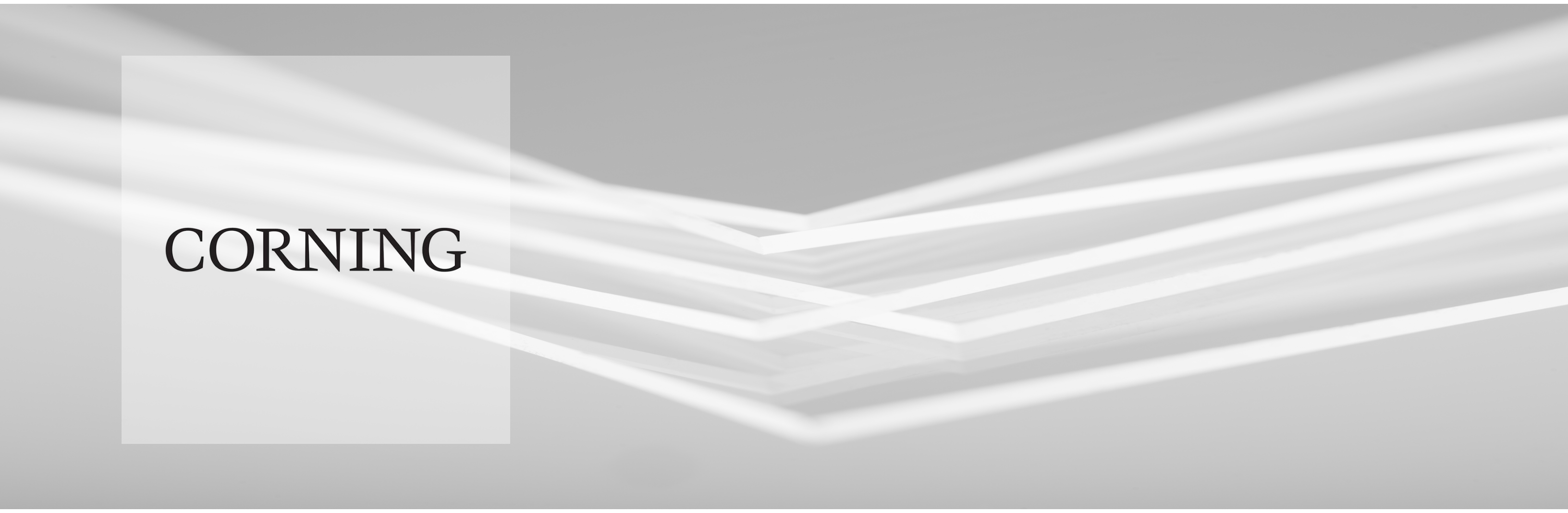
# Corning Lotus™ NXT Glass, through its advantaged and balanced glass attributes, was designed to address the challenges of today's LTPS-OLED manufacturing processes

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## Abstract

Over the next five years, industry forecasts for the mobile display market continue to trend toward higher resolution devices with brighter displays and lower power consumption. These display attributes will provide a common foundation for the majority of mobile devices. In an effort to distinguish their devices, OEMs will seek a means to differentiate their product attributes and performance. The display can play two roles in meeting this differentiation need: one is through industrial design and the other, VR (virtual reality) capability. Industrial design is driving panel makers' needs to manufacture displays that are conformable or flexible. Devices that are optimized for VR require the highest resolution and fastest response time. All of these trends can today be met with LTPS-OLED (low temperature polysilicon organic light emitting diode) display panels, particularly applicable in handheld and smaller application devices. LTPS-OLED is uniquely positioned to address these market trend needs. This paper discusses the key differences between LTPS-LCD displays and LTPS-OLED displays and the specific process challenges for LTPS-OLED. It provides an overview of how the advantaged and balanced glass attributes of Lotus NXT Glass, our third-generation high performance display substrate, were designed to address the challenges of today's LTPS-OLED manufacturing processes.

Lotus NXT Glass is optimized to produce OLED panels with the highest resolutions, brightest displays, lowest power consumption, a maximized lifetime and reduced realized glass cost.

## 1. Introduction: LTPS-OLED Panels

The illumination of a traditional LTPS-LCD panel requires an always on backlight to emit light that is filtered by the liquid crystal layer, before passing through the CF (color filter) to create the viewing pixel. In contrast, in an LTPS-OLED panel, the light for the display is created by switching self-emitting diodes on and off by an electric current. An LTPS-LCD display is made with two pieces of glass: one for the high temperature TFT (thin film transistor) substrate and one for the CF. LTPS-OLED displays use glass substrates for different functions, depending on whether the LTPS-OLED display is rigid or flexible. A rigid LTPS-OLED panel is similar to the traditional LTPS-LCD panel in that it also requires a piece of high performance display glass for the high temperature TFT substrate, but rather than a glass CF, it requires a thin, transparent encapsulant for the OLED; this encapsulant is typically glass. In contrast, a flexible LTPS-OLED uses a high performance display glass substrate as the carrier for a high temperature plastic TFT to be built, then encapsulates the OLED with thin films. These two types of LTPS-OLED panels will be referred to in this document as “rigid” and “flexible.”

An OLED display can be up to 45% thinner than an LCD display. In an OLED panel, the need for a back light and one of the two polarizers is eliminated, and an OLED display has a thinner cover. Despite the addition of a heat sink needed in an OLED display, a rigid OLED display module may be up to 25% thinner than an LCD module display and a flexible OLED dis-play may be up to 45% thinner. Figure 1 shows a cross-section of an LTPS-LCD display module compared to both rigid and flexible LTPS-OLED display modules.

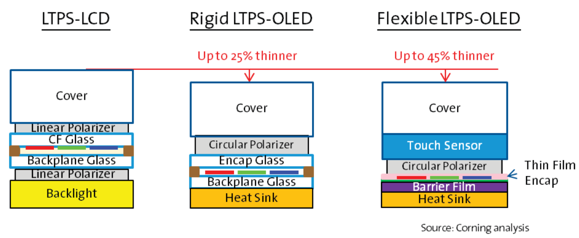


**Figure 1. Display Module Cross-section Comparison.**

Today, handheld OEMs are attracted to OLED displays’ value prop of superior color, response time and latency, as well as the potential for interesting industrial design options (Table 1). The industrial design benefits include thinner and lighter panels, and in the case of a flexible OLED, conformable and flexible panels. It had been a common belief that LTPS-OLED display lifetime was a handicap compared to LTPS-LCD, but in the handheld market, OLED lifetimes exceed typical device lifetimes,so this is no longer viewed as an issue.

| | LTPS-LCD | LTPS-OLED (Rigid) | LTPS-OLED (Flexible) |
|---|---|---|---|
| Resolution | >500ppi RGB | >500 Pentile* | >500 Pentile* |
| Response time | 3-10ms | 0.1-0.5ms | 0.1-0.5ms |
| Bezel width | ~1.0mm | ~1.0mm | ~1.0mm Border could be folded |
| Color (NTSC) | 70~85% | 100% | >100% |
| Module Thickness | 1.8 ~ 2.0mm | 1.5-1.7mm | 1.1-1.4mm |
| Flexibility | Bend radius >100mm | Bend radius >100mm | Bend radius <3mm |

**Pentile: a pixel layout which could achieve same vertical and horizontal resolution by 2/3 of sub-pixels as RGB strip**

**Table 1. Display Module Performance Comparison.**

## 2. Manufacturing Process for Rigid vs. Flexible LTPS-OLED

The processes for producing rigid and flexible OLED panels are shown in Figures 2 and 3. Both processes are similar in requiring high temperature LTPS TFT lay down. However, the role of glass is distinctly different in these two processes. In the rigid OLED display, glass is an integral component of the panel, serving as both the backplane and encap material. In a flexible OLED display, the display is plastic, but still requires high precision, display quality glass as the carrier onto which the plastic high temperature TFT is built. Further detailing the differences in these processes, first, as mentioned, the flexible OLED process starts with a glass carrier onto which a high-temperature plastic, such as polyimide, is coated and cured. Second, to encapsulate the display, multi-layer thin films, rather than glass, are used in the flexible display. Third, in the flexible display, the developed TFT structure built on top of the glass carrier must be de-bonded from the carrier. And last, the flexible OLED panel is at the desired thickness upon completion of these process steps, while the rigid OLED panel requires acid etch to reach the desired thickness.

Although the role of glass in these processes fundamentally differs, glass plays a critical role for both. High performance display glass is integrated into the rigid OLED display, while in the flexible OLED process, high performance display glass is used as the carrier to make the panel, then cut into a half or quarter of the original substrate size prior to OLED deposition. Finally, the display must be de-bonded from the carrier using UV light. In both cases, it is vital to begin these processes with a high performance display glass substrate with a clean surface, as well as superior dimensional stability and optics.

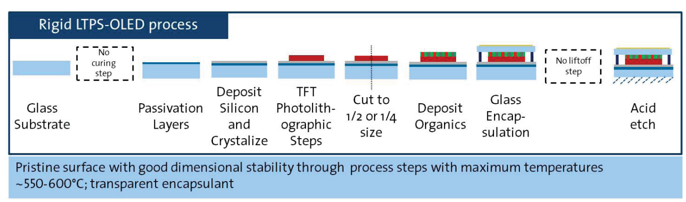


**Figure 2. Rigid LTPS-OLED Process Flow Diagram.**

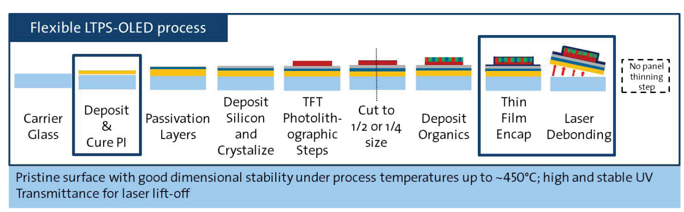


**Figure 3. Flexible LTPS-OLED Process Flow Diagram.**

## 3. LTPS-OLED Process Challenges

### 3.1.LTPS-OLED (Rigid):

The rigid OLED manufacturing process begins with a high temperature TFT lay down process, similar to the process for LTPS-LCD backplane production. Given the absence of a back light or CF, a rigid OLED panel uses a native RGB (red/green/blue) OLED to create light and color. In the rigid OLED process, there are challenges in five key process steps that glass can help panel makers address: passivation and deposition layering, TFT photolithographic steps, organic deposition, encapsulation and panel thinning.

The passivation and first deposition layers require a clean surface without particles and scratches, which may cause a disruption in the layer.

The TFT photolithographic steps require low TPV (total pitch variation) for accurate patterning alignment, like in the LTPS-LCD process, but in the LTPS-OLED process for a rigid display, low TPV also benefits the organic deposition step, which requires good alignment of the backplane to the FMM (fine metal mask). The variation in this step can be described by the following equation:

FMM process variation (V)

$$V = \sqrt{\left(\frac{TPV}{2}\right)^2+(P)^2+(CD)^2+(A)^2+(S)^2+\left(\frac{T}{2}\right)^2}$$

The components contributing to FMM process variation, V, are TPV (total pitch variation of the substrate), P (FMM pitch variation), CD (FMM pattern dimension bias), A (alignment accuracy), S (shadow effect) and T (thermal mismatch effect). Reducing any or each of these contributors reduces the overall FMM variation, meaning lower TPV can help to reduce alignment error. Additionally, the shadow effect component of the FMM process variation, S, can be reduced with higher Young's Modulus, E, driving reduced sag of the substrate.

OLED lifetime can also be improved by using lower TPV glass, such as Lotus NXT Glass. Lower TPV helps to minimize FMM process variation, which can allow the design of larger emitting area. The following equation shows the relationship between aperture area and current density:

$$L = f(I \times \eta \times A)$$

where $L$ = target luminance,

$I$ = current density, $\eta$ = light efficiency,

and $A$ = aperture area

Panel luminance target is con-stant, so a larger emitting area helps to reduce current density, therefore, improving the OLED material lifetime.

For higher resolution devices, some panel makers are adopting higher design rule (DR) exposure equipment. This newer equipment has a tighter depth of focus (DOF) requirement, so tighter TTV enables the adoption of tighter DR equipment without DOF issues.

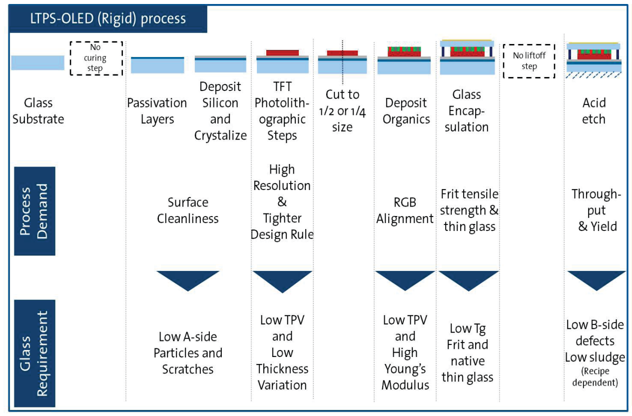


**Figure 4. Rigid LTPS-OLED Process Demands and Glass.**

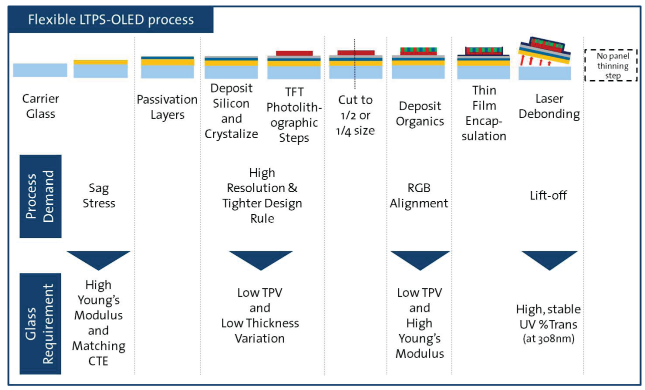


**Figure 5. Flexible LTPS-OLED Process Demands and Glass Requirements.**

Hermetic sealing is a requirement of an OLED display. The absence of a hermetic seal would allow the OLED materials to be destroyed by the migration of moisture and oxygen. A thin piece of glass is used for encapsulation, generally by frit sealing. Multi-layer thin films or hermetic films may be used for the encapsulation, but glass typically provides the lower-cost alternative. Additionally, using a glass encapsulant with low Tg (glass transition temperature) and CTE (coefficient of thermal expansion) enables improvement in panel reliability by reducing residual stress near the sealing area and offers a broader sealing process window.

Lastly, for the thinning process, using a glass that has a balanced etch rate and sludge generation optimizes the throughput and lowers total manufacturing costs.

### 3.2 LTPS OLED (Flexible):

The flexible OLED process is similar to the rigid pro-cess in that it also begins with high-temperature TFT lay down process steps. In this case, however, the TFT substrate is plastic, and the role of the glass is to function as the display grade carrier onto which the display is built. The plastic display is then removed from the glass carrier in the final laser lift off step.

Given the flexible OLED process begins with high temperature TFT lay down steps similar to rigid OLED, the benefits from the glass for these early steps are the same as discussed before in Section 3.1. It is critical to start with a high performance display glass carrier with a clean surface to ensure there are no particles captured beneath the polyimide layer.

As in the rigid OLED TFT lay down, lower TPV and tighter TTV provide benefits in the high-temperature deposition and exposure steps. The organic deposition step for a flexible OLED has essentially the same contributors to FMM variation as in the rigid OLED case, so will have reduced variation for FMM alignment by using a carrier with lower TPV and higher Young's Modulus, and will also have the same lower TPV benefit for the OLED lifetime.

A process step unique to the flexible OLED process is the laser lift-off step, where a laser emits energy through the glass carrier body to release the display from carrier. This step requires a carrier glass with a high and consistent UV transmittance to maximize yields and display quality, as described in Figure 6.

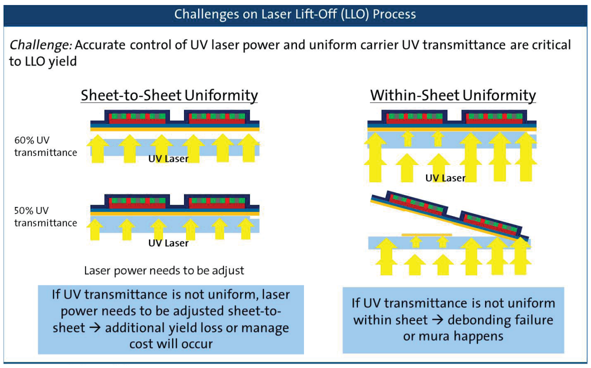


**Figure 6. Laser Lift-Off Process Challenges.**

If UV transmittance is not uniform sheet-to-sheet, the laser power needs to be adjusted to account for trans-mission variation, and additional yield loss or process management cost will occur. UV transmittance must be uniform within sheets to avoid debonding failure or mura. The glass carrier surface cleanliness can also impact localized transmittance and de-bonding of the display if such defects block or disperse the energy path during this process step.

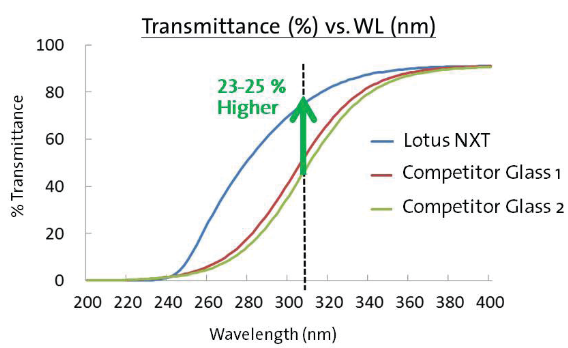


**Figure 7. Glass Carrier Transmittance Curve Comparison.**

**Figure 7 illustrates the transmittance curves for Lotus NXT Glass and two next-best glass offerings and shows that Lotus NXT Glass has a higher UV transmittance at the wavelength of interest, 308nm for the laser lift-off process steps.**

## 4. Corning Lotus™ NXT Glass Address Glass Related OLED Process Challenges.

Lotus NXT Glass was designed to address OLED panel making process challenges. The attributes designed into Lotus NXT glass was designed to include dimensional stability under high temperature processing conditions, ideal for the LTPS process.

### 4.1 Lotus NXT Glass Benefits for Rigid OLED Lotus NXT Glass has:

- a strong particle performance to provide a clean surface for TFT layering
- total pitch variation (TPV) up 45% than the two next best display glass offerings which is critical for the dimensional stability in the high temperature processes for OLED backplane manufacturing and in the FMM alignment for organic deposition
- total thickness variation (TVV) tow times better than, or half of that, float glasses, which enables panel makers to use higher resolution exposure equipment.
- a high Young's Modulus to ensure rigidity, which also enables better FMM alignment
- a native thickness range reducing or eliminating the need for etching encap glass
- a balanced etch rate and sludge generation rate for better throughput in the acid thinning process.

Corning also offers a frit solution (Vita™ Hermetic Sealing Solution for OLEDs) for a glass encapsulant with long Tg and low CTE.

### 4.2 Lotus NXT Glass Benefits for Flexible OLED Lotus NXT Glass has:

- a high Young's Mondulus, which helps prevent substrate sag in the process handling steps
- excellent particle performance to provide a clean surface for the plastic deposition process
- CTE that is lower, closer to that of the plastic layer which helps maintain dimensional stability between the plastic layer and the carrier onto which it is deposited
- a TPV up to 45% better than the next best display glass offerings, providing dimensional stability in the higher temperature processing
- TTV that is two times better than, or half that of, float glasses, which supports even, thin deposition of the plastic layer
- UV transmission at a 308nm wavelength that is up to 25% better than next best display glass offerings and allows efficient and effective laser lift off of the panel in the last process step.
- UV transmission that is uniform within sheets and sheet-to-sheet, which allows a consistent laser setting and a higher yielding de-bonding process.

The attributes providing glass related benefits to the OLED processes discussed in Section 4 are shown in Tabe 2 for Lotus NXT Glass compared to the two next best glass offerings, which are float based glasses.

| Glass Attribute Comparison | | | |
|---|---|---|---|
| | Lotus NXT Glass | Competitor Product 1 | Competitor Product 2 |
| Young's Modulus | 84 | 79 | 86 |
| Particle | Low | N/A | N/A |
| CTE | 34.8 | 36.4 | 37.2 |
| TPV | Lowest TPV | Up to 45% > NXT | Up to 25% > NXT |
| TTV | 2x better than float glass | 2x worse than NXT | 2x worse than NXT |
| UV trans% @ 308nm | Highest UV %T | 23% < NXT | 25% < NXT |

**Table 2 . Comparison of Key LTPS-OLED Glass Attributes.**

## 5. Summary

Corning has spent unparalleled time in close interaction with panel makers to understand their requirements and to enable innovation within the emerging LTPS and Oxide TFT backplane spaces that are used in both LCD and rigid OLED panels. We also understand the processes used for both rigid and flexible OLED displays and the challenges panel makers face in these processes, as well as how glass can play a key role in overcoming these process challenges. Lotus NXT Glass has been optimized for TPV, TTV, Young's Modulus and UV transmittance and is made using Corning's unique fusion process, delivering a superior uniformity in these attributes as well. There are five glass-related process challenges discussed for rigid OLED manufacturing and four for flexible OLED manufacturing. These process challenges can be summarized by the eight areas shown in Table 3, along with the attributes of Lotus NXT Glass that enable panel makers to overcome the challenges.

| | Challenges | Requirements (met by Lotus NXT Glass) | LTPS-OLED (Rigid) | LTPS-OLED (Flexible) |
|---|---|---|---|---|
| 1 | Design rule | Low TTV | ✓ | ✓ |
| 2 | FMM alignment | Low TPV | ✓ | ✓ |
| 3 | Shadow effect | High Young's Modulus | ✓ | ✓ |
| 4 | Lifetime | Low TPV and high Young's Modulus | ✓ | ✓ |
| 5 | Laser Lift-off | High UV transmittance | | ✓ |
| 6 | Encapsulation | Low Tg, low CTE frit | ✓ | |
| 7 | Thinning | High etching speed, low sludge formation | ✓ | |
| 8 | Reliability | Hermetic seal; pass system drop test | ✓ | |

**Table 3. How Lotus NXT Glass Addresses Process**

The goal of any glass substrate is to optimize panel makers' processes and display performance, which may require trade offs to balance all performance items. Corning recognizes the important role glass plays in OLED manufacturing and has used panel makers' feedback to provide an advantaged and balanced glass substrate and carrier for these processes.